NATIONAL COOPERATIVE
HIGHWAY RESEARCH PROGRAM REPORT 229

METHODS FOR ANALYZING FUEL SUPPLY LIMITATIONS ON PASSENGER TRAVEL

TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL

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TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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FOREWORD

By Staff
Transportation
Research Board

This report advances the state of the art in applying travel demand forecasting methods to energy contingency and energy conservation planning that were heretofore used only by a handful of researchers. It is documented in three self-standing parts for three different audiences. The appendixes are of use to the technologist (the technical planner) applying the methods. The body of the report is of use to both technologists and planning administrators. The summary is of interest to the administrator/decision-maker in addition to the two previously mentioned audiences. Researchers will find reviews of the literature helpful but contributing little advancement in the frontiers of knowledge.

The future of energy supplies, particularly petroleum, is uncertain. Numerous forecasts show significant differences in the magnitude of shortfalls (if any) between supply and demand from the early 1980s up through 2000 and beyond. If such shortfalls or extended interruptions occur, personal travel is likely to be affected. Yet our knowledge of the nature of such a response is extremely limited. The experience of the energy crises of 1973–1974 and 1979 suggests that supplies have more effect on transportation fuel demand than does price. But these episodes were too short lived and too small in magnitude to produce significant shifts in travel behavior, consumer budgets, activity locations, residential moves, or changes in travel by different consumer groups. In short, our knowledge of the differential impacts of fuel shortages on travel (trip rate, mode, purpose and priority, destination, length, etc.) is extremely limited as is our knowledge of the distribution of impacts on different groups, and of changes in residential location and auto ownership. Such deficiencies make it difficult for state and metropolitan planning organization planners to comply with energy contingency and conservation planning requirements of the Federal Government. Because the Nation and its states, regions, and cities continued to be faced with this problem, research was conducted to understand and forecast the nature of travel behavior under energy constraints.

This report describes the development and testing of methodologies for analyzing the travel impacts of fuel supply limitations. Quantitative approaches are used to analyze work and nonwork travel. The work trip analysis combines incremental logit analysis with the traveler classification aggregation approach. The nonwork trip analysis is based on linear VMT and transit trip models. Input data and computational requirements are modest. The quantitative forecasting system was applied to several fuel shortfall scenarios and produced reasonable results. Qualitative analysis was used to refine the assessment of work and nonwork travel responses; to analyze long-run impacts, such as residential location and auto ownership changes; and to evaluate the distribution of impacts across income or geographic groups. The report also contains guidelines for applying the methodologies, recommendations for further research, discussion of new approaches to travel behavior research that are potentially useful for energy policy analysis, and guidelines for data collection.

This report provides individual highway and transportation agencies with recommendations for calibrating road roughness measuring systems to maintain year-to-year continuity in measurement data and to standardize measurements from their different systems. Further research is recommended to improve comparability of measurements between agencies and to relate roughness measurements to pavement serviceability.

CONTENTS

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Mr. Tardiff and Ms. Benham were authors of the quantitative analysis sections, the review and evaluation of methodologies, the state-of-the-art discussions, and the secenario definitions. Mr. Dunbar contributed to the scenario definitions. Ms. Benham was author of the section on qualitative analysis of short-run travel behavior and the appendix on guidelines for data collection. Ms. Greene authored the discussion of qualitative analysis of long-run impacts.

The work was performed under the general supervision of Harrison Campbell, Vice President and Officer-in-Charge of the project. Daniel Brand, Vice President, also contributed to the guidance of the project.

METHODS FOR ANALYZING FUEL SUPPLY LIMITATIONS ON PASSENGER TRAVEL

SUMMARY

This report describes the development and applications of methods for analyzing the impacts of fuel supply limitations on passenger travel. Recent experience with gasoline shortages clearly indicates that all levels of government need to develop transportation energy conservation and contingency plans. In addition, recent federal legislation and proposed rules require energy planning by state and local governments. The Emergency Energy Conservation Act of 1979 (EECA) requires state contingency plans for meeting conservation targets established by the President. On August 29, 1980, the U.S. Department of Transportation published proposed rules for energy conservation planning in programs receiving federal financial assistance (*1*). The rules included mandates for energy conservation to be considered in ongoing transportation planning conducted at the state, regional, and local levels. The methods described in the report can be used in these planning activities.

The perspective of the project was medium to long range. Six energy shortfall scenarios covering the period 1979 to 2000 were developed to describe alternative future travel and energy environments. These scenarios were defined in terms of: (1) magnitude (percentage) of the shortfall, (2) gasoline price, (3) frequency of occurrence, (4) shortfall duration, and (5) governmental actions to mitigate the impacts of the shortfall. Four special cases (also called scenarios in subsequent discussion) of these scenarios were analyzed in detail. They include: (1) 1985 15 percent shortfall with a vehicle sticker plan (the sticker plan requires that all vehicles in a household not be used on one or more days of the week); (2) 1985 15 percent shortfall with gasoline pump prices decontrolled and local actions taken to encourage transit and carpooling; (3) 1990 25 percent shortfall with white market coupon rationing and local actions to encourage high-occupancy vehicles and discourage single-occupancy vehicles; and (4) 1990 scenarios with the same conditions as the previous scenario and with the assumption that households have made additional long-run conservation adjustments including living close to work and driving more fuel-efficient vehicles. The local actions included express lanes for transit, reduced tolls for carpools, and increased parking charges for private vehicles.

A quantitative forecasting system was developed and used to analyze the travel behavior impacts of each of the four cases. The system includes work and nonwork travel models. The models are based on recent findings from travel behavior research. They are designed to require modest amounts of input data and can be used by transportation planning staffs by hand, with the assistance of a calculator, or with a microcomputer. The models can be applied to urban areas or regions of various sizes.

Input data include variables such as level of service for transportation modes; vehicle fuel economies; information on work trip distances; and demographic

variables, for example, number of households, population, average income, and average household size. Outputs emphasize miles traveled, and fuel consumption by private vehicles, and transit for work and nonwork trips.

The forecasting system was used to analyze the travel and energy impacts of the four scenarios described earlier. A hypothetical, medium-sized urban area was used in the applications. Although the numerical findings should be generalized cautiously to any particular location, the general tendencies are noteworthy and consistent with previous findings.

The adjustments in work and nonwork travel appear to vary with the severity of the shortfall, the policies used to allocate gasoline and/or reduce demand, and whether long-run conservation adjustments are made. The two 1985 scenarios can be used to compare the pricing and level of service policy with the restrictive sticker plan. Although both scenarios resulted in reductions in total private vehicle travel fairly close to the 15 percent shortfall used to define the scenarios, the sticker plan affected work travel much more. This finding is consistent with findings on travel adjustments made during previous shortfalls. That is, given the flexibility to choose among travel adjustments, people appear to reduce nonwork travel relatively more than work travel. The sticker plan clearly offers less flexibility.

Comparison of the two 1990 scenarios suggests that long-run conservation adjustments may affect responses to future energy shortfalls. In particular, greater improvements in vehicle fuel economies and shorter work trip distances result in less sensitivity to a particular gasoline price increase.

The results of the scenario tests also can be used to compare the relative importance of the gasoline price increases resulting from shortfalls and the other level of service changes. In general, the forecasting system suggests that price effects are more important, although the travel adjustments resulting from the level of service changes are not insubstantial.

The quantitative findings were supplemented with qualitative analyses that addressed impacts not directly covered by the forecasting system. Extensive use of recent findings, based on new approaches to travel behavior research, provided insights useful for the qualitative analyses.

Three areas were emphasized in the qualitative analyses. First, the quantitative findings were supplemented by considering issues such as the role of complex travel patterns (trip chaining) and the use of nonmotorized modes as responses to fuel shortages situations. Results from surveys of travel attitudes and behavior, conducted during previous fuel shortage periods, provided useful insights.

Second, both theoretical and empirical evidence was used to consider longer term adjustments to fuel supply limitations. These adjustments include changes in household employment, residential location decisions, and vehicle ownership. Both the effects of actual or perceived shortfalls on these decisions and the effects of long-range choices on the travel behavior impacts of future periods of fuel supply limitation were considered. Much uncertainty is associated with the analysis of these longer range impacts. The development and testing of scenarios that are based on alternative long-run assumptions are useful means for dealing with uncertainty.

The key issues in the analysis of long-term adjustments were (1) the relative importance of transportation energy costs and other factors in employment and residential location choices; and (2) the relative effectiveness of location changes and other adjustments, such as improved vehicle fuel economy, in transportation energy conservation. Consideration of both issues suggests that household location choices are not necessarily the most likely or most effective conservation adjust-

ment in the short- to medium-term. For example, scenario tests suggested that improved vehicle fuel economies were more effective conservation adjustments than were changes in employment and residential location. These findings do not mean that land-use policies emphasizing energy conservation are ineffective. Such policies may have important long-run impacts, although other policies, such as vehicle fuel economy standards, may be more effective sooner.

Qualitative analysis was also used to address the issue of how the impacts of fuel supply limitations are distributed over income and geographic groups in an urban area. Existing information, which is probably most appropriate for analyzing the immediate impacts of a limited fuel supply shortfall, indicates that higher income people have more flexibility to respond to fuel shortages. Lower income people appear to be more sensitive to increases in gasoline prices. The analysis of the distributional consequences of long-run impacts is more difficult. A plausible hypothesis is that higher income people have more flexibility to make long-run adjustments, for example, buy new cars or move, which would mitgate the negative impacts of fuel supply limitations.

The report presents detailed guidelines for applying the quantitative and qualitative methodologies to particular urban areas. Such applications are a high-priority recommendation for demonstration. Also recommended are refinement and updating of the quantitative models used in this project and continued basic research on travel behavior. Promising areas of emphasis include gaming and laboratory simulation approaches, activity and time allocation studies, complex travel pattern analyses, resource-constrained travel behavior studies, and analysis of the use of nonmotorized modes.

In addition to providing more details on the research approaches used in this project, the appendixes contain a discussion of newer research approaches that eventually may lead to improved energy policy analysis capabilities. Guidelines for data collection are also provided for (1) developing early-warning capabilities for detecting fuel supply shortages, (2) assisting in quick-response decision-making during fuel shortage emergencies, and (3) providing researchers with more information on how people adjust their travel and related behavior in response to fuel supply limitations.

CHAPTER ONE

INTRODUCTION AND RESEARCH APPROACH

RESEARCH PROBLEM

There is a growing consensus that fuel supply disruptions will be a recurring phenomenon. For example, Kilgore stated at the 1980 National Energy Users Conference for Transportation that fuel supply shortages are likely to be more severe in the future in terms of frequency, magnitude, and duration. In addition, recent Federal legislation and proposed regulations mandate that fuel supply limitations and energy conservation must be considered in state and local planning and decision-making. The Emergency Energy Conservation Act of 1979 (EECA) establishes a strong state role in contingency planning for energy emergencies, and the rules proposed by the U.S. Department of Transportation on August 29, 1980 (*1*) requires that energy conservation be considered in ongoing transportation planning activities. Therefore, decision-makers at all levels of government need to incorporate information on the impacts of fuel supply limitation into transportation planning, alternatives evaluation, and policy development.

Potential supply shortfalls must be addressed both in contingency planning activities, which focus on the operation of the transportation system during emergency periods, and in mid- and long-range transportation planning.

RESEARCH APPROACH

Two major issues must be addressed in designing a research approach that will result in better information on the impacts of fuel supply limitations on passenger travel. First, in order to develop procedures that are easy to understand, reasonably straightforward to apply, and rapidly disseminated, existing approaches to understanding travel behavior are likely to be emphasized. However, although some insights have been gained into travel behavior responses during the recent limited fuel shortage periods of 1973–1974 and 1979, these insights have yet to be directly incorporated into well-known quantitative travel forecasting methodologies. Further, very little is known about longer range adjustments such as economic activity changes and residential location choices in response to fuel supply limitations.

The need for practical methods based on existing approaches is addressed by designing a quantitative forecasting system for analyzing work and nonwork travel behavior impacts. The system emphasizes incremental methodologies to facilitate quick response applications with limited input data requirements. Travel impacts, such as modal splits, miles traveled by mode, and fuel consumption by mode, are produced at a regional level.

The uncertainty resulting from imperfect knowledge of fuel supply futures and behavioral responses to fuel shortage situations is addressed in a number of ways. First, several alternative fuel supply shortage scenarios are defined. These scenarios are then used to illustrate the predictive properties of the quantitative forecasting system.

Second, the uncertainty of the response of work and nonwork travel to changes in the transportation environment is addressed by varying the travel parameters (coefficients) of the quantitative forecasting system. Sensitivity analyses of this type produce a range of possible travel behavior responses.

Third, qualitative analysis approaches are used to deal with impacts not considered by the quantitative forecasting system (e.g., possible changes in work trip lengths resulting from energy price or availability limitations). Changed work trip lengths would reflect changes in residences and/or jobs. Qualitative analysis is also used to refine the quantitative impact estimates. Several sources are consulted for information useful for qualitative analyses. Prominent sources include travel surveys conducted during the 1973-1974 and 1979 fuel shortage episodes and recent travel behavior studies that emphasize new approaches. These approaches include laboratory and gaming methods, studies of complex travel patterns such as trip chaining, and analysis of the use of nonmotorized modes.

Research on transportation energy issues has been progressing on several fronts. The present study can be viewed as complementary to these other efforts. For example, the emphasis on mid- to long-range analyses established for this project complements the short-range emphasis of the contingency planning studies that have been conducted at the national, state, regional, and local levels. The state of the art in contingency planning was the focus of the recent National Energy Users Conference for Transportation (*2*), which was sponsored by the Transportation Research Board and the U.S. Departments of Energy and Transportation.

The emphasis on quick response methodologies in the quantitative forecasting system produces an alternative approach to methodologies based on computer models with fairly large input data requirements, such as the energy policy analysis systems developed by Cambridge Systematics (*3*). This system has been applied by regional agencies (*4*) and will be used in an ongoing transportation energy analysis study being conducted by Argonne National Laboratory (*5*).

Finally, national studies of long-run energy supplies and consumption may be of interest to the readers. Two recent studies of this type were conducted by the National Academy of Sciences (*6*) and Dartmouth University (*7*).

ORGANIZATION OF THE REPORT

This report is organized into four additional chapters and six appendixes. Chapter Two describes the quantitative analyses. Specific items include definition of shortfall scenarios, description of the forecasting system, and applications of the system to shortfall scenarios. Chapter Three presents findings on qualitative analysis procedures, including further analyses of work and nonwork travel, household residential and employment location choices, analysis of activity levels and locations, and analysis of the distributional consequences of fuel supply limitations and subsequent policies. In Chapter Four, the findings in Chapters Two and Three are evaluated and procedures for applying the quantitative and qualitative methods are presented. Chapter Five presents conclusions and suggestions for future research.

Appendix A is a detailed presentation of fuel supply scenarios. It contains projections to the year 2000 for nonshortage gasoline price levels, private vehicle fuel economies, and costs of operating private vehicles. In addition, six energy shortfall scenarios are defined in terms of shortfall level, gasoline price, frequency, duration, and governmental response. A classification of contingency actions available to state and local governments is also included.

Appendix B contains a description of existing methodologies for analyzing behavioral responses to fuel supply shortages. These approaches, as well as new approaches, are then evaluated with respect to several criteria.

In Appendix C, the quantitative forecasting system is described in detail. Appendix D discusses new approaches to travel behavior. These approaches, which include analyses of complex travel patterns, studies of nonmotorized modes, and analysis of travel behavior under resource constraints, are useful in qualitative analysis and may be important research developments that eventually result in better methodologies for transportation energy policy analyses.

Guidelines for data collection are presented in Appendix E. Data on travel behavior responses to energy environments can serve a number of purposes. Reliable supply and demand indicators could provide advance warning of fuel supply shortages. During shortfall periods, data could be used to monitor the transportation system and to guide rapid response decision-making. Data of this type also could lead to improved understanding of travel behavior and better analytical methods. Both standard and innovative data collection procedures are discussed.

Finally, Appendix F describes in detail the input variables used in the analyses presented in Chapter Two. Also included are sample calculations for the forecasting system and a discussion of the sensitivity analysis involving alternative sets of coefficients for the work trip model.

CHAPTER TWO

FINDINGS–QUANTITATIVE METHODS

In this chapter, a forecasting system for analyzing the short-run travel impacts of fuel supply limitations is described and applied to several fuel shortage scenarios. The chapter is organized as follows. First, several fuel shortage scenarios are defined in terms of (1) shortfall levels, (2) gasoline price, (3) governmental actions, (4) shortage duration, and (5) shortage frequency. Next, the components of the quantitative forecasting system are outlined. Following this, the work and nonwork trip components are described. Finally, the results of several scenario tests of the forecasting system are presented.

SCENARIO DEFINITIONS

In this section, six fuel supply limitation scenarios are presented. In addition, a base (nonshortage) scenario is presented. This is necessary because some of the variables characterizing fuel shortage scenarios are defined in terms of this base scenario. Particular values assumed for the variables characterizing the scenarios are emphasized. Details on the assumptions and analytical techniques used to derive the scenario are given in Appendix A.

Base Case Scenario

The base case scenario focuses on gasoline price levels and the costs of private vehicle travel. Three sets of projections are developed for the 1979–2000 period: (1) gasoline price levels, (2) on-road fuel economy of the private vehicle fleet, and (3) per mile out-of-pocket costs for operating the private vehicle fleet.

Gasoline price projections are based on an assumed rate of annual growth in the real price of gasoline (in June 1979 prices). A rate of 0.0235 per year, which is the historic rate for the 1969–1979 period, is used. In addition, the effects of the decontrol of domestic crude oil, estimated to total $0.11 per gallon by the end of 1981, and the effects of the recently announced petroleum import fee are included in the projections. The projections produce pump prices that include taxes. Table 1 gives the price projections and Appendix A presents more details on the derivation of the projections. (Chapter Four discusses the possibility of alternative price projections. The approaches presented there can be used by other analysts. For example, after the analyses in the chapter were completed, the petroleum import fee was defeated in Congress. A revised projection deleting the fee could be generated.)

TABLE 1

PROJECTIONS OF NATIONAL AVERAGE PUMP PRICE OF GASOLINE—BASE CASE, NONSHORTAGE SCENARIO

(Cents per Gallon* in June 1979 Dollars)

Year	Pump Price
1979	86.24
1980	99.27
1981	110.84
1982	113.22
1983	115.66
1984	118.15
1985	120.71
1990	134.40
1995	149.79
2000	167.06

*1 cent per gallon = .26 cents per liter

Two fuel economy projections are presented. The first set of projections assumes that the 1985 Corporate Average Fuel Economy (CAFE) standard of 27.5 mpg for new car fuel economy is reached and no subsequent improvements occur. The second set allows post-1985 improvements by assuming that the rates of improvement for automobile and light truck fuel economies from 1985 to

TABLE 2

ON-ROAD FUEL ECONOMY PROJECTIONS FOR THE PERSONAL VEHICLE FLEET

Year	Low Fuel Economy: On-Road Fuel Economy* (Miles per Gallon)+	High Fuel Economy: On-Road Fuel Economy** (Miles per Gallon)+
1975	13.6	13.6
1979	14.7	14.7
1980	15.0	15.0
1981	15.4	15.4
1982	15.8	15.8
1983	16.1	16.1
1984	16.5	16.5
1985	16.9	16.9
1990	17.7	20.2
1995	18.4	24.1
2000	19.2	28.9

*From Table A-1.

**From Table A-2.

+1 mile per gallon = .425 kilometers per liter.

TABLE 3

PERSONAL AUTOMOBILE OPERATING COSTS

(Cents per Mile* in June 1979 Dollars)

Year	Operating Costs**: Base Case	Operating Costs**: Conservation Scenario
1979	10.77	10.77
1980	11.69	11.69
1981	12.46	12.46
1982	12.62	12.62
1983	12.79	12.79
1984	12.98	12.98
1985	13.20	13.20
1990	14.88	13.93
1995	16.86	14.92
2000	19.14	16.23

*1 cent per mile = .62 cents per kilometer.

**From Table A-4.

2000 are 50 percent greater than the rates for 1975 to 1985. Table 2 presents the projections. It should be noted that, because the CAFE standards apply to new cars only, the overall fleet fuel economy is lower.

The two fuel economy projections can be used to test alternative hypotheses concerning longer term impacts of fuel shortages. The first set of fuel economy projections is consistent with the assumption that temporary shortages have no long-run impacts on choice processes resulting in vehicles more fuel efficient than those mandated by the 1985 CAFE standards. The alternative projections can be viewed as incorporating a long-run adjustment to more fuel-efficient vehicles.

Projections for operating costs are derived from the gasoline price and fuel economy projections. Operating costs are estimated using Eq. 1:

$$\text{Cost}_i = \text{Gas price}_i / FE_i + OC_i \qquad (1)$$

where cost, gas price, fuel economy, FE, and other (non-gasoline) costs, OC, are defined for each year, i. The "other" costs are based on historic rates of change in the real costs (see App. A). Table 3 presents the two operating cost projections corresponding to the two fuel economy projections.

Shortfall Scenarios

In Appendix A, six shortfall scenarios are defined in terms of (1) shortfall level (percent shortfall), (2) gasoline price, (3) frequency of occurrence between 1979 and 2000, (4) shortfall duration, and (5) governmental actions. Actions such as gasoline rationing, pump price decontrol, and contingency measures (e.g., odd-even gasoline sales plans) are considered. In addition to these actions, which are likely to be initiated by federal or state governments, local or regional governments may implement other actions. The six scenarios are given in Table 4.

In addition to the criteria used to define the scenarios, other factors must be considered in any analysis of travel impacts. These factors include specific combinations of locally initiated actions affecting transportation levels of service. Also, possible long-run conservation adjustments, such as people living closer to work or buying more fuel-efficient vehicles, can be considered.

A prohibitively large number of specific travel environments can be derived from the six scenarios in Table 4. For example, in each year different combinations of long-run adjustments and locally initiated level of service actions define distinct travel environments. In order to keep the analysis and discussion manageable, four special cases are selected from these scenarios for purposes of testing the quantitative forecasting system. These are:

- 1985: 15 percent gasoline shortfall, vehicle sticker plan implemented (the sticker plan is described in the Federal Emergency Energy Conservation Plan (*8*); under this plan, all vehicles in a household could not be driven on day(s) of the week indicated by the sticker).
- 1985: 15 percent shortfall, local actions to encourage high occupancy vehicles (buses, carpools).
- 1990: 25 percent shortfall, gasoline rationing with white markets for coupons, local actions to encourage high occupancy vehicles (HOV) and discourage single occupancy vehicles (SOV), no long-run fuel economy and location choice impacts assumed.

- 1990: 25 percent shortfall, gasoline rationing with white markets, local actions to encourage HOVs and discourage SOVs, long-term adjustments in vehicle fuel economy and location choice assumed.

These four special cases are clearly only a small fraction of the number of possible cases. However, they should be sufficient to illustrate the capabilities of the forecasting system. In addition, results from testing these cases are useful in illustrating the sensitivity of travel to shortfalls and resulting governmental action. For example, comparison of the first two cases provides information on the relative effectiveness of coercive (sticker plan) and noncoercive actions, and comparison of the last two cases demonstrates the possible impacts of long-run adjustments in auto ownership (fuel economy) and residential location on travel during fuel shortage periods.

TABLE 4

DEFINITIONS OF THE SCENARIOS

		Shortage Assumptions			
	Pump Price	Magnitude (Percent)	Duration*	Frequency	Government Allocation
A	Low	10-15	3 months	5-year intervals (1985, 1990, 1995, 2000)	Actions that do not involve price decontrol taxes, or rationing**
B	High	10-15	3 months	5-year intervals	Decontrolled pump price
C	Low	20-25	3 months	10-year intervals (1990, 2000)	Rationing with white markets
D	High	20-25	3 months	10-year intervals	Rationing with white markets
E	Low	20-25	1 year	1990	Rationing with white markets
F	High	20-25	1 year	1990	Rationing with white markets

*For scenarios where rationing is implemented, duration refers to the period during which rationing is in effect.

**These actions likely include measures used in previous shortages such as the odd-even gasoline sales plan and Sunday gasoline sales ban as well as some of the actions described in the Standby Federal Emergency Energy Conservation Plan (DOE, 8). These actions include: 1) public information; 2) minimum fuel purchase requirements; 3) odd-even; 4) employer-based commuter and travel measures; 5) speed limit enforcement; 6) compressed work week; 7) vehicle use sticker plan; and 8) recreational vehicle use restrictions.

OVERVIEW OF THE FORECASTING SYSTEM

In this section, a brief description of the modeling system is given. Particular attention is given to the inputs and outputs. The system, which consists of work trip models and nonwork trip models, is designed to produce estimates of the vehicle-miles traveled (VMT) and fuel consumption resulting from fuel shortage conditions and governmental responses to these shortages. Methods that facilitate the use of hand or calculator-assisted analysis are emphasized. An incremental, or pivot point, approach can be used in applying these methods. Thus, the approach is an alternative to methodologies that require a large set of computer programs, such as the energy policy analysis program developed by CSI (*9*).

The work trip component combines several characteristics that have been recommended in previous research. The basic model is a logit modal choice model that includes single-occupancy vehicle, shared ride, and transit modes. In order to improve the aggregate forecasting capabilities of the model, a traveler classification aggregation procedure is used. That is, work trip makers are classified into groups based on trip length and the availability of alternative modes. Average modal choice probabilities are estimated for each group. The incremental logit formulation is used—that is, modal choice forecasts are based on current modal choice probabilities and changes in level of service variables. (The models can also be applied in the more conventional manner in which mode choice forecasts are based on future values of level of service and other variables. Incremental logit was selected because it facilitates manual applications and because it appears to perform at least as well as conventional logit (see App. C).) Incremental logit is a pivot point approach that is quite similar to elasticity analysis in its input requirements and interpretation. Finally, because model parameters from existing modal choice models differ for different studies, sensitivity tests, which involve the use of alternative sets of model coefficients, are an important feature of the application of the work trip models.

Input variables (for each trip distance/choice set class) include: (1) base level of service variables; (2) forecast period level of service variables (alternatively, the change in level of service variables can be used; this simply involves taking differences between forecast and base period values); (3) base modal shares; (4) forecast period work trips; (5) average occupancies of modes; and (6) fuel economies for private vehicles and transit. Forecasts of vehicle-miles traveled and fuel consumed are derived in a straightforward manner from the modal choice forecasts, the average occupancies and fuel economy inputs, and the work trip length frequency distribution. Because the level of service variables are for work trips, peak period values would be used.

The nonwork trip models are linear equation models that estimate private vehicle VMT and transit use. Explanatory variables include level of service factors, socioeconomic characteristics, and urban form variables. Because the models are linear, no special procedures for aggregation are necessary. The models can be used directly or in an incremental (pivot point) manner. The applications presented later in the chapter use the incremental approach. This approach parallels the work trip analyses and can be shown to be equivalent to elasticity analysis.

Input requirements include base level nonwork VMT and transit usage for the city or region in question and the changes in the independent variables. The outputs are areawide VMT and transit ridership. Fuel consumption estimates can be derived by using the fuel economy factors described earlier.

In the following two sections, the work and nonwork trip components are described in greater detail.

WORK TRIP MODELS

In this section, the essential features of the work trip

component are described. The section is organized into four parts: (1) description of the traveler classification approach; (2) incremental logit analysis; (3) estimation of VMT and fuel consumption; and (4) sensitivity analysis.

Traveler Classification

Because the logit model is nonlinear, the use of areawide average values of the level of service and other independent variables in the logit formula can produce biased predictions of the areawide modal shares. This is the well known "aggregation problem" that has been described in detail elsewhere (*10, 11*).

Several procedures have been proposed for dealing with this problem. Probably the most practical procedure is the traveler classification approach. In previous studies it also has been called the market segmentation (*11, 12*) approach. The trip makers in an area are segmented into groups that have reasonably similar values for the independent variables. For each class, the average values for the variables are inserted into the logit formula to estimate modal shares for that traveler class. These modal shares are then multiplied by the total trips to obtain the number of trips by each mode for each class. Areawide results are obtained by adding the results for each class.

The particular traveler classification procedure used in this study is based on previous findings on effective procedures for aggregating forecasts. CRA (*11, 12*) has used trip distance, auto availability, transit access, and income to define groups of work trip makers. Koppelman (*13*) found that choice set availability was an effective classification criterion. The present classification combines these findings by using trip distance and choice set availability as criteria. Six classes are defined. For each of two average trip distances (long and short), three choice set subgroupings are used: (1) trip makers with the full choice set (drive alone, shared ride, transit); (2) trip makers with drive alone and shared ride; and (3) trip makers with shared ride and transit. (The construction of these traveler classes from data available to transportation planners is discussed in Chap. Four.)

The derivation and justification for this classification procedure are discussed in detail in Appendix C. The main conclusions from this discussion are that the procedure has a number of desirable features. First, the small number of classes (6) requires fewer calculations than the 12 and 36 traveler classes proposed in previous studies. Second, the procedure yields results that appear to be at least as accurate as the results of alternative classifications (including more complex classifications and simpler ones based on distance or choice set alone). Third, the classification criteria are sensitive to alternative policies. The distribution of modal shares by trip distance is of direct use in estimating VMT and fuel consumption and the distribution of trip makers across choice set classes can be influenced by policy actions. For example, improving transit accessibility would shift trip makers from a drive alone/shared ride class to a full choice set class. Similarly, policies that ban the use of automobiles on particular days would shift trip makers from classes containing the drive alone mode.

Incremental Logit Analysis

The incremental form of the logit model has been described and applied by Ben-Akiva and Atherton (*13*) and Kumar (*14*). Modal shares for particular traveler classes are forecast by the following formula:

$$MS^N_{ij} = MS^B_{ij} \exp(\Delta V_{ij}) / \sum_k MS^B_{kj} \exp(\Delta V_{Kj}) \quad (2)$$

$$\Delta V_{ij} = a_1 (X^N_{ij1} - X^B_{ij2}) + a_2 (X^N_{ij2} - X^B_{ij2}) + \ldots + a_\ell (X^N_{ij\ell} - X^B_{ij\ell}) + \ldots \quad (3)$$

where:

MS^N_{ij} = the forecast share for the ith mode and the jth class;
MS^B_{ij} = the base share for the ith mode and the jth class;
$X^N_{ij\ell}$ = the value of the ℓth independent variable for the ith mode and the jth class for the forecast period;
$X^B_{ij\ell}$ = the corresponding variable for the base period; and
a_ℓ = the coefficient of that variable.

The particular models used in this study include trip cost, in vehicle travel time, and walk time as independent variables. They are based on earlier CRA studies (*16, 17*) that resulted in the development of work trip models.

Estimation of VMT and Fuel Consumption

The incremental logit model forecasts modal shares for the traveler classes. Private vehicle VMT is estimated from this information as follows:

$$\text{VMT} = \sum_{j=1}^{6} [MS^N_{Dj}\, TL_{Dj} + MS^N_{Sj}\, TL_{Sj}/LF_S] \quad (4)$$

where D is drive alone; S is shared ride; TL is the trip length; and LF is the average vehicle occupancy. It should be noted that for a particular traveler class, the trip length for shared ride will be longer than the corresponding length for drive alone because of the trip circuity involved in picking up and dropping off passengers. For the two classes in which drive alone is not available, $MS^N_{Dj} = 0$.

Fuel consumption is assumed to be proportional to VMT; that is,

$$\text{Fuel consumption} = \text{VMT}/FE \quad (5)$$

where FE is the average fuel economy of the private vehicle fleet measured in miles per gallon. The proportionality assumption is an approximation, because fuel economy varies with trip length, speed, average occupancy, trip purpose, and other factors (*9, 18*). However, this approximation should be sufficiently accurate for the types of analyses for which the forecasting system is designed.

Miles traveled and fuel consumption for transit can also be estimated. The estimating equations are:

$$\text{BMT} = \sum_{j=1}^{6} MS^N_{Tj}\, TL_{Tj}/LF_T \quad (6)$$

$$\text{Transit fuel consumption} = \text{BMT}/(\text{Transit fuel economy}) \quad (7)$$

where BMT is transit miles traveled. ($MS_T = 0$ for segments without transit available.)

In cities with excess capacity for work trips, Eqs. 6 and 7 may overestimate transit vehicle travel. That is, vehicle occupancy, LF_T, could increase, especially earlier in the shortfall before backup capacity can be put into use. Therefore, these estimates should be viewed as upper bounds.

These estimates also can be viewed as indicators of the transit resources necessary to handle the increased ridership at reasonable levels of service. If sufficient resources are unavailable, transit level of service would deteriorate, resulting in fewer trips being diverted to transit. Some of these trips may be diverted to nonmotorized modes (witness the increase in bicycle travel resulting from the New York City transit strike) or not made at all.

Another issue is the fact that private vehicle access modes are not accounted for. In urban areas where park-and-ride access is not prominent, energy consumption by access modes will not be large. In areas where private vehicles are an important access mode, it may be desirable to address the transit access mode issue either by defining transit modes in terms of access mode (e.g., bus with walk access, bus with auto access) or by assigning the transit share to alternative access modes. If access by private vehicles is not considered, energy savings derived from the modeling system may be somewhat overestimated.

Sensitivity Analysis

Although it has been hypothesized that parameters resulting from behavioral travel models should be transferable across geographic locations and over time, the empirical evidence on this issue is inconclusive. Therefore, rather than recommending a single set of parameters (model coefficients), the use of alternative sets of coefficients is recommended.

In addition to the transferability issue, there is the issue of the representation of level-of-service variables. In many existing models, they are entered linearly (i.e., the variable is multiplied by its coefficient). However, other functional forms might be appropriate. For example, the logarithm of the level-of-service variables can be multiplied by the coefficient. Although models with alternative functional forms for level-of-service variables tend to fit calibration data sets similarly (*17, 19*), substantial differences in predictions beyond the range of the calibration data set can occur. For example, modal share decreases faster with increasing travel costs when cost is linear rather than logarithmic.

Three sets of coefficients for cost, in vehicle time, and walk time are used. The first set is derived from the original CRA work trip model (*16*). This model has been used extensively in the analysis of transportation policies (*12, 20, 21*). The cost coefficient is updated by multiplying the original coefficient by the ratio of the 1979 consumer price index to the 1967 index (the year of the calibration data set).

The second set is constructed by dividing each coefficient in the first set by two. The procedure used in constructing this set is consistent with the suggestion of Atherton and Ben-Akiva (*22*) that coefficients should be transferable up to multiplication by a scaling factor. Multiplication of a set of coefficients by a scaling factor preserves the relative tradeoffs between variables (e.g., values of time) but changes the absolute sensitivity of modal choice to level-of-service changes. The scaling factor of one-half was chosen because the coefficients of a similarly specified model estimated with 1968 Washington, D.C., data (*19*) were roughly one-half the magnitude of the coefficients of the CRA model (estimated with 1967 Pittsburgh data). Because the coefficients of the CRA model appear to be large (in absolute size) relative to other estimates (*15, 23*), only smaller coefficients are tested.

The third set of coefficients is derived from the version of the 1967 Pittsburgh model in which cost and in-vehicle time are entered logarithmically. Values for the three sets of coefficients are given in Table 5.

NONWORK TRIP MODELS

A simultaneous linear equation model is used for analyzing nonwork travel. The model was estimated with data from the 1969 Nationwide Personal Transportation Survey (NPTS). The model was developed by CRA (*12*) as an alternative to more complex probability choice nonwork trip models. The two-equation version of the model is used in incremental form. The choice of the incremental, or pivot point, form was based on computational convenience and on the fact that this form of the model may produce more accurate results (*12*). Because the model is linear, no special aggregation problems arise. Therefore, the model can easily be applied by hand (or with the assistance of a hand-held calculator).

The two equations include an equation that predicts household VMT for a 4-day period and an equation that predicts transit trips for the same period. Therefore, in order for the output from the nonwork trip model to be compatible with the work trip analyses, these predictions are divided by four.

The derivation of the incremental form of the simultaneous equation model, which is discussed in Appendix C, is represented by Eqs. 8a and 8b.

$$\Delta\text{VMT} = a\ \Delta\text{Transit trips} + \Sigma\ b_i\ \Delta X_i \qquad (8a)$$

$$\Delta\text{Transit trips} = c\ \Delta\text{VMT} + \Sigma\ d_i\ \Delta X_i \qquad (8b)$$

TABLE 5

ALTERNATIVE SETS OF COEFFICIENTS USED IN SENSITIVITY ANALYSES INVOLVING THE WORK TRIP

	Variables		
	Cost	In-Vehicle Time	Out-of-Vehicle Time
Linear I*	-1.04	-0.0411	-0.114
Linear II	-0.52	-0.0205	-0.055
Log** (Cost, In-Vehicle Time)	-1.34	-2.0300	-0.110

SOURCES: *From Domencich and McFadden (16) with adjusted cost coefficient. Domencich, T. and McFadden, D., Urban Travel Demand: A Behavioral Analysis. Amsterdam, North-Holland Publishing Co. (1975).

**From CRA (17), p. C-65.

In Eqs. 8a and 8b Δ signifies a change in a variable from the base period to the forecast period, and X_i signifies the independent or exogenous variables, which include household characteristics, level-of-service variables, and urban area characteristics.

Equations 8a and 8b can be transformed so that only the independent variables are on the right side (reduced form). The resulting equations are

$$\Delta \text{VMT} = \frac{1}{1\text{-}ac} \sum_i (b_i + ad_i)\, \Delta X_i \qquad (9a)$$

$$\Delta \text{Transit trips} = \frac{1}{1\text{-}ac} \sum_i (d_i + cb_i)\, \Delta X_i \qquad (9b)$$

To apply Eqs. 9a and 9b, the changes in the independent variables are inserted into each of the two equations to estimate the changes in VMT and transit trips. The changes in the dependent variables are then added to the values for the base period to produce the forecasts.

The original model estimated by CRA is given in Tables B-1(a) and B-1(d). Because the model was estimated with 1969 data, it is necessary to update the cost and income coefficient to reflect the difference between 1969 and 1979 costs of living. Also, because the representation in Tables B-1(a) and B-1(d) is in the form of Eqs. 8a and 8b, it is necessary to transform the models to reduced form. The resulting models are represented in Table 6. Table 7 defines the variables used in the models. (Note that because VMT does not appear in the transit trips (#T.TRP) equation, $c = 0$ and the resulting coefficients are identical to those in Table B-1(d), except for the updated income coefficient. No constant terms appear because they cancel out in the incremental form of the model.

VMT for private vehicles is a direct output of the model. Fuel consumption for nonwork travel can be derived from Eq. 5 (i.e., fuel consumption is obtained by dividing VMT by average fuel economy). The model produces the number of nonwork transit trips. Bus miles can be estimated by assuming an average bus trip length and a nonwork bus occupancy average. Bus fuel consumption would then be derived by dividing bus miles by bus fuel economy as in Eq. 7.

As is the case for the work trip analysis, the simple relation used to calculate modal fuel consumption is an approximation. In the case of private vehicle fuel consumption, VMT per trip could change as total VMT was reduced. For example, increased trip chaining could change the average VMT per trip. Because fuel economy improves with longer trips, a change in the average VMT per trip could mean that fuel savings were not strictly proportional to total VMT reduction.

The evidence on whether average trip distance increases or decreases with VMT is inconclusive. Alternative versions of the nonwork models are given in Tables B-1(b) and B-1(c). These models show a negative interaction between trip frequency and average trip length. This interaction suggests that if a VMT reduction is the result of reduced trip frequency (e.g., more trip chaining), average trip lengths would increase and the fuel savings would be greater than proportional to the VMT reduction. The interaction is also consistent with VMT reduction resulting from more, but shorter, trips. In this case, fuel savings would be less than proportional to VMT.

Horowitz (*24*) used a nonwork model that incorporated the effects of trip chaining in analyzing policies for allocating gasoline during a fuel shortage. In all cases, average trip distance decreased and fuel savings were less than proportional with VMT reduction. Fuel savings percentages ranged from about 80 to 90 percent of VMT reduction percentages.

TABLE 6

REDUCED FORM NONWORK TRAVEL EQUATIONS CHARLES RIVER ASSOCIATES MODEL—VMT AND NUMBER OF TRANSIT TRIPS

CHARLES RIVER ASSOCIATES MODEL: VMT

Variable	Coefficient
VMT	Dependent
D.TM/MI	-7.838
D.V.HH.TM/MI	- .2422
D.CO/MI.V.HH	-51.01
#PPL>4	-14.128
URBAN	-3.394
SM.SZE	-2.897
PLCSZE	-1.979
#LIC.D	15.14
D.PKAV	-20.04
T.TIME	.2414
TAVL.D.TRP	- 41.38
H.H.$	.0007728
H.H.SZE	9.022

CHARLES RIVER ASSOCIATES MODEL: NUMBER OF TRANSIT TRIPS

Variable	Coefficient
#T.TRP	Dependent
T.TIME	-0.009959
TAVL.D.T.TRP	1.707
H.H.$	- .00003188
HH.SZE	- .3722
#PPL>4	.7877

TABLE 7

VARIABLE DEFINITIONS FOR NONWORK TRAVEL MODELS

Variable Name	Variable Definition*
VMT	Vehicle miles traveled by a household for nonwork trips over a four day period**
#T.TRP	Number of nonwork transit trips by a household over a four day period
D.CO/MI.V.HH	Average gasoline price per mile of a nonwork auto trip for a household divided by the household wage per minute in minutes/miles***
D.TM/MI	Average travel time per mile for an auto nonwork trip by a household, in minutes/mile
D.V.HH.TM/MI	Average travel time per mile for an auto nonwork trip by a household multiplied by the household wage per minute, in cents/mile***
T.TIME	Average travel time for a transit nonwork trip by a household, in minutes
D.PKAV	Fraction of household's nonwork auto trips for which free parking was available+
TAVL.D.T.TRIP	Fraction of household's nonwork auto and transit trips for which transit was available within 6 blocks
H.H.$	Household income, in dollars/year
#LIC.D	Total number of licensed drivers in the household
HH.SZE	Total number of household members
#PPL>4	Number of household members aged 5 or older
URBAN	Coded variable indicating population of urban area ranging from 1, for largest area, to 8, for smallest area++
SM.SZE	Coded variable indicating population of SMSA ranging from 2, for smallest area, to 7, for largest area+++
PLCSZE	Coded variable indicating population of household residence place ranging from 0, for smallest, to 15, for largest#

*The variables were defined at the household level in estimating the model. Areawide averages are used in the applications of this project.

**Nonwork trips exclude trips to school and church for those individuals less than 26 years old.

***Household wage per minute is equal to household annual income in dollars divided by 120,000 minutes and transformed to cents.

+Because parking at home is typicably free, this variable will take on values between 0.5 and 1.0

++The code urban population correspondence is as follows:

urban in urbanized area:

1	3,000,000 or more
2	1,000,000 - 2,999,999
3	250,000 - 999,999
4	under 250,000

urban not in urbanized area:

5	25,000 or more
6	10,000 - 24,999
7	2,500 - 9,999
8	rural

+++The code SMSA population correspondence is as follows:

2	100,000 - 249,999
3	250,000 - 499,999
4	500,000 - 999,999
5	1,000,000 - 1,999,999
6	2,000,000 - 2,999,999
7	3,000,000 and over

#The code place population correspondence is as follows:

0	under 200
1	200 - 499
2	500 - 999
3	1,000 - 1,499
4	1,500 - 1,999
5	2,000 - 2,499
6	2,500 - 4,999
7	5,000 - 9,999
8	10,000 - 19,999
9	20,000 - 24,999
10	25,000 - 49,999
11	50,000 - 99,999
12	100,000 - 249,999
13	250,000 - 499,999
14	500,000 - 999,999
15	1,000,000 or more

Hartgen and Neveu (*25*) analyzed fuel conservation resulting from adjustments such as trip chaining by referring to average trip distances for both home-and nonhome-based trips. Nonhome-based average trip distances can be longer or shorter than the corresponding home-based distance, suggesting that the effects of trip chaining on average trip distance are uncertain. If better trip planning accompanied trip chaining, however, average trip distance would probably decrease. The resulting fuel savings would be less than proportional to VMT savings.

For transit fuel consumption, because nonwork occupancies are typically much lower than work trip occupancies, extra person miles of travel could be accommodated with less than proportional increases in vehicle-miles by increasing average occupancies. This effect may be either enhanced or offset by changes in transit trip lengths.

Unlike the case for work trip analysis, there is not much information on the possible range for values of the model coefficients. In fact, this particular model may be the only one with this type of simultaneous equation specification. Further, because the model was estimated with national data, it is likely to be generally applicable to urban areas. For these reasons, sensitivity analyses on the coefficients are not performed, although such analyses might be useful when further knowledge on the likely range of coefficients is available.

Because of the linear form of the model, forecasts can be made by substituting the areawide averages for the independent variables into the equations to derive average household VMT and transit trips. These averages are then multiplied by the number of households in the area and divided by four to obtain area totals.

It should be noted that two variables in the VMT equation, average per mile gasoline price divided by wage (D.CO/MI.V.HH) and average travel time multiplied by wage (D.V.HH.TM/MI), are products of individual variables. The former variable is the product of gas price, average gallons per mile, and the inverse of the household wage rate. The latter is simply the product of average travel time and wage. Although the average of the product of variables is generally not equal to the product of the averages, it appears that the individual components of the two products of interest are sufficiently uncorrelated so that approximating the average product by the product of the averages is reasonable (*12, 24*). This approximation is used in the applications of the models. For example, the projections for gasoline price and average fuel economy for 1985 are $1.21 and 16.9 mpg, respectively, for the nonshortfall case. If the average income for the area were projected to be $20,000 (in 1979 dollars) per year, D.CO/MI.V.HH would be:

$$121\,\frac{\text{cents}}{\text{gallon}}\times\frac{1}{16.9}\,\frac{\text{gallons}}{\text{mile}}\times\frac{1{,}200}{20{,}000}\,\frac{\text{minutes}}{\text{cents}}=0.43\,\frac{\text{minutes}}{\text{mile}}$$

SCENARIO TESTS

In this section, four scenarios are defined for testing the capabilities of the modeling system. The scenarios include gasoline price increases to represent the effects of fuel shortages and level of service changes to represent the

effects of actions to encourage the use of high-occupancy vehicles (HOVs) and/or discourage the use of low-occupancy vehicles. To assess the relative importance of price increases and the other level of service changes, the travel behavior impacts of each scenario are compared to the travel impacts under nonshortfall conditions and the travel impacts resulting from the gasoline price increases without the other level-of-service changes. In the following discussion, these alternative sets of conditions are referred to as the nonshortfall and high price comparisons, respectively. The scenarios, which were identified earlier, are labeled (1) 1985 Sticker Plan, (2) 1985 Market Price/TSM, (3) 1990 Rationing/TSM, and (4) 1990 Rationing/TSM with Long-Run Conservation Adjustments.

The price increases associated with the shortfall scenarios are derived exogenously by using a simple price elasticity model; specifically:

$$P_S = P_N\left(1 - \frac{S}{\eta}\right) \qquad (10)$$

where P_S is the shortfall price; P_N is the nonshortfall price; S is the shortfall level (expressed as a decimal function); and η is the price elasticity, which is assumed to be —0.2. The nonshortfall prices, which are given in Table 1, are $1.21 and $1.34 for 1985 and 1990, respectively (in 1979 prices).

Alternatively, gasoline price can be defined endogenously (i.e., price can be set at the level at which the gasoline consumption predicted by the modeling system matches the assumed shortfall level). Although the exogenous approach is emphasized here, the endogenous price estimates are given later, mainly as a test of the validity of the modeling system.

In addition to gasoline price, vehicle fuel economies are necessary to define operating costs and fuel consumption. Private vehicle fuel economy for the 1985 scenarios is assumed to be 16.9 mpg. The figures for the 1990 scenarios are 17.7 for the scenario without long-run conservation adjustments and 21.2 mpg for the scenario that assumes long-run adjustments. These projections are given in Table 2. Transit fuel economy is 4.1 mpg for all scenarios.

In the scenario tests, the forecasting system is applied to a hypothetical medium-sized city of 327,000 population and 145,200 employees in 1980, which is the base case for the incremental forecasting procedures. The input variables for the 1980 base case and the scenarios further define the city. Appendix F presents this information. Both employment and population are assumed to grow at the national averages during the period represented by the scenarios (1980–1990). Other demographic variables appearing in the models (e.g., average household size, household income, etc.) are also assumed to follow the national trends.

Scenario Description

Each scenario may be defined in terms of the variables of the modeling system. That is, each scenario involves changes in the independent variables, represented in Tables 5 and 6, from the base case. Additional input variables are also necessary for calculating miles traveled and fuel consumption. These include the work trip length for the modes for each traveler class, vehicle occupancies (1, 2.5, and 75 for drive alone, shared ride, and transit), fuel economy, number of work round trips, number of households, and number of transit miles per nonwork transit trip.

As explained earlier, the total number of work trips is divided into six traveler classes based on modal choice set and trip length. The six classes are given in Table 8. Therefore, part of the scenario definition is the distribution of work trips across traveler classes that in part may be determined by travelers' long-run responses to fuel market forces. Each scenario is briefly described next. A complete description of the input variables for each scenario and the base case is given in Appendix F. Sample calculations illustrating the work and nonwork models are also covered in Appendix F.

1985 Sticker Plan Scenario

This scenario represents a 15 percent energy shortfall in 1985 and implementation of the sticker plan. The impacts of the sticker plan are of interest because the plan is one of the measures proposed in the federal standby plan. The sticker plan is expected to affect both the length of gasoline lines and the distribution of work trips among traveler classes. Because households are restricted from using automobiles one day per week, the demand for gasoline is decreased, resulting in shorter gasoline lines than if prices were controlled and no government actions were initiated. Similarly, because households are restricted from using automobiles, the automobile (drive alone) mode is not available to a certain proportion of households each day for work trips. This is represented by shifting one-seventh of the trips from classes (1) through (4) into classes (5) and (6). (Short trips are shifted to class (5) and long trips are shifted to class (6).) Average auto availability is also decreased in the nonwork trip analyses.

If the sticker plan does not reduce total gasoline demand by at least 15 percent, gasoline lines will form. Following Dorfman and Harrington (*27*), this effect is represented by an increase in gasoline price over the nonshortfall price even though the "price increase" is paid in waiting time and not money. This approach is chosen because of the difficulty involved in estimating actual waiting times, which are a complex function of many factors such as fuel economy, gas station operating policies, and panic buying. In addition, the total waiting time would have to be assigned to individual work trips in order for it to be represented as a time rather than a cost component in the model.

TABLE 8

TRAVELER CLASSES USED IN WORK TRIP ANALYSES

Class	Choice Set	Trip Length
1	Drive Alone/Shared Ride/Transit	Short
2	Drive Alone/Shared Ride/Transit	Long
3	Drive Alone/Shared Ride	Short
4	Drive Alone/Shared Ride	Long
5	Shared Ride/Transit	Short
6	Shared Ride/Transit	Long

Under one set of assumptions, the impact of the sticker plan alone (without the accompanying gasoline lines) is a total reduction in gasoline consumption of 6.25 percent, with 5 percent coming from work trip reductions and 1.25 percent from nonwork trip reductions. (If households choose their carless days from among the 7 days, and each day is equally likely to be selected, one-seventh of work VMT is likely to be lost. Because work-related trips were 42 percent of total VMT in the 1969 Nationwide Personal Transportation Study (*26*), about a 6 percent VMT reduction results. This is reduced to 5 percent to account for circuity in carpooling. It is also assumed that much of the nonwork (all of the social and recreational and one-half of the medical, dental, shopping, and other nonwork) VMT can be shifted to other days, resulting in the 1.25 percent reduction attributable to nonwork travel.) This is somewhat higher than the amount estimated in the analysis of the federal standby plan (*8*).

By using a shortfall level of 8.75 percent (0.15 — 0.0625) in Eq. 10, the estimated pump price per gallon of gasoline is $1.735. It should be realized that this price is a first approximation. The reasonableness of this price level will be determined by how accurately the total work and nonwork reduction in fuel consumption matches the assumed 15 percent level.

For nonwork trip forecasts, the level-of-service variables for this scenario are generally the same as the base case values, with the exception of the two variables defined in terms of income, gasoline, price, and fuel economy (D.V. HH.TM/MI and D.CO/MI.V.HH). The effect of banning household automobiles one day per week is represented by reducing the average number of licensed drivers per household by 1/14. This reduction is based on the assumption that, because of opportunities to reschedule travel, only one-half of the maximum potential loss in vehicle availability is actually lost.

1985 Market Price/TSM Scenario

This scenario describes a 15 percent shortfall in 1985 gasoline price at the market clearing level ($2.11 per gallon) and several nonrestrictive contingency actions. The market clearing level is the price that causes demand to decrease by 15 percent; it is estimated with Eq. 10. These actions may be more likely than the sticker plan because state and local governments have been unwilling to impose restrictions on automobile use in the past. The actions considered are free tolls for carpools, bus priority treatment at intersections and traffic signals, and exclusive contraflow bus lanes on highways. (Although these actions are considered in the context of a fuel shortage here, they are certainly applicable in other situations.) Because it is expected that these actions will not significantly affect total gasoline demand, the pump price is assumed to be determined by the 15 percent shortfall. This assumption is made for analytical convenience. Later, a discussion of the effect of contingency actions on lowering gasoline prices is presented.

The free toll policy is reflected in trip costs for the carpool mode. The bus priority treatment is assumed to affect only short bus trips that use local streets; the in-vehicle travel time (IVTT) variable for short transit trips is adjusted to reflect a reduction in line-haul time. The exclusive bus lane is assumed to affect only long trips that use highways; a reduction in line-haul time for these trips is assumed. The relative distribution of work trips among traveler classes is the same as that defined under the base case.

The free toll policy for carpools results in a slight reduction in trip costs for carpools—$0.04 and $0.08 for short and long trips, respectively. The bus priority treatment is assumed to reduce line-haul time for short bus trips by 10 percent. This leads to between a 6.91 percent and 7.5 percent reduction in IVTT. The exclusive bus lane is assumed to affect only long bus trips, resulting in a 20 percent reduction in line-haul time, or a 18.4 percent reduction in IVTT.

For nonwork trips, it is assumed that preferential treatment for transit reduces average trip time by 5 min to 25 min and that transit is now available for 45 percent rather than 40 percent of all nonwork trips.

1990 Rationing/TSM Scenario

This scenario represents a 25 percent shortfall in 1990, rationing with white markets, and several restrictive contingency actions in addition to actions included under the previous scenario. The total price of gasoline (pump price plus coupon price) is at the market clearing level ($3.02 per gallon). The restrictive actions include a $1.00 parking surcharge levied on commercial lots, municipal lots, and fringe parking areas, and a reduction in on-street parking near employment centers. The surcharge results in an increase in trip cost for the automobile and carpool modes for those commuters who pay for parking and use the affected facilities. The reduction in on-street parking is assumed to increase walk time for the automobile and carpool modes for the proportion of travelers who park on the street, reflecting the fact that these commuters will have to park further from their workplace. These restrictions also affect times and costs for nonwork trips.

The surcharge will affect only 3.1 percent of the vehicles because only this proportion of vehicle trips pay for parking in these facilities, resulting in a $0.03 average cost increase for drive alone and a $0.02 increase for carpool. The reduction in on-street parking affects only the 12.1 percent of vehicles that park on the street. The result of this policy is assumed to be a 50 percent increase in walk time for affected trips. Therefore, walking time for this scenario equals 1.0605 times walking time for the previous scenarios. The relative share of work trips by traveler class under this scenario is the same as for the base case.

The main feature of this scenario for nonwork trips is that it includes private vehicle disincentives as well as the transit incentives of the previous scenario. Free parking is reduced so that it applies to 75 percent rather than 85 percent of trips. This reduction in parking availability is also assumed to increase average per mile trip time to 3.5 min per mile from the 3.23 min per mile used in the base case.

1990 Rationing/TSM with Long-Run Conservation Adjustments Scenario

This scenario describes a 25 percent shortfall in 1990, rationing with white markets, contingency actions included in the previous scenario, and adjustments in long-run household location decisions. The alternative 1990 scenario assumes that past energy shortages do not lead to changes in households' long-run decisions. In this scenario, however, it is assumed that as a result of periodic shortages in the past and anticipated future shortages, several adjustments have occurred in the private passenger vehicle fleet and residential location decisions. Because of the increased demand for fuel-efficient vehicles, the average on-road fuel economy in 1990 is assumed to be higher than under the previous scenario. It is also assumed that households will locate closer to their workplaces or will choose workplaces closer to their homes. This adjustment is described by shifting the distribution of work trips in favor of the short traveler classes. In particular, changes in residential and/or workplace locations are assumed to lead to a 10 percent increase in short work trips relative to the alternative 1990 scenario and an offsetting reduction in long trips. For nonwork trips, the main difference from the previous scenario is in per mile gasoline costs, which results from the assumed difference in average fuel economies.

As noted earlier, the travel impacts of each scenario are compared to the travel impacts of the nonshortfall (low price) situation and to the travel impacts of a gasoline price increase alone. Those impacts are also included in the tables describing the results of the scenario tests.

Work Trip Results

Each of the three sets of coefficients in Table 5 was used to analyze the four scenarios. As described in Appendix F, the second set of linear coefficients produced the most reasonable results. The first set of linear coefficients produced reductions in work trip VMT that exceeded the assumed shortfall levels by large amounts. The logarithmic coefficients produced VMT estimates that appeared to be too large. The second set of linear coefficients was used in the results reported here.

The results are given in Tables 9 and 10 for the 1985 and 1990 scenarios, respectively. Comparison of each scenario with its nonshortfall and high price alternatives reveals several interesting findings. First, the energy savings relative to nonshortage conditions are largely the result of the high gasoline price. For example, in 1985 the energy savings (measured in private vehicle reduction in fuel consumption) resulting from the price increase alone are 8.3 percent; the total energy savings when the nonrestrictive TSM actions are implemented are 11.9 percent. Hence, the marginal savings associated with the contingency actions are 3.6 percent. As the gasoline price becomes larger relative to the nonshortage price, the marginal savings associated with contingency actions appear to become a smaller proportion of total savings. The energy savings from price increases alone in Table 10 are 16.8 percent (no long-run conservation adjustment); the energy savings under the rationing/TSM scenario are 21.5 percent. The marginal savings associated with the contingency actions, which included restrictive actions as well as actions to encourage HOVs, were only 4.7 percent.

TABLE 9

WORK TRIP RESULTS—1985 SCENARIOS

Modal Share	Base Case (1980)	Nonshortfall	High (Shortfall) Price Only	Sticker Plan	Market Price/TSM
Automobile	.65	0.64	0.59	0.52	0.58
Carpool	.21	0.21	0.24	0.22	0.24
Transit	.14	0.15	0.17	0.25	0.19
Trips (thousands)	145.20	160.15	160.15	159.97*	160.15
Private VMT (thousands)	1688	1,820.30	1,669.30	1,516.17	1,603.20
Transit Miles (thousands)	3.34	3.98	5.16	7.91	6.12
Fuel (thousands of gallons)	112.50	107.70	98.80	88.70	94.90
Transit Fuel (thousands of gallons)	.81	0.97	1.26	1.93	1.49

*Difference from other 1985 trip estimates due to rounding.

Comparison of the scenarios provides some indication of the relative effects of price, contingency actions, and sticker plan on fuel consumption. It appears that the driving restrictions imposed by the sticker plan lead to the highest reduction in private vehicle fuel consumption—16.6 percent relative to nonshortfall conditions. This is not surprising because, given reasonable compliance, the unavailability of household vehicles one day per week is likely to cause substantial inconvenience in commuting habits.

A relatively large shift to transit is estimated for the sticker plan scenario. Because the modal share for shared ride does not change substantially, this shift is a net shift from drive alone to transit. The reason for the estimated shift is that, on the day of the driving ban, trip makers in "stickered" households are assumed to behave like trip makers in the classes without drive alone available. These classes contain a majority of transit commuters. If, in fact, trip makers in "stickered" households have a higher carpooling propensity, the shift to transit would be somewhat less and the carpool share would be greater.

For the rationing/TSM with long-run adjustments scenario, the total energy savings resulting from the gasoline price increase alone are 13.0 percent; the energy savings from both the price increase and contingency actions are 17.1 percent. Note that the savings percentage is less than under the alternative 1990 scenario, although total fuel consumption is lower under this scenario. The reason for the decrease in relative savings is that under this scenario conservation behavior was assumed as reflected in higher fuel economy and shorter work trips. Hence, there is some tradeoff between conservation actions such as not driving alone to work and buying a fuel-efficient vehicle. Travelers may choose to conserve fuel in some ways so that they may continue to consume fuel in other ways.

TABLE 10

WORK TRIP RESULTS—1990 SCENARIOS

		No Long-Run Conservation Adjustments			Long-Run Conservation Adjustments Assumed		
Modal Share	Base Case (1980)	Non-Shortfall	High (Shortfall) Price Only	Rationing/TSM	Non-Shortfall	High (Shortfall) Price Only	Rationing/TSM
Automobile	0.65	0.62	0.53	0.51	0.64	0.57	0.55
Carpool	0.21	0.22	0.26	0.26	0.21	0.25	0.24
Transit	0.14	0.16	0.21	0.23	0.15	0.19	0.21
Trips (thousands)	145.20	170.57	170.57	170.57	170.57	170.57	170.57
Private VMT (thousands)	1,688.00	1,889.70	1,572.00	1,484.10	1,734.20	1,508.90	1,438.20
Transit Miles (thousands)	3.34	4.60	7.33	8.68	3.83	5.63	66.78
Fuel (thousands of gallons)	112.50	106.80	88.80	83.90	85.90	74.70	71.20
Transit Fuel (thousands of gallons)	0.81	1.12	1.79	2.12	0.93	1.37	1.63

Nonwork Trip Results

Tables 11 and 12 present the travel impacts forecast for the 1985 and 1990 scenarios. In interpreting the results, the corresponding nonshortfall (low price) conditions are the appropriate bases for measuring the amounts of change in travel behavior. Under nonshortfall conditions, average household VMT is forecast to decline slightly, except for the 1990 nonshortfall conditions under long-run conservation adjustments. Most of the reduction can be attributed to smaller household sizes and somewhat higher per mile gasoline costs (the full effects of gasoline price increases are offset by greater fuel economy). The increases in real income have two effects: (1) they lower VMT by increasing the assumed value of time in the travel time times wage variable, and (2) they increase VMT through the effect of the income coefficient. (This effect is actually indirect. In the direct form of the VMT equation, transit trips are an independent variable with a negative coefficient. Transit trips decrease with increasing income in the transit trip equation. This effect is represented by the positive income coefficient in the reduced form VMT equation.) The two effects almost cancel out. In the 1990 nonshortfall condition with long-run conservation adjustments, there is a slight decrease in average costs resulting from improved fuel economies. The effect of improved fuel economy on VMT leads to an increase in VMT when long-run adjustments are assumed relative to the alternative 1990 assumptions. Even though the average household VMT does not change much, the projected increase in the number of households leads to a definite increase in area-wide VMT.

Under the low price conditions, transit trips are projected to decline. The major factors are increased incomes and the net effect of decreased household sizes. These decreases more than offset the projected increases in the number of households, resulting in projected declines in overall transit ridership.

By comparing the scenarios to their corresponding high price conditions, the relative effects of price and the other level of service policies can be ascertained. Price is forecast to have the largest effect on VMT reduction, although the effects of the other policy actions are not insignificant. It should be noted that the VMT reductions from price alone are larger than the shortfall levels assumed in the scenario definitions. This outcome is consistent with the apparently greater sensitivity of nonwork travel to fuel shortfalls (*28*).

By comparing the 1985 scenarios, the relative nonwork travel impacts of the sticker plan versus the higher price/transit incentives policy can be examined. Unlike the case for work travel, the market price/TSM scenario leads to greater VMT reduction. This outcome is plausible in that for similar levels of total VMT reduction, the sticker plan is likely to affect work travel disproportionately more than nonwork travel, because work travel is not rearranged as easily. The pricing/transit incentives policy is likely to fall more evenly on work and nonwork travel.

It should be noted that pricing/incentive policies are more naturally analyzed with the nonwork trip model than is the sticker plan. The assumed gasoline price increase under the sticker plan is actually the monetary equivalent of waiting time in gasoline queues. Because this effect cannot be directly captured in models developed from data collected during nonshortfall periods, it must be handled indirectly. (Prins et al. (*29*) and Mahmassani and Sheffi (*30*) have developed simulation models that incorporate waiting time effects. Tye (*31*) has noted that these models

TABLE 11

NONWORK TRIP RESULTS FOR 1985 SCENARIOS

	Base (1980)	Nonshortfall	High (Shortfall) Price Only	Sticker Plan	Market Price/TSM
Private Vehicles					
Average VMT per Household*	80.00	78.96	62.91	67.78	59.64
Total VMT**,+	2,343.00	2,568.00	2,046.00	2,205.00	1,940.00
Fuel Consumption**,+	156.20	152.00	121.10	130.50	114.80
Percent Change in Fuel Consumption++			-20.30	-14.10	-24.50
Transit					
Average Number of Trips per Household*	0.60	0.49	0.49	0.49	0.63
Total Trips**,+	17.57	16.06	16.06	16.06	20.46
Transit Miles Traveled**,+	4.39	4.02	4.02	4.02	5.12
Fuel Consumption**,+	1.07	0.98	0.98	0.98	1.25
Households	117.15	130.10	130.10	130.10	130.10

*These are the four-day totals produced by the models.

**VMT, fuel consumption, total transit trips, and transit miles are daily estimates so that the nonwork trip results will be compatible with the work trip results.

+The figures in these rows should be multiplied by 1,000.

++Relative to low (nonshortage) price results.

use different assumptions and have different policy implications. Tye further indicated that data would have to be collected during shortfall periods to analyze completely the effects of gasoline queues on travel behavior.) Similarly, there is very little information as to how automobile resources would be reallocated following the driving ban. The reduction by one-fourteenth of the licensed drivers reflects one possible reallocation.

As noted earlier, the improved fuel economy under the 1990 long-run conservation scenario leads to increased VMT relative to the alternative 1990 scenario. This is in contrast to the work trip results, where decreased home-to-work distances in the conservation scenario more than offset the effects of improved fuel economy and lowered travel costs. Of course, it is possible that the reduced home-to-work distance resulting from household location choice decisions could be accompanied by a reduction in average home-to-nonwork trip distances. Unfortunately, location effects relative to nonwork destinations are not well represented in existing location and travel behavior models.

Because of the recursive structure of the nonwork trip model (transit trips were found to influence VMT, but not vice versa), private vehicle disincentives, including gasoline price increases, are forecast to have no effect on transit travel. Although survey evidence from previous gasoline shortage periods indicates that increased transit riding has not been a dominant adjustment (*28, 32*), the recent growth in transit ridership suggests that gasoline prices do have some effect. Therefore, the transit ridership forecasts could be low.

Synthesis of Work and Nonwork Trip Analyses

In this section, a brief discussion of the overall performance of the quantitative forecasting system is presented. Tables 13 and 14 summarize the combined results for the 1985 and 1990 scenarios, respectively. Particular attention is given to the reduction in VMT relative to the nonshortage case for the scenario in question.

In combining the results, work and nonwork trip impacts are added. This is the same approach as used by Horowitz (*24*) in a similar analysis. An alternative combination would involve weighting the work and nonwork trips differently. For example, to derive annual totals, the work trip impacts might be multiplied by 230 (the number of working days) and the nonwork results by 365.

The forecasting system appears to perform quite reasonably overall. In all cases, the VMT reduction resulting from the gasoline price increase alone is very close to the shortfall level assumed in the scenario definitions. Thus, the price elasticity of gasoline demand implied by the forecasting system appears to be consistent with that used in the shortfall scenario definitions.

TABLE 12

NONWORK TRIP RESULTS FOR 1990 SCENARIOS

		No Long-Run Conservation Adjustments			Long-Run Conservation Adjustments Assumed		
	Base (1980)	Non-Shortfall	High (Shortfall) Price Only	Rationing/TSM	Non-Shortfall	High (Shortfall) Price Only	Rationing/TSM
Private Vehicles							
Average VMT per Household*	80.00	78.17	50.97	46.46	80.86	57.03	52.51
Total VMT**,+	2,343.00	2,781.00	1,813.00	1,653.00	2,877.00	2,029.00	1,868.00
Fuel Consumption**,+	156.20	157.10	102.50	93.40	142.40	100.40	92.50
Percent Change in Fuel Consumption++			-34.80	-40.50		-29.50	-35.00
Transit							
Average Number of Trips per Household*	0.60	0.42	0.42	0.56	0.42	0.42	0.56
Total Trips**,+	17.57	15.04	15.04	19.85	15.04	15.04	19.85
Transit Miles**,+	4.39	3.76	3.76	4.96	3.76	3.76	4.96
Fuel Consumption**,+	1.07	0.92	0.92	1.21	0.92	0.92	1.21
Households+	117.15	142.30	142.30	142.30	142.30	142.30	142.30

*These are the four-day totals produced by the models.

**VMT, fuel consumption, total transit trips, and transit miles are daily estimates so that the nonwork trip results will be compatible with the work trip results.

+The figures in these rows should be multiplied by 1,000.

++Relative to low (nonshortage) price results.

TABLE 13

SYNTHESIS OF WORK AND NONWORK TRIP RESULTS FOR 1985 SCENARIOS

	Nonshortfall	High (Shortfall) Price Only*	Sticker Plan*	Market Price/TSM*
Work trips**				
VMT+	1,820.00	1,669.00(-8.3)	1,517.00(-16.6)	1,603.00(-11.9)
Transit Miles+	3.98	5.15(29.4)	7.91 (98.7)	6.11 (53.5)
Nonwork Trips				
VMT	2,568.00	2,046.00(-20.3)	2,204.00(-14.2)	1,940.00(-24.5)
Transit Miles	4.02	4.02 (0)	4.02 (0)	5.12 (27.3)
Total				
VMT	4,388.00	3,715.00(-15.3)	3,721.00(-15.2)	3,543.00(-19.3)
Transit Miles	8.00	9.17(14.6)	11.93 (49.1)	11.23 (40.4)

*Percentage changes from Column 1 are in parentheses.

**Work trip impacts are from the second set of linear coefficients.

+In thousands of miles.

TABLE 14

SYNTHESIS OF WORK AND NONWORK TRIP RESULTS FOR 1990 SCENARIOS

	(1)	(2)	(3)	(4)	(5)	(6)
	No Long-Run Conservation Adjustments			Long-Run Conservation Adjustments Assumed		
Work trips[+]	Non-Shortfall	High (Shortfall) Prices Only*	Rationing/TSM*	Non-Shortfall	High (Shortfall) Prices Only**	Rationing/TSM**
VMT[++]	1,890.00	1,572.00(-16.8)	1,484.00(-21.5)	1,734.00	1,509.00(-13.0)	1,438.00(-17.1)
Transit Miles[++]	4.60	7.33 (59.3)	8.68 (88.7)	3.83	5.63 (47.0)	6.68 (74.4)
Nonwork trips						
VMT	2,781.00	1,813.00(-34.8)	1,653.00(-40.6)	2,877.00	2,029.00(-29.5)	1,868.00(-35.0)
Transit Miles	3.76	3.76 (0)	4.96 (31.9)	3.76	3.76 (0)	4.96 (31.9)
Total						
VMT	4,671.00	3,385.00(-27.5)	3,137.00(-32.8)	4,611.00	3,538.00(-23.3)	3,306.00(-28.3)
Transit Miles	8.36	11.09 (32.7)	13.64 (63.2)	7.59	9.39 (23.7)	11.64 (53.4)

*Percentage change for Column 1.

**Percentage change from Column 4.

[+]Work trip impacts are from the second set of linear coefficients.

[++]In thousands of miles.

It should be noted that independently derived gasoline price elasticities will not necessarily be consistent. For example, if the work trip results obtained from the first set of linear coefficients were added to the nonwork trip results, the reduction in VMT would be much larger than that used in the scenario definitions. Because independently derived estimates of figures such as the VMT reduction resulting from gasoline price increases are reasonable criteria for evaluating the performance of a modeling system, the performance of the system is quite encouraging.

As expected, additional transit incentives and/or private vehicle disincentives further reduce VMT. Because the reduction is greater than the assumed shortfall level, the price of gasoline would decrease to the point at which the shortfall level was matched. The gasoline price reduction and the resulting changes in travel behavior can be analyzed with the equilibrium approach developed by Horowitz (*24*). The approach is a fairly complex nonlinear method that incrementally adjusts gasoline price until predicted VMT (or fuel consumption) matches the assumed shortfall level. The equilibrium gasoline prices derived by using this approach are given in Table 15.

One implication of the equilibrium of gasoline price, shortfall level, and VMT reduction is that gasoline prices in the 1990 conservation scenario would be higher at equilibrium than the corresponding prices from the alternative 1990 scenario. (This argument assumes the same percentage reduction. As can be seen in Table 14, the nonshortfall VMT levels are slightly different in the two scenarios; therefore, the same percentage reduction leads to slightly different absolute reductions.) Because improved private vehicle fuel economy eases the impacts of gasoline price increases, a larger price increase would be necessary for the same percentage reduction.

TABLE 15

GASOLINE PRICES WHICH MATCH PREDICTED FUEL CONSUMPTION ASSUMED SHORTFALL LEVELS

(Dollars)

Scenario	Nonshortage Price	Assumed Price*	Equilibrium Price**
1985 Nonshortfall	1.21	1.21	1.21
1985 High Price Only	1.21	2.11	2.09
1985 Sticker Plan	1.21	1.74	1.72
1985 Market Price/TSM	1.21	2.11	1.87
No Long-Run Conservation			
1990 Nonshortfall	1.34	1.34	1.34
1990 High Price Only	1.34	3.02	2.87
1990 Rationing/TSM	1.34	3.02	2.55
Long-Run Conservation Adjustments Assumed			
1990 Nonshortfall	1.34	1.34	1.34
1990 High Price Only	1.34	3.02	3.14
1990 Rationing/TSM	1.34	3.02	2.78

*Shortfall gasoline price used as input variable in the forecasts.

**Gasoline price which matches predicted private vehicle fuel consumption to assumed shortfall level.

CHAPTER THREE

FINDINGS—QUALITATIVE ANALYSES OF SHORT-RUN AND LONG-RUN TRAVEL IMPACTS

Qualitative analysis is a particularly useful tool for evaluating the impacts of fuel supply limitations on passenger travel in light of the uncertainties concerning both travel behavior and energy futures. (See App. D for a discussion of travel behavior under resource constraints.) Because travel behavior research has traditionally focused on explaining observed choices, responses beyond the observed range that may involve choices previously discarded may be difficult to predict. (See App. B for an evaluation of existing travel choice models.) For example, models of travel behavior generally have assumed simple travel patterns. Evidence suggests that more complex patterns are adopted in response to fuel supply limitations and that simple models are unable to predict such responses. Similarly, long-run mobility decisions and the dynamics of land-use patterns are not well understood and are particularly uncertain beyond the observed range. Qualitative analysis represents a technique by which existing models and data are extended beyond the observed range through the use of assumptions. These assumptions are based on empirical evidence and subjective judgments. Because qualitative analysis is by definition applied in the uncertain range, sensitivity analysis should be employed to test the impact of alternative assumptions.

In the first part of this chapter, qualitative analysis is used to investigate travel responses to fuel supply limitations that are beyond the domain of travel choice models presented in Chapter Two. In the second part of this chapter, the long-run impacts of fuel supply limitations are analyzed. The distribution of impacts on income and geographic groups is discussed in the third part.

QUALITATIVE ANALYSES OF TRAVEL RESPONSE

As noted earlier, there is some evidence of the type of responses made by travelers facing fuel supply limitations. This evidence can be used to complement the analyses derived from simple travel choice models. In this section the available literature is reviewed to determine the likely range of responses.

During and following the 1973–1974 energy shortage and during the recent 1979 shortage, a number of studies of transportation attitudes and behavior were performed (*33–52*). (Other reviews of studies of travel behavior and attitudes during energy shortages include (*37, 41, 53, 28*).) These studies typically rely on data collected from household surveys. Three types of data were generally collected: (1) adjustments in travel behavior during the energy shortage; (2) attitudes towards the energy shortage and government actions taken or suggested during energy shortages; and (3) hypothetical behavior during future energy shortages and/or price increases.

The most frequently collected information on previous behavior was checklists of actions taken during the energy shortage. This type of information provides a good qualitative view of the type and complexity of actions taken during the shortage. Unfortunately, little information is available on the magnitude of these adjustments—that is, how the stated actions contributed to reduced energy consumption. The attitudinal data collected reveal how attitudes are correlated with demographic variables and provide a preference ranking of government actions. The survey data, however, do not provide an explanation of why certain actions are preferred beyond a general distinction that can be drawn between incentive actions and restrictive actions. Similarly, the hypothetical behavioral responses are often of the checklist variety and do not allow estimation of the magnitude of responses.

These studies of transportation energy shortages are reviewed with respect to three issues: (1) what are the findings and conclusions of these studies; (2) what are the policy implications of these findings; and (3) what methods are required to analyze the effects of these policies. The following discussion addresses each of these issues in turn.

Findings and Conclusions

The major nationwide survey effort to date is the National Opinion Research Center's (NORC) continuous household survey undertaken during the 1973–1974 oil embargo (*42*). This survey focused on perceptions of the energy shortage and government responses and on how individuals' behavior and attitudes were affected. The NORC survey found that there was little change in behavior between the precrisis and the crisis periods. Rather than changing travel modes completely, there was a slight shift to occasional use of public transportation. The unimportance of transit in dealing with the gasoline shortage was also ascertained in other studies of the 1973–1974 gasoline shortage (*34, 41*). Most of the conservation appeared to have been achieved by higher income households that in normal times enjoy a high level of discretionary travel (*38, 41, 42*).

The key role of discretionary travel during gasoline shortage periods is supported by both early and recent survey findings. Changes in both shopping and vacation travel were made before the work trip was altered (*34, 37, 40*). A survey undertaken by the *New York Times* during May 1979 revealed that during the gasoline shortage, changes in vacation plans included shorter auto trips

(particularly when original plans required more than a tankful of gas), increased use of public transportation, and increased travel and lodging reservations (*49*). The Empire State Poll found that travelers were more likely to combine nonwork trips and shop closer to home and less often than to alter their journey to work (*52*). The schedule flexibility and wide range of options (in terms of destination, mode, and frequency) associated with discretionary travel make it a logical source of conservation actions. The willingness of the public to conserve energy when sufficient options exist is also demonstrated by the public's preference for conservation policies that are voluntary and provide alternatives rather than policies that are restrictive (*42, 47, 49*).

Households with higher income and education levels were found to have a higher degree of concern about the energy shortage (*48*). A statewide poll in Wisconsin taken in June 1977 found that level of education and awareness of energy issues were directly correlated (*49*). A survey administered in fall 1973 by the New York State Department of Transportation (NYSDOT) found that concern about the energy problem and belief that a problem exists are requirements for willingness to conserve gasoline. A nationwide survey of 20- to 34-year-olds (taken by the National Assessment of Educational Progress) during the summer of 1977 also found that educational level was the most significant statistical variable in explaining differences in attitudes toward energy use and awareness of the energy problem (*49*). (Using both 1975 aggregate data and 1978 household data, Lave and Bradley (*54*) found that education had a significantly positive impact on the market-share of imported cars. To the extent that imported cars are on average more fuel-efficient than domestic cars, this finding supports the relationship, identified here, between education and willingness to conserve gasoline.) The Empire State Poll found that between January and October 1979 higher income households were more likely to take actions to conserve energy that involved combining trips and taking shorter nonwork trips (*52*). The fact that high income households in this sample enjoy a higher level of education further suggests that education is related to willingness to conserve gasoline. Middle income households were found to be more likely to take public transportation for work and nonwork trips than both high and low income households. This difference may reflect the fact that high income households enjoy more alternatives for conserving fuel and that low income households are often unable to change their travel behavior because they have very few choices.

The relationship between education and willingness to conserve gasoline must be evaluated in the context of certain moderating variables. These moderating variables may be situational factors such as opportunity (either subjective or objective) to take conservation actions (*55*). The effect of moderating variables is demonstrated in the case of actions taken by respondents residing in the Westchester/Rockland region (*52*). These respondents have a significantly higher level of education than respondents from other areas. They tended, however, to shift modes and combine or reduce trips to a significantly lesser extent than other respondents. Westchester/Rockland residents may resist using transit because there is less extensive service, they are not aware of the transit service available, or there is social pressure not to take transit. The latter two reasons constitute subjective restrictions on behavior and are as important as objective restrictions in many instances.

It appears that transit use has recently become a more viable option for conserving gasoline than it was during the 1973–1974 crisis (*56*). Since the Arab Oil Embargo, many public transit systems have increased and improved their public information activity; hence, more people are likely to be aware of the transit service available to them. Similarly, the belief was widespread that energy was a problem during the spring and summer of 1979 and the use of public transit as a conservation measure may have become more socially acceptable or even highly regarded. The effect of such factors that moderate the attitude-behavior relationship must be considered in assessing the likely response of individuals.

A number of conclusions can be drawn from these surveys that are of use to planners:

1. Awareness of an energy problem is a likely precondition for willingness to conserve.
2. Willingness to conserve appears to be related to education level, all other things equal.
3. People are more likely to conserve energy when there are sufficient alternatives available, and when they have flexibility of choice. Their conservation actions often involve complex travel patterns.
4. Individuals' attitudes toward energy conservation and transportation choices will lead to behavior consistent with those attitudes only if the objective and subjective opportunities exist.

Policy Implications

The conclusions noted suggest that public information campaigns may be an important component of energy contingency plans in order to: increase awareness of the energy problem; increase awareness of government actions both to alleviate the crisis and to provide alternatives to travelers; and increase individuals' awareness of how they can conserve energy. Therefore, planners should make efforts to influence their perception of opportunities to conserve gasoline as well as their willingness to conserve. The need for adequate flexibility of choice also suggests what kind of contingency actions will receive public support. In designing energy contingency plans, planners may have to trade off public support for energy cost-effectiveness. If restrictive policies are required on the basis of energy saving potential, they should be accompanied by actions that provide alternative travel choices.

The need for flexibility cannot be assessed solely in the context of an individual's travel choices. Planners must be aware that individuals require flexibility to meet interpersonal and time obligations. These obligations often define the range of objective and subjective opportunities for action and, therefore, moderate the attitude-behavior relationship. The effect of these interpersonal and tem-

poral linkages on travel response to contingency actions varies with the policy. Some policies can be adequately analyzed in the context of individual travel choice. The impacts of other policies are dependent on these secondary linkages. To analyze such policies, measurement techniques other than travel demand models are required (*57*).

Analytic Methods

Two techniques have been used to analyze policies where responses involve secondary linkages: tradeoff analysis and interactive games. Tradeoff analysis is an attitude scaling method that has been refined by NYSDOT and applied to a number of transportation policies (*58–60*). Tradeoff analysis uses survey data in the form of a set of matrices filled in by each respondent. Each matrix consists of rank-order responses representing tradeoffs among levels of a specified pair of attributes. Preference utilities for each level of each attribute, as well as the effect of each level of an attribute on total preference, can be calculated. (For a description of how utilities are computed, see Eberts (*58*).)

Preliminary evidence suggests that this technique produces reliable predictions of behavioral responses. In an evaluation of alternative work hour schedules by NYSDOT, shifts observed by employees were found to be within the range predicted by the tradeoff procedure (*60*). The survey data also revealed that the desire to have flexibility in family activities is the basic motivating factor behind attitudes toward work schedule changes (*59*). The ability to change the timing of activities was also found to be an important impact of the work schedule policy.

The use of gaming techniques to evaluate transportation policies has also revealed the importance of interpersonal and temporal linkages in responses to certain policies. Jones and his colleagues developed an interactive game, HATS, and applied it in England (*61–64*). Use of this technique to evaluate transit improvements revealed that in one-car households, the husband may relinquish his use of the car to enable his wife to use it for nonwork activities or a part-time job if his workplace is easily accessible by bus or by walking. NYSDOT developed a similar interactive game, called REACT, to evaluate a modified sticker plan whereby each car in the household was subject to a driving ban one day each week (*65*). The game involves allowing all members of a household to work out their responses to a given policy. Responses to the hypothetical sticker plan included changing the work trip mode, altering the timing of activities, and foregoing some discretionary trips. The decisions regarding how to comply with the driving ban were clearly based on obligations between household members and daily schedule obligations.

Use of traditional travel demand models alone to evaluate policies where significant interpersonal and temporal linkages exist may result in biased results. Unfortunately, the resources required to apply trade-off analysis and gaming techniques are large, and experience with these methods is minimal among state and local planners. Although new applications of these methods for energy contingency planning may require more resources than are typically available to state and local planners, the results of previous applications can be used. (For a discussion of how to collect new data with surveys and games, see App. E.) The likely impacts of temporal and interpersonal linkages can be assessed qualitatively, and travel responses predicted by traditional travel demand models can be adjusted to account for these linkages. In the same fashion, predicted behavior can be adjusted to account for the likely effect of attitudes on travel responses. For example, behavioral shifts based on level of service and socioeconomic variables may be enhanced or diminished by the expected attitudes of travelers. Given the uncertainty surrounding the magnitude of the impacts of attitudes and secondary linkages on travel behavior, planners should employ sensitivity analysis to evaluate the effects of varying assumptions.

APPLICATIONS OF QUALITATIVE ANALYSIS

Surveys of travel behavior during energy shortages suggest that changes in discretionary or nonwork travel are the most frequently made adjustments. Some of these changes involve complex travel patterns that may not be adequately represented in traditional travel choice models. Similarly, traditional travel choice models have disregarded travel choices such as the use of nonmotorized modes. Under constraints such as fuel supply shortfalls, these choices may become significantly more attractive, given the proper policy actions. Qualitative analysis can be used by adjusting traditional models to include nonmotorized modes. In the following, qualitative analyses of complex travel patterns and shifts to nonmotorized modes are described.

Complex Travel Patterns

In a recent paper by Hartgen and Neveu (*25*), the results of the Empire State Poll (*52*), concerning conservation actions taken during 1979, were used to estimate the energy saved during the shortfall period. New York State travel and energy consumption data were also used to estimate the savings associated with each conservation action taken.

The analysis performed by Hartgen and Neveu (*25*) was based on standard simple trip definitions. An alternative approach to estimating the savings associated with changes in discretionary travel is based on Horowitz's (*66*) model of complex nonwork travel behavior, which is described in Appendix D. The model is used to estimate the energy savings resulting from three conservation actions; estimated energy savings are then compared to the Hartgen and Neveu estimates.

Horowitz's model for estimating daily nonwork VMT has the following form:

$$\mathrm{VMT} = 2DN_t + r(N_s - N_t) \qquad (11)$$

where VMT is vehicle-miles traveled; D is the weighted average distance from home to destinations in a tour (a tour is a travel pattern that begins and ends at home; it may contain one or more nonhome destinations); N_t is the number of tours; r is the average distance between

destinations within a tour; and N_s is the number of sojourns (nonhome destinations).

The model of tour frequency is as follows:

$$N_t = kN_s \tag{12}$$

where k is a constant. Substitution of Eq. 12 into Eq. 11 yields:

$$\text{VMT} = 2DkN_s + r(1-k)N_s \tag{13}$$

Note that N_s is analogous to nonwork trip generation when trips are defined as simple, unlinked trips. Equation 13 can be applied in a qualitative fashion by deriving elasticities of VMT with respect to each variable. The elasticities can be calculated using the following formulas that are derived in Appendix D.

$$\eta_{N_s} = 1 \tag{14a}$$

$$\eta_D = \frac{2DkN_s}{2DkN_s + r(1-k)N_s} \tag{14b}$$

$$\eta_k = \frac{2DkN_s - rkN_s}{2DkN_s + r(1-k)N_s} \tag{14c}$$

$$\eta_r = \frac{r(1-k)N_s}{2DkN_s + r(1-k)N_s} \tag{14d}$$

where η_i is the elasticity of VMT with respect to the ith variable.

The three conservation actions to be analyzed are shopping closer to home, shopping less often, and combining shopping and other nonwork trips. The necessary input parameters were derived from data presented in Hartgen and Neveu (*25*), Horowitz (the values reported in the following were supplied by Horowitz in a personal communication; they have been rounded slightly for analytical convenience), and other published sources.

Input Data

Using 1968 Washington, D.C., household survey data, Horowitz found that average VMT for nonwork trips was 9.42 miles per household per day. At an average fleet fuel economy of 15 mpg (*25*), average fuel consumption for nonwork trips is 4.40 gal per household per week. Horowitz reports that trip frequency for nonwork trips is 1.15 trips per household per day, average home to centroid distance is 4.65 miles, average length of intratour trips is 3.75 miles, and the ratio of tours to sojourns is 0.8. Because two of the actions considered here involve only shopping trips, the parameters of shopping trips are of interest. Hartgen and Neveu report data for both shopping trips and all nonwork trips. Using the relationships between shopping trips and all nonwork trips for each variable in Hartgen and Neveu's sample, Horowitz's nonwork trip variables are adjusted to reflect values for shopping trips. Shopping trip frequency is assumed to be 0.78 trips per household per day, home to centroid distance is 3.35 miles, intratour shopping trip distance is 2.70 miles, and the ratio of shopping trip tours to sojourns is 0.8.

Using these values, the relevant elasticity estimates can be calculated with Eqs. 14a through 14c. The elasticity of VMT with respect to shopping trip frequency is equal to +1. The elasticity of VMT with respect to home to tour centroid distance for shopping trips is equal to +0.91. The elasticity of VMT with respect to the tour to sojourn ratio for nonwork trips is equal to +0.54.

Energy Savings Estimates

The Empire State Poll (*52*) provided respondents with a checklist of conservation actions. Each respondent was asked in one question to indicate which actions he or she had taken since January 1, 1979. (The survey was conducted in October 1980). The survey did not ask how often or to what extent these actions were taken. Consequently, energy savings estimates must be based on assumptions about the magnitude of change associated with taking these actions. These assumptions and the estimated savings for each action are described in the following. In addition, the results derived here are compared to the findings presented by Hartgen and Neveu (*25*).

Shopping Closer to Home. Assume that the weighted average distance from home to tour destinations for households taking this action decreased 10 percent, from 3.35 miles to 3.015 miles. Given an elasticity +0.91, the reduction in VMT for these households was 9.1 percent. A 9.1 percent decrease in VMT and gasoline results in a savings of 0.400 gal per week per household. Of the households surveyed, 41 percent reported they had taken this action. Therefore, the average energy savings for the entire population resulting from shopping closer to home is 0.164 gal per week per household.

Hartgen and Neveu (*25*) estimated that households taking this action saved 0.424 gal per week. This savings represents a 9.64 percent decrease in weekly gasoline consumption. Because 41 percent of the households reported this action, the average energy savings resulting from this action is 0.174 gal per week per household for the entire population. The estimates derived from the two approaches are very close.

Shopping Less Often. Assume that those households taking this action decrease their shopping trip frequency by 5 percent from an average of 0.70 trips to 0.665 trips per day per household. Given an elasticity of VMT with respect to N_s of +1.0, the decrease in VMT is 5 percent. Therefore, gasoline consumption is reduced by 5 percent, resulting in a savings of 0.220 gal per week per household. Of the households surveyed, 35 percent reported they had taken this action. Thus, for the population, the average energy savings due to shopping less often is 0.079 gal per week per household.

Hartgen and Neveu estimated that households taking this action saved 0.282 gal per week or 6.41 percent of gasoline consumption. The resulting average energy savings for the entire population is 0.099 gal per week per household. Again, the two approaches produce very close estimates.

Combining Nonwork Trips. The degree to which trips are combined is measured by the ratio of sojourns to tours. In Horowitz's (*66*) model of tour frequency, the

constant k is equal to this ratio. Given that frequency of nonwork trips, N_s, is equal to 1.15 and k is equal to 0.8, the number of tours, N_t, is equal to 0.42. Therefore, over a 100-day period, each household makes 115 sojourns and 92 tours. Assume that there are only one or two sojourns in tours. On average, households make 69 one-sojourn tours (simple trips) and 23 two-sojourn tours. (The number of one- and two-sojourn tours can be calculated by solving the following system of equations: $N_s = Y + 2X$ and $N_t = Y + X$, where Y is the number of one-sojourn tours and X is the number of two-sojourn tours.) For those households reporting they had taken this action, assume that they now make 59 one-sojourn tours and 28 two-sojourn tours; that is, above 15 percent of the one-sojourn tours were combined into two-sojourn tours. The tour frequency for these households is now 0.87 tours per day per household, resulting in a 5 percent decrease in k, from 0.8 to 0.76. Given the estimated elasticity of VMT with respect to k of +0.54, VMT decreases by 2.7 percent. The 2.7 percent savings represents 0.119 gal per week. Of the households surveyed, 45 percent reported they had taken this action. The average energy savings for the population, resulting from this action, is 0.054 gal per week per household.

Hartgen and Neveu (*25*) estimated that households taking this action saved 0.203 gal per week, or 4.6 percent. The average energy savings for the population resulting from this action is 0.091 gal per week per household. The major reason for the higher savings estimated by Hartgen and Neveu was that they assumed a larger amount of trip chaining. They assumed that two single-destination tours would be combined into a single two-destination tour each week. The assumption in this report is equivalent to combining about 0.7 single-destination tours.

Summary

The qualitative analysis described is useful in that energy savings associated with conservation behavior can be estimated using readily available data and easily calibrated travel parameters. The comparison of estimates based on previously derived estimates (*25*) and estimates derived in this chapter serve to illustrate the reasonableness of the assumptions concerning the magnitude of travel behavior change. The assumptions implied by the Hartgen and Neveu estimates appear to be somewhat less conservative than those used here, although the results of both analyses are quite similar. In addition, using similar assumptions about the degree to which each action was taken, the relative savings potential of each action was revealed. Shopping less often results in the largest energy savings, followed by shopping closer to home and combining nonwork trips. Qualitative policy analyses, such as those demonstrated above, can be used to determine the relative energy savings potential of conservation actions for both the entire population and specific market segments.

Nonmotorized Modes

(For a review of current literature on nonmotorized modes, see App. D.) The construction and improvement of bicycle facilities has become increasingly popular in the face of high gasoline prices, anticipated fuel shortages, and emphasis on physical health and exercise. To evaluate the impact of improved bicycle facilities on work trip mode choice, the bicycle can be introduced as a new mode in the logit model. Because measures such as provision of bicycle storage facilities and bicycle paths improve the safety and convenience of the bicycle mode, attributes not included as variables in most demand models, these actions are represented by adjusting the bicycle constant.

This approach is classified as qualitative here because the selection of the appropriate constant is based on the judgment of the analyst. The work trip model used in Chapter Two is adapted for this analysis. To illustrate the procedure, bicycle travel is added to the nonshortage (low price) conditions for 1985. Specifically, it is assumed that the bicycle is only used for short trips.

It is also assumed that before the facilities are improved the number of bicycle trips for short work trips is 1 percent of the number of trips by the other modes for the corresponding market segments. To introduce the bicycle in the base case modal split, the bicycle trips are added to the existing work trips, and then the modal shares estimated prior to the improvements are adjusted.

As is the case in any analysis involving the adjustment of modal constants, the adjustment of the constant to represent the effects of improved bicycle facilities is based on the judgment of the analyst. In this case it is assumed that the improved bicycle facilities reduce both travel and walking time an average of 10 min per round trip and also improve safety and convenience. Assuming the second set of linear coefficients in Table 5 is used, the time impacts change the bicycle utility function by 0.755. Because safety and convenience improvements are often considered to be more important for bicyclists, it is assumed that these lead to a change of 1.245 in the bicycle constant. The total change in bicycle utility is 2.

The incremental logit analysis can then be applied to the three short trip market segments. The modal shares and level-of-service variables before the bicycle improvements are the base case for the analysis. The future level of service variables would include only the effect of the change in the bicycle constant. The modal splits for the market segments and for the entire region before and after the improvements are given in Table 16.

As expected, the introduction of the bicycle as a new mode and the improvement of bicycle facilities reduce the use of all other modes. However, the impact on the region modal split is relatively small because of the limited attractiveness of bicycles, even for short trips. The reduction in regionwide private vehicle fuel consumption for work trips associated with these improvements is 1.4 percent.

This policy simulation is designed to illustrate one approach to estimating the impact of a policy that is outside the parameters of the model. The results of this analysis and all applications of qualitative methods should be interpreted as suggestive rather than definitive. Sensitivity analysis should be applied to evaluate the uncertainty. A range of values for the bicycle constant should be tested, as well as different sets of logit coefficients. Results of

TABLE 16

MODAL SHARES BEFORE AND AFTER BICYCLE FACILITIES IMPROVEMENTS *

Modes	Traveler Classes** 1	2	3	4	5	6	Region
Drive Alone							
Before	.686	.664	.789	.673	0	0	.635
After	.644	.664	.739	.673	0	0	.610
Shared Ride							
Before	.150	.212	.201	.327	.193	.222	.213
After	.141	.212	.189	.327	.182	.222	.206
Transit							
Before	.154	.123	0	0	.797	.778	.146
After	.145	.123	0	0	.749	.778	.140
Bicycle							
Before	.010	0	.010	0	.010	0	.006
After	.071	0	.072	0	.069	0	.044

*The second set of linear coefficients, presented in Table 5, is used in the calculations.

**Traveler classes are defined in Table 8.

qualitative analyses are also useful in formulating questions for further research. For example, the results obtained here suggest that nonmotorized modes may capture a significant, although small, share of the market. Depending on how detailed the analysis is, which is a function of available budgets and time, these models can be included in definitions of the modal choice set.

LONG-TERM IMPACTS OF ENERGY SHORTAGE ON LOCATIONAL PATTERNS

Previous sections of this report concentrated primarily on the use of qualitative and quantitative analysis techniques to evaluate short-run behavioral adjustments to alternative scenarios of energy availability and cost. In this section, qualitative techniques for evaluating the long-term effect of continued energy shortfall and price changes are discussed.

Among the key long-term behavioral responses available to consumers, when faced with the prospect of continued energy supply and price fluctuations, are purchasing more fuel-efficient vehicles; moving closer to place of employment; changing place of employment; making permanent adjustments in the location, frequency, and combination of discretionary travel; and making permanent changes in work and nonwork travel mode. In view of the uncertainty surrounding the possible severity, repeated frequency, and duration of future energy shortages, the task of forecasting the extent of location-related response is difficult at best. Whereas transportation energy consumers desire to minimize the risk of being vulnerable to future shortages, they also desire to minimize the risk associated with making large capital investments and behavioral adjustments, given the uncertain probability that future shortages will occur.

This section of the report focuses on two related research questions facing transportation and energy planners:

1. To what extent are changes in locational patterns or urban form likely to result from continued energy shortages?
2. Do the energy savings associated with changes in locational patterns merit this form of adjustment?

To assist planners in formulating responses to these questions, qualitative analysis is used to draw inferences from available research and modeling approaches to urban location and travel behavior. The following methodological approaches are reviewed for relevance to the analysis of long-term locational response: analytical models, inferences from short-run behavior, intrametropolitan moving behavior, empirical evidence, and scenario testing.

Analytical Models

Much of this discussion in this section is drawn from CRA (*67*). The household location decision can be expected to be affected by changes in transportation system characteristics because spatial proximity and transportation services are substitute goods. The household location decision requires trading off proximity to employment centers and other amenities, which, other things equal, imposes higher land rent costs relative to a more distant lower rent location, which imposes higher travel costs.

Should improvements in fuel economy standards make auto transportation less costly or onerous, households would be expected to move further from workplaces and other travel destinations to lower rent locations. Should auto transportation become more costly or onerous, households would be expected to move closer to workplaces and other travel destinations.

In the location models, metropolitan or urban regions are characterized by relatively high population densities and high land rents. These rents are supported by real locational advantages of land close to activity centers and the fixed supply of such land. The traditional and simplest way of structuring a theory of urban areas is to assume that all production (employment) activities group together due to agglomeration economies in a central business district (CBD), that households must commute to and from the CBD for work and shopping trips, and that, except for the presence of the CBD, the metropolitan area is a featureless plain with travel time and costs the same in all directions from the CBD. All other things held equal, households will want to locate close to the CBD to save travel time and money costs, and competition among households for space close to the CBD will determine a rent gradient for land that declines with distance from the CBD. The steepness of the rent gradient, reflecting the marginal value of preferred location, will reflect the time and money costs of transportation. An important extension of the model allows different groups to locate in different places, depending on their income levels and their relative preferences for housing, nonhousing goods, and time and money expenditures on commuting.

Extensions of the Land-Use Model

Although the land-use model previously sketched is too simplistic to be descriptive of any real urban area, the concepts underlying the model are useful and the model can be modified to make it more realistic. Extensions of the model do not negate the conclusions that:

1. Land rents do arise from the advantages of spatial proximity to activity centers (and from other location characteristics).
2. These proximity advantages vary directly with transportation costs.
3. The spatial distribution of different groups of households in an urban area arises from differences in household income levels, perceived costs of travel, and preferences for land and other yet unmentioned, location-related attributes.

Extensions of theoretical household location models to allow greater realism are, in general, easy to explain conceptually, but cumbersome to formulate mathematically. An extension of the model with particular relevance to understanding the effects of continued energy shortage includes the presence of dispersed non-CBD workplaces. Dispersed employment centers tend to lessen the slope of the urban rent gradient while creating local rent gradients centered around "suburban" employment locations. In order for a system with both CBD and non-CBD employment centers to be in equilibrium, most models assume that, because of lack of agglomeration economies, labor marginal productivity and money wages are lower in the non-CBD areas than in the CBD. The advantages of higher CBD wages just offset the disadvantages of higher CBD commuting costs.

Applicability of Theory to Continued Energy Shortage

The theory of household residential location provides a sensible framework within which households are assumed to allocate income among housing location, housing type, travel, and other goods in a utility-maximizing manner. A change in travel costs (costs are understood to mean money costs plus the level of all other transportation amenities, including travel time and comfort suitably weighted into an inclusive cost index) can be shown to affect the housing location in a predictable direction, relative to relevant activity centers. However, the theory gives little help in structuring an empirical model capable of simulating the effects on spatial form of a policy that will change travel costs (gasoline price and availability changes). In particular, one wants to know the relative importance of changes in transport costs compared to other factors influencing the household location decision. To what extent do households react to changes in characteristics of available autos by changing the types of autos owned (large or small, fuel efficient or inefficient, old or new)—rather than to make the more dramatic lifestyle changes involved in a change in the number of autos owned or in residential location? How will the characteristics of the automobiles affect transportation costs and thus alter residential locations?

In order to make projections of consumer behavior, it is necessary to:

1. Identify and estimate a household demand function including demand for housing location, other housing attributes, auto ownership by auto attributes, and work and nonwork travel. Levels of demand must be related to auto costs, which vary with the number and types of vehicles owned.
2. Either identify and estimate or make reasonable assumptions about housing supply functions. In particular, one wants to know the price sensitivity of supply changes in residential density and other housing characteristics; that is, how quickly and in what ways the stock may be expected to change in response to changes in consumer demand. The purely theoretical literature gives little help in identifying and estimating these functions.

Although auto demand models and Leman's (*68*) joint housing location, type, auto ownership, and work mode choice model (these models are reviewed in App. B) partially discuss these issues, the prospects for a quantitative model that addresses all of these factors are not good in the near future.

Inferences From Short-Run Behavior

An earlier part of this chapter reviewed, at length, findings concerning behavioral adjustments made by transportation energy consumers in the short run. A brief review of the applicability of the short-run findings may be of assistance to planners concerned with qualitative analysis of possible long-term effects.

Among the major points associated with short-run behavior and of relevance to long-term/locational analysis are the following:

1. Perceptions about the severity of the "energy problem" and knowledge of available alternatives greatly affected short-run behavioral response.
2. Subjective and objective restrictions on behavior served as moderating variables affecting choice among conservation actions.
3. Strategies that preserved flexibility of choice were generally preferred to more restrictive approaches.

Short-run responses during energy shortages were more typically in the form of changes in discretionary or nonwork travel. As discussed by Hartgen and Neveu (*25, 52*), these adjustments included shopping closer to home, shopping less often, and combining shopping and other nonwork trips. Hartgen (*69*) also noted that certain major actions, such as changes in work and nonwork mode choices, changes in vacation travel, and purchase of fuel-efficient vehicles, were taken by a significant share of most groups. Relatively few consumers took more drastic actions such as moving job or residence.

Applicability of Reported Short-Run Behavior Adjustments to Continued Energy Shortage

Efforts to utilize data on short-run behavior responses to draw inferences about possible long-run effects raise

technical problems that are difficult to resolve. One problem concerns the difficulty of distinguishing the extent to which the data used in the analysis are likely to reveal long- or short-run relationships.

The relationships between travel behavior and the independent variables observed from cross-section data are typically assumed to be short-run. Closer examination of cross-section data, however, reveals that long-run relationships are implicit in these models (*70*). Analysis of cross-section data reveals residential and job location preferences. Because accessibility to various activities and the availability of different travel alternatives have been considered by households in making these longer run decisions, their travel behavior is largely determined by these actions. For example, it would be expected that households with an *a priori* preference for transit will locate near transit. Cross-section data, therefore, reveal a high correlation between transit use and transit access. One therefore might conclude that households in neighborhoods not now served by transit will increase transit use. This conclusion would be completely incorrect, however, if the short-run relationship between transit access and transit use was confounded by the long-run relationship. The long-run relationship will be observed only after all adjustments are made; in the short run, the impacts of such changes on ridership are likely to be smaller. The resulting errors in predicting short-run impacts based on cross-section data are called "cross-sectional bias."

In terms of the content of the data reported in consumer surveys, such as the Crossley Survey, that report on short-run behavioral adjustments to energy shortages, it is thus quite likely that the reported results reflect a combination of short- and long-run behavioral effects. On the one hand, responses concerning the extent of temporary mode shifts to transit reflect long-term locational relationships between transit access and relative preference for transit (whether exercised or not). On the other hand, responses concerning the extent of longer run adjustments, such as residential or employment relocation, reflect limitations imposed by short adjustment periods and thereby understate the magnitude of such adjustment possibilities in the long run. The following discussion concerns influences of long-run effects from data on short-run behavior in the context of the foregoing cautionary statements on cross-sectional bias.

The Role of Perceptions

As in short-run behavior, perceptions about the magnitude, repeated frequency, and duration of future energy shortage will likely have a profound effect on the type of behavioral response made in the long run. It is more likely that transportation energy consumers will take the more "drastic actions" described by Hartgen if they perceive the energy future to be either a prolonged period of shortage or a series of short-term crises. Although consumers desire to minimize the risk of being vulnerable to future shortages, they also desire to minimize the risk of making large capital investments and relatively irreversible behavioral adjustments in the face of uncertainty. In this regard, it is important to note that much of the existing evidence on response to energy shortage is based on data from non-shortage periods or from periods in which the shortage was perceived to be temporary.

Existence of Subjective and Objective Restrictions

Among the advantages of longer adjustment periods are that less costly behavioral adjustments are possible in the long run and that additional time is available in which to address and overcome subjective and objective restrictions to particular types of behavioral response. For example, longer response periods may allow for improved transit marketing programs aimed at reducing subjective restrictions to transit use. Similarly, objective restrictions to residential relocation imposed by inordinately high mortgage interest rates and inflation at the time of the 1979 shortage are likely to be relaxed over time. It is important to note that certain restrictions are more easily addressed than others, and it is partially within the power of the public sector to formulate policies and programs to overcome them.

Less easy to overcome is the relatively fixed nature of the housing stock and the relatively small increments to supply occuring over time (*71, 72*). For example, Gomez-Ibanez notes that it may take a long time before location decisions fully adjust to the incentives created by transportation changes, given that over 55 percent of the U.S. metropolitan housing stock is over 20 years old.

It is important to note the relatively limited potential of the existing urban housing stock to absorb an increase in demand for city locations through such factors as changes in vacancy rates and postponement of building abandonment. More likely to occur as a result of changes in demand in the short run is capitalization of demand in the form of higher prices for city properties. In the longer run, however, such increases in value of inlying properties would contribute to a stabilization of location preference at the metropolitan level.

Small (*72*) notes that the processes of migration, building abandonment, and construction are ongoing, and that changes in the rates at which they occur can provide a strong indication of the likely course of future patterns of urban centralization.

The relatively slow nature of location adjustments does not imply that land-use policies that encourage transportation energy conservation (e.g., encouraging higher density housing close to employment locations) are unproductive. Just as present land-use patterns reflect past policies (or nonpolicies), land-use policies instituted now and in the future will affect future land-use patterns. However, the energy savings from land-use policies are likely to be small for some time and may produce less conservation than other policies such as vehicle fuel economy regulations.

Preference for Flexibility of Response

As noted earlier, one of the key advantages of long adjustment periods is the ability of consumers to make more flexible and less costly behavioral adjustments over time. For this reason, it is likely that more flexible response options will continue to be preferred by consumers, regard-

less of how long the period of response. Assuming for the moment that equal energy savings could be achieved by consumers either switching to a more fuel-efficient vehicle or relocating their residence closer to place of employment, the former is the more flexible option and the option which necessitates less costly adjustment. In this regard, it is likely that the location models reviewed earlier, which do not account for greater auto fuel economy, may overstate the amount of location changes.

Inferences from Moving Behavior

An additional methodological approach of relevance to the issue of projecting long-term locational response to energy shortages is found in the literature on intraurban locational choices and moving behavior. Studies of this nature have used various methodologies and have arrived at differing conclusions, usually based on the disciplinary perspective of the study. Some of the studies hypothesize a utility maximization decision process. Other studies, mainly in the geography literature, hypothesize a search process that does not necessarily lead to utility maximization. In these studies, the key accessibility concept is often the accessibility of potential new homes to the old home, rather than home-to-work accessibility (*73, 74*). A third type of study emphasizes the effects of household characteristics and reported reasons for moving on the decision to move (*75–78*). These studies, often involving sociologists, demographers, or planners, seem to indicate that accessibility considerations are relatively unimportant as stated reasons for moving. Rather, household characteristics, dwelling unit characteristics, and neighborhood characteristics appear to be more important. However, there is evidence that actual behavior of households is consistent with an accessibility hypothesis (*79, 80*).

On this basis, it would appear that energy considerations alone would be unlikely determinants of locational choice. The relative importance of energy may differ over time, however; particularly if perturbations in cost and/or supply are large.

Empirical Evidence

Among the key growth-related phenomena of the 1970s has been the rapid growth of nonmetropolitan locations. Contrary to the trend during the decade of the 1960s, the 1970–1977 period was characterized by an increase in the annual growth rate of nonmetropolitan counties to 1.2 percent, or almost twice the annual growth rate of metropolitan areas. As discussed by Sternlieb and Hughes (*81*):

> [W]hile counties with the heaviest incidence of commuting to more concentrated areas were at the forefront of the nonmetropolitan resurgence, their growth rates were nearly matched by noncontiguous areas. Even nonmetropolitan counties in which less than 3 percent of workers commuted to metropolitan areas secured gains at ten times the rate of the previous decade.

In the new phase of growth characterizing the 1970s, the emerging growth poles are nonmetropolitan areas and smaller metropolitan places. Within the metropolitan area itself, central cities experienced an absolute decline in population. Thus, in spite of promising rhetoric about a "return to the center city" or about urban gentrification, for the vast majority of urban areas, such movements are localized and small, at best.

As viewed by Sternlieb (*81*) and other demographers, the key characteristics of future population growth include the following:

- A marked decline in the rate of population growth associated with the sustained decline in fertility rates.
- A major concentration of population within the 25 to 44 years of age cohort.
- A rapid increase in the rate of household growth, in particular, among smaller households with fewer children and among "atypical" households unconstrained in their choice of housing environments to suburban child-oriented domains.
- An increase in female participation in the labor force.

Viewed as a whole, some urbanists such as Downs foresee a continuation of suburbanization (or *ex*urbanization) of the population, as technological improvements and lifestyle preferences also indicate. In the face of this trend, assumptions about reversing the direction of population growth back to the city for the purpose of energy conservation may not be likely.

As discussed by Small (*72*), the argument that higher energy costs will result in centralization of urban development patterns rests on two questionable assumptions: (1) that travel destinations are more centralized than residences; and (2) that residences rather than jobs will be relocated. The former assumption implies that people can reduce auto use by living closer in. With respect to work trips, however, this is not nearly as true as commonly believed. A disaggregation of residential and employment location indicates that nearly 70 percent of commuting to metropolitan area jobs takes place within the central city or the suburbs. Only 18.6 percent of metropolitan jobs are filled by suburban residents commuting to the central city, whereas some 7.8 percent commute from central city to suburbs. On this basis, Small estimated that the cost savings to individual households achieved by relocating are small, particularly when compared to the high costs of relocation. Similar data evaluated by Small considered the extent to which firms would have incentive to relocate closer to their employees. The conclusion was that such incentives were of insufficient magnitude to merit the relocation of firms.

Evidence from the 1975 Census (*82*) assembled by Small provides little support for the view that urban development patterns will be altered within the next two decades because of energy shortages. First, less permanent and costly technological approaches that preserve flexibility are viewed as preferable to relocation. In addition, a substantial shortening of average work trips could occur simply through interchange of the residential locations of suburban workers without any net change in overall degree of concentration of population.

Scenario Testing

Previous research methodologies reviewed in this chapter considered the issue of the extent to which changes in locational patterns were likely to result from continued energy shortages. In this section, the issue of whether the energy savings associated with possible changes in locational patterns merit this form of adjustment is considered.

To address this issue, four alternative scenarios have been defined for the year 1990. Two of these were presented and analyzed in Chapter Two. These scenarios reflect the possible trade-off between two key means of energy conservation in the longer run: (1) reduced dispersion between place of residence and place of employment (represented by shorter work trip length as in Chap. Two), and (2) switching to more fuel-efficient vehicles. These scenarios combine the long-run assumptions used in the 1990 scenarios of Chapter Two. The four scenarios are defined as follows:

1. Continued dispersal between residential and employment locations, with average automobile fuel economy increasing to 17.7 mpg consistent with federal law and with normal turnover in the vehicle fleet. This scenario, which is a continuation of existing trends, is the 1990 scenario without long-run adjustments of Chapter Two.
2. Continued dispersal between residential and employment locations, but with a switch to more fuel efficient vehicles such that average automobile fleet fuel economy increases to 20.2 mpg. This scenario reflects a lower capital, higher flexibility form of adjustment to the prospect of continued energy shortage. (This scenario combines the work trip length assumptions of the 1990 scenario without long-run conservation adjustments, with the fuel economy assumptions of the 1990 scenario with long-run adjustments.)
3. Reduced dispersal between residential and employment locations. Automobile fleet fuel economy increases to 17.7 mpg consistent with federal law and with turnover in the vehicle fleet. This scenario reflects a higher cost form of adjustment to the prospect of continued energy shortage and is one that requires major behavioral adjustment and forecloses future flexibility. (The scenario combines the work trip length assumptions of the 1990 scenario with long-run adjustments with the fuel economy assumption of the 1990 scenario without long-run adjustments.)
4. Reduced dispersal between residential and employment locations, combined with a switch to more fuel-efficient vehicles, such that average fleet fuel efficiency increases to 20.2 mpg. This scenario assumes that two energy efficiency strategies will be selected. As such, it may be less likely to occur. This is the 1990 scenario with long-run conservation adjustments presented in Chapter Two.

As in Chapter Two, for each of the four scenarios defined above, three alternate sets of impacts were generated:

1. The nonshortage situations for 1990 (prevailing gasoline prices are comparatively low).
2. Only gasoline price changes, the price reflecting the assumed 25 percent shortfall.
3. Not only are prevailing gasoline prices high, reflecting the 25 percent shortfall, but TSM strategies are also undertaken to encourage modal shifts away from private auto. The TSM strategies are the same as those used in the 1990 scenarios of Chapter Two.

Of particular interest in the four scenarios is the relative amount of VMT generated and fuel consumed under each of the three price and TSM conditions. VMT and fuel use have been modeled for each scenario/future combination using the modeling system described in Chapter Two. The results of this analysis are given in Tables 17, 18, 19, and 20, and are summarized in the following. (Note that these tables present generally the same information as Table 14.)

As indicated in the tables, the greatest fuel savings are achieved under the scenario in which energy consumers are assumed both to reside closer to place of employment and to switch to more fuel-efficient vehicles. As noted previously, however, there is reduced likelihood that these two substitute strategies would occur simultaneously for a substantial portion of the same population.

Among the three remaining scenarios, the scenario combining improved fuel economy with continued dispersal results in the lowest fuel use, although VMT is comparatively high. This finding is of major importance for two reasons: (1) Based on the assumptions made in this analysis, switching to fuel-efficient vehicles is a more effective strategy for reducing fuel use than is moving to reduce the dispersal between place of residence and place of employment; this is particularly true under nonshortage conditions. (2) Because fuel-efficient vehicles are, by definition, capable of reducing fuel consumption per VMT, there is less incentive to cut back on VMT under the higher fleet fuel efficiency scenarios (Tables 18 and 20).

There is greater incentive to reduce VMT under scenarios in which automobile fleet fuel efficiency is comparatively low (Tables 17 and 19) and under shortfall conditions in which gasoline prices are high. Under the nonshortage conditions, however, when gasoline prices are low, there is no incentive to reduce VMT or fuel use. Thus, fuel use is high when no shortage exists in 1990.

In all four scenarios, nonwork travel is the principal target for cutbacks in VMT and fuel use in response to short-run energy shortages in 1990. VMT reductions made in nonwork travel are roughly twice the VMT reductions made in work travel. It should be noted that the alternative 1990 futures are short-term events and thus short-run behavioral responses would be expected.

Summary

On the basis of the qualitative review, the main conclusions regarding the likelihood of long-term locational impacts occurring in response to continued energy shortage are summarized as follows:

1. In view of the high costs and extensive behavioral adjustments associated with relocating residences and/or places of employment, such adjustments are more likely to occur if public perception is one of continuing or recurring shortages of moderate or intense severity.

TABLE 17

PRIVATE VEHICLE-MILES TRAVELED AND FUEL CONSUMPTION—NO LONG-RUN CONSERVATION ADJUSTMENTS*

	Nonshortfall	High (Shortfall) Price**	High Price and TSM**
Work			
VMT (thousands)	1,890	1,572 (-16.8)	1,484 (-21.5)
Fuel Consumption (thousands of gallons)	106.8	88.8	83.8
Nonwork			
VMT (thousands)	2,781	1,813 (-34.8)	1,653 (-40.5)
Fuel Consumption (thousands of gallons)	157.1	102.4	93.4
Total			
VMT (thousands)	4,671	3,385 (-27.5)	3,137 (-32.8)
Fuel Consumption (thousands of gallons)	263.9	191.2	177.2

*Numbers may not add due to rounding. This scenario assumes 17.7 average mpg and no long-run changes in the work trip distance distribution.

**The numbers in parentheses are the percentage changes from nonshortfall conditions.

TABLE 18

PRIVATE VEHICLE-MILES TRAVELED AND FUEL CONSUMPTION—IMPROVED FUEL ECONOMY *

	Nonshortfall	High (Shortfall) Price**	High Price and TSM**
Work			
VMT (thousands)	1,917	1,647 (-14.1)	1,560 (-18.6)
Fuel Consumption (thousands of gallons)	94.9	81.5	77.2
Nonwork			
VMT (thousands)	2,877	2,029 (-29.5)	1,868 (-35.1)
Fuel Consumption (thousands of gallons)	142.4	100.4	92.5
Total			
VMT (thousands)	4,794	3,676 (-23.3)	3,428 (-28.5)
Fuel Consumption (thousands of gallons)	237.3	182.0	169.7

*Numbers may not add due to rounding. This scenario assumes 20.2 average mpg and no long-run changes in the work trip distance distribution.

**The numbers in parentheses are the percentage changes from nonshortfall conditions.

TABLE 19

PRIVATE VEHICLE-MILES TRAVELED AND FUEL CONSUMPTION—REDUCED WORK TRIP LENGTHS *

	Nonshortfall	High (Shortfall) Price**	High Price and TSM**
Work			
VMT (thousands)	1,712	1,446 (-15.5)	1,375 (-19.7)
Fuel Consumption (thousands of gallons)	96.7	81.7	77.7
Nonwork			
VMT (thousands)	2,781	1,813 (-34.8)	1,653 (-40.6)
Fuel Consumption (thousands of gallons)	157.1	102.4	93.4
Total			
VMT (thousands)	4,493	3,259 (-27.5)	3,028 (-32.6)
Fuel Consumption (thousands of gallons)	253.8	184.1	171.1

*Numbers may not add due to rounding. This scenario assumes 17.7 average mpg and long-run reductions in work trip distances.

**The numbers in parentheses are the percentage changes from nonshortfall conditions.

TABLE 20

PRIVATE VEHICLE-MILES TRAVELED AND FUEL CONSUMPTION—IMPROVED FUEL ECONOMY AND REDUCED WORK TRIP LENGTHS *

	Nonshortfall	High (Shortfall) Price**	High Price and TSM**
Work			
VMT (thousands)	1,734	1,509 (-13.0)	1,438 (-17.1)
Fuel Consumption (thousands of gallons)	85.8	74.7	71.2
Nonwork			
VMT (thousands)	2,877	2,029 (-29.5)	1,868 (-35.0)
Fuel Consumption (thousands of gallons)	142.4	100.4	92.5
Total			
VMT (thousands)	4,611	3,538 (-23.3)	3,306 (-28.3)
Fuel Consumption (thousands of gallons)	228.3	175.1	163.7

*Numbers may not add due to rounding. This scenario assumes 20.2 average mpg and long-run reductions in work trip distances.

**The numbers in parentheses are the percentage changes from nonshortfall conditions.

2. Technological adjustments that preserve flexibility are more likely to be made by transportation energy consumers, particularly if consumers are uncertain as to whether or not future shortages will occur. The technological adjustment affording maximum potential for reducing fuel use is purchase of a more fuel-efficient vehicle. This adjustment allows for reductions to be made in fuel use for both work and nonwork travel. In addition, nonwork travel fuel use reductions may be achievable without the necessity to combine trips, travel shorter distances, or travel less frequently. On this basis, dislocation of shopping activity would be less likely to occur if energy consumers purchased more fuel-efficient vehicles.

DISTRIBUTION OF THE IMPACTS OF FUEL SUPPLY LIMITATIONS

In this section, issues involved in analyzing the distribution of impacts across various groups are discussed. Although it is possible to segment the population in an area in many different ways, probably the most useful groupings are by income and location (e.g., central city, suburb, etc.).

The discussion focuses on three major themes. First, procedures for distributional analyses are described. Second, the distribution of impacts related to work and nonwork travel adjustments to fuel supply limitations are discussed. Finally, the distribution of long-run impacts is considered.

Distributional Analysis Procedures

Although the methodologies described in the previous chapter emphasized areawide impacts, they could be modified to produce distributional impacts. The approach would essentially involve repeating the procedures for each group. For example, the work and nonwork trip models could be applied to income groups or to subareas of an urban area.

It should be noted that this approach to distributional analyses multiplies the data and computational requirements by the number of groups being analyzed. In fact, in the limiting case where each individual represents a separate group, the data requirements are essentially identical to the requirements for forecasting procedures based on random samples.

Short-Run Distributional Impacts

Because of the greater data and computational requirements for distributional analyses using travel demand models like the ones described in Chapter Two, an alternative approach would consist of quantitative analyses of areawide impacts supplemented by qualitative analysis of how these impacts might vary by income or locational groups. In this subsection, theoretical and empirical evidence on likely distributional impacts is presented.

Several factors must be considered in analyzing distributional effects. These include the shortfall level, governmental actions to deal with the shortfall, transportation levels of service available to different groups, and peoples' expectations about the magnitude, duration, and frequencies of current and future shortfalls.

Although alternative shortfall situations may lead to very similar areawide travel impacts, their distributional consequences can be quite different. For example, as discussed in Appendix A, decontrol of pump price of gasoline during a shortfall would lead to a transfer of income from gasoline consumers to producers. Rationing with white markets results in a transfer from high gasoline users to low users. Insofar as low users tend to have lower incomes, rationing would have a favorable distributional impact relative to price decontrol. However, many analytical techniques would predict very similar areawide impacts.

Because past experience with fuel shortages has involved relatively short durations and knowledge of travel behavior relationships is based on nonshortage conditions, it is likely that inferences from empirical and theoretical evidence are most appropriate for limited duration shortfalls that are perceived to be infrequent. Longer term or more frequent shortfalls might lead to long-run adjustments that are not adequately reflected in currently available information.

Available information can be used to make distributional inferences about short-run travel responses to shortfalls and to price increases. As noted earlier in this chapter, surveys conducted during previous fuel shortage periods indicated that higher income households tended to be able to make more travel behavior adjustments because of a greater degree of discretionary travel. These adjustments may have mitigated some of the negative impacts of gasoline shortages, particularly that of waiting in gasoline lines. Similarly, the increases in transit ridership experienced in areas with good levels of service suggest that there are geographic variations in the impacts of gasoline shortfalls (i.e., the availability of transit may offer more flexibility in adjusting travel behavior and mitigating negative impacts). Detailed distributional analyses for New York State are presented by Hartgen and Neveu (*25*).

Much of the available information on the distributional impacts of price increases is inferred from travel demand models. Many work and nonwork travel demand models imply that the travel behavior of lower income households is more price elastic than that of higher income households. This elasticity effect is often a consequence of the assumptions of the models. For example, in many work mode choice models, the modal cost variables are divided by income, thus indicating that lower income individuals are more cost sensitive. The greater price elasticity implies that lower income people will reduce their travel to a greater extent with increased gasoline price. This reduction may lead to a smaller impact on the income available for nontravel purposes relative to higher income groups. In fact, Horowitz's (*24*) model indicated that nontravel income would actually increase for the lowest income group (under $11,500) under a 15 percent shortfall and decontrolled gasoline pump price.

The greater price sensitivity and usually lower nonshortage travel demand of the lower income group explain the favorable distributional consequences of white market rationing. The reduced travel can be converted into income through the sale of ration coupons. The increased income would likely offset some of the travel reductions, however, since travel appears to increase with income. For example, Horowitz's model predicted a 67 percent reduction in gasoline consumption under the price increase scenario described earlier and a 65 percent reduction under rationing with white markets for the low income groups.

It should be noted that the distributional impacts of fuel supply unavailability and price increase appear to be quite different. A possible explanation for the difference is that higher income people are more sensitive to the time penalties involved in fuel shortages (gasoline lines)

and that lower income people are more sensitive to cost increases. Further development of approaches to understanding travel behavior under resource constraints, which are described in Appendix D, potentially could be used to explain these differences more fully.

The geographic distribution of the impacts resulting from price increases can also be analyzed with travel demand models. As in the case of supply unavailability, the key factor appears to be the availability of alternatives to private vehicle travel. For example, the work trip models of the forecasting system for this project predict a substantial shift to transit in response to gasoline price increases when that mode is available. The market segments without transit must absorb a greater proportion of the price increase.

Long-Run Impacts

As stated earlier, much less is known about the distributional impacts of long-run choice (e.g., vehicle purchase and residential location decisions). Available survey evidence indicates that responses to previous shortfalls have been mainly short-run travel behavior adjustments. However, in the event of actual or perceived shortfalls of greater magnitude, duration, and/or frequency than previously experienced, long-run adjustments may be more prominent.

There is reason to believe that higher income people have greater flexibility to make long-run adjustments that mitigate the impacts of gasoline price increases and/or supply limitations. For example, low income households are more likely to own older vehicles, which are usually less fuel-efficient. (This effect may lessen over time if the CAFE standards eventually lead to more uniform fuel economies.) Similarly, higher income may provide greater choice of residential location. For example, if middle to upper income households opt for central city locations in increasing numbers, the "gentrification" process being observed in some central city neighborhoods may price lower income households out of previously available neighborhoods and, perhaps, lead to longer work trips.

CHAPTER FOUR

INTERPRETATION, APPRAISAL, AND APPLICATION

In this chapter the strengths and limitations of the quantitative and qualitative analysis procedures are discussed. Following this, guidelines for applying the procedures are presented.

INTERPRETATION AND APPRAISAL

This section is organized into two subsections. First, the methodologies used in the study are evaluated. Next, the results obtained from applying the methodologies are discussed.

Evaluation of Methodologies

The major focus of this project was the examination of procedures for analyzing the medium- to long-run travel behavior impacts of fuel supply limitations. In the preceding two chapters, quantitative procedures were presented for analyzing travel behavior, and qualitative analyses were suggested for impacts, such as residential location choices, and for the distribution of impacts across groups.

The quantitative forecasting system was applied to four energy shortfall scenarios. The overall performance of the system was quite encouraging. Plausible work and nonwork trip forecasts emerged, and the overall response of travel behavior to fuel supply limitations predicted by the forecasting system was consistent with the independently derived shortfall levels. The system also requires relatively little data and can be applied with minimal computer resources.

It should be emphasized that the tests of the forecasting system were for a hypothetical medium-sized city. The major purposes for the tests were to illustrate the procedures for applying the system and to assess its overall performance. Actual numerical results, such as total VMT and fuel consumption forecasts, do not necessarily describe actual urban areas. For the outputs to be of direct use to particular areas, they should match the hypothetical area reasonably well in terms of current travel patterns and independent variables of the models, both for a base period and a forecast period.

Qualitative analysis is recommended for addressing impacts, such as changes in residential location decisions and activity patterns resulting from actual or potential fuel supply limitations. The recommended procedure involves establishing ranges of possible outcomes for these impacts and examining the travel behavior consequences of the alternative outcomes. Qualitative analysis also can be used to explore travel behavior responses in greater detail. For example, specific changes in travel behavior resulting in VMT reduction may not be completely identified through the quantitative analysis. Qualitative proce-

dures, such as energy survey analyses and gaming data collection and analysis, can be used to explore travel behavior responses in greater depth.

Because understanding of travel behavior, in general, and travel responses to fuel supply limitations, in particular, is not completely developed, any forecasts will be uncertain. Two procedures for dealing with uncertainty were examined and are recommended in further applications. First, the use of alternative scenarios addresses the uncertainty associated with input variables, such as future gasoline prices, vehicle fuel economies, and home and employment locations. The use of scenarios does not guarantee that the full range of possible outcomes will be considered, however. For example, it is noted in the next section that gasoline price projections made before 1979 were typically too low. However, the use of scenarios seems to be more judicious than producing point predictions for a single set of assumptions.

There is also uncertainty in the response of travel behavior to changes in input variables, such as gasoline price. Sensitivity analysis of the coefficients of the travel behavior models is a method for dealing with this uncertainty. The "Behavioral Parameters" subsection later in this chapter discusses sources for alternative sets of coefficients for sensitivity analyses. Since previous research has produced more information on the range of coefficients for the work trip models, this report focuses on sensitivity analyses for the work trip results. Forecasts are definitely quite sensitive to the values of the coefficients. Therefore, sensitivity analysis appears to be important in model applications and should be the subject of further examination in model development.

Limitations to the approach, especially the quantitative component, are of two types. First, relatively little current knowledge of transportation behavior is based on data collected after the 1973–1974 oil embargo or during periods of gasoline shortages. Therefore, unless behavioral relationships are extremely stable over time and highly invariant under different gasoline price and availability situations, it is possible that models developed with newer data may be somewhat different from the older models. It is possible that a nonwork transit demand model with a specification similar to the model used in this study would show greater transit response to auto disincentives. In the next chapter, specification of new models with more recent data sources is recommended. Results from work of this nature should be disseminated quickly and widely. The practicing analyst should consider substitution of newer models, estimated with more recent data (if they appear to be more reliable), for existing models.

Second, the study of travel behavior is a developing area of research. Newer research approaches, which are still very much in the early stages, have emerged and may improve understanding of the travel behavior impacts of fuel supply limitations. These approaches include gaming and simulation studies, examinations of complex travel patterns, studies of activity and time allocation, and explorations of the effect of resource constraints (e.g., time and money budgets) on travel behavior. These approaches are discussed in Chapter Three and Appendix D. Other approaches also may contribute useful knowledge. Again, it is important that new breakthroughs of this nature be incorporated into quantitative and qualitative analyses and disseminated to practicing analysts.

Evaluation of Travel Behavior

As noted earlier, because the quantitative analyses were based on a hypothetical medium-sized city, the actual numerical results are not necessarily applicable to all areas. However, there are some general patterns in both the quantitative and qualitative findings that are noteworthy. Many of these findings are consistent with results from other studies.

For adjustments in travel behavior, both the quantitative forecasting system and the review of survey data describing behavior during previous shortfalls indicate that nonwork travel is more likely to be adjusted than is work travel. Other quantitative studies (e.g., Horowitz's (*24*) analysis) also show the same trend.

The adjustments in work and nonwork travel appear to vary with the severity of the shortfall, the policies used to allocate gasoline and/or reduce demand, and whether long-run conservation adjustments are made. As an example, it was noted in Chapter Three that people with lower incomes are likely to be more responsive to price increases, while people with higher incomes appear to have adjusted their travel more in response to gasoline lines.

Horowitz's (*24*) analysis produced another contrast between pricing allocation and supply limitations. Under policies resulting in increased gasoline prices, Horowitz's models estimated that there would be less trip chaining for nonwork travel. Under strict rationing (no legal coupon market), however, the propensity to combine trips was estimated to increase.

The two 1985 scenarios analyzed in Chapter Two can be used to compare pricing and level of service policies with the restrictive sticker plan. Although both scenarios resulted in reductions in total private vehicle travel fairly close to the 15 percent shortfall used to define the scenarios, the sticker plan affected work travel much more. This finding is consistent with findings on travel adjustments made during previous shortfalls. That is, given the flexibility to choose among travel adjustments, people appear to reduce nonwork travel relatively more than they do work travel. The sticker plan clearly offers less flexibility. (It also should be noted that flexibility of choice among travel adjustments was an important issue in the surveys of travel behavior during gasoline shortages.)

Comparison of the two 1990 scenarios suggests that long-run conservation adjustments may affect responses to future energy shortfalls. In particular, greater improvements in vehicle fuel economies and shorter work trip distances result in less sensitivity to a particular gasoline price increase. Conversely, for the same percentage shortfall, the gasoline price increase that reduces travel to match the shortfall level is higher under the long-run conservation scenario.

The results of Chapter Two also can be used to compare the relative importance of the gasoline price increases resulting from shortfalls and the other level of service changes. In general, the forecasting system suggests that price effects are more important, although the travel adjustments resulting from the other level of service changes are not insubstantial.

Long-run adjustments were considered in Chapter Three. The key issues were (1) the relative importance of transportation energy costs and other factors in employment and residential location choices; and (2) the relative effectiveness of location changes and other adjustments, such as improved vehicle fuel economies in transportation energy conservation. Consideration of both issues suggests that household location choices are not the most likely or most effective conservation adjustments in the short to medium term. For example, scenario tests conducted in Chapter Three suggested that improved vehicle fuel economies were more effective conservation adjustments than were changes in employment and residential location. These findings do not mean that land-use policies emphasizing energy conservation are ineffective. Such policies may have important long-run impacts, although other policies, such as vehicle fuel economy standards, may be more effective sooner.

APPLICATIONS

In this section, guidelines for applying and interpreting the quantitative and qualitative impact analysis procedures are presented. First, procedures for developing alternative fuel price and shortfall scenarios are presented. Second, methods for estimating base level and future values of the input variables for the work and nonwork model components of the forecasting system are described. Next, selection of behavioral parameters (e.g., model coefficients) is discussed. The interpretation of quantitative outputs is then considered. Finally, the issue of integrating quantitative and qualitative impact estimates is addressed.

Alternative Fuel Shortage and Price Scenarios

As noted in Chapter Two, fuel supply scenarios can be defined in terms of shortage level, gasoline price, frequency, duration, and governmental actions. Because there is much uncertainty in each of these factors, analysts may desire to test alternative scenarios to those defined and used in this report. Indeed, during the course of this project, changes have been made in projecting variables such as gasoline price both by the research team and by analysts at other agencies such as the U.S. Department of Energy (DOE). The supply disruptions and world petroleum price increases of 1979 generally exceeded even the most pessimistic assumptions (*83*) and necessitated upward revision of forecast prices during the course of this project. The issues involved in defining scenarios are discussed in detail in Appendix A. In this subsection, particular attention is given to price projections because price is an important factor in existing analytical procedures.

The base (nonshortage) projections used in this report were estimated using a constant annual real price growth rate assumption and assumptions about the effects of the decontrol of domestic petroleum prices and the recently announced import fee. The gasoline price for a particular year was estimated with Eqs. 15 and 16:

$$\text{Gas price}_t = \$0.8624\,(1+r)^{t-1979} + \tfrac{1}{2}\,(t-1974)\,DC + \text{New tax for 1980 and 1981} \qquad (15)$$

and

$$\text{Gas price}_t = (\text{Gas price}_{(t-1)} - \text{New tax}_{(t-1)}\,(1+r) + \text{New tax}_t \text{ for } t > 1981 \qquad (16)$$

There are three factors that can be modified to yield new projections; the real growth rate, r, the effects of decontrol, DC, and New tax_t. These factors were assigned the values $r = 0.0235$ (the 1969–1979 historic real growth rate), $DC = 11$ cents per gallon, and New $\text{tax}_t = 5.5$ cents for 1980 and 9.5 cents for subsequent years. The 1979 price level is \$0.8624.

An example of an alternative base price scenario using this approach would be to assume that the oil producers will have greater market control, resulting in a 3 percent sustained annual growth rate; that domestic petroleum price decontrol adds 10 cents per gallon in 1980 and 20 cents by the end of 1981 (when decontrol is completely phased in; i.e., $DC = 20$ cents per gallon); and a 50 cent real tax on gasoline is implemented starting in 1981 (new tax = 0 for 1980 and 50 cents per gallon afterwards). The price projection resulting from these assumptions is given in Table 21 (Note that the projection is not endorsed; it merely illustrates the approach.)

An alternative approach can be based on the assumption of a long-run ceiling price on petroleum, which, in turn, is based on the cost of alternative energy sources such as synthetic fuels. The real price of petroleum and gasoline is assumed to remain constant after the date the ceiling is reached. Because the ceiling price is based on long-run assumptions, intermediate prices are not directly determined. A possible assumption for deriving intermediate prices is that prices grow at a constant rate from the base price to the ceiling price. Equations 17, 18, and 19 produce the price projections:

$$\text{Gas price}_t = \text{Base gas price}\,(1+r)^{(t-\text{base year})} \qquad (17)$$

for intermediate years;

$$\text{Gas price}_t = \text{Ceiling price} \qquad (18)$$

for years beyond the date at which the ceiling price is reached; and

$$r = \left(\frac{\text{Ceiling price}}{\text{Base price}}\right)^{1/T} - 1 \qquad (19)$$

where T is the number of years necessary to reach the ceiling price.

The ceiling price of gasoline must be related to the ceiling price of the alternative energy source. For example, if the ratio of gasoline price to petroleum price also applies to gasoline derived from synthetic fuels, the ceiling price of gasoline would be about 2.2 times the ceiling price of the alternative energy source.

TABLE 21

AN ALTERNATIVE BASE GASOLINE PRICE SCENARIO (JUNE 1979 $)

Year	Price
1979	0.862
1980	0.988
1981	1.615
1982	1.648
1983	1.683
1984	1.718
1985	1.755
1990	1.955
1995	2.186
2000	2.455

TABLE 22

GASOLINE PRICE PROJECTIONS BASED ON CEILING PRICE OF ALTERNATIVE SOURCE (JUNE 1979 $)

Year	Price
1979	0.862
1980	0.905
1981	0.950
1982	0.997
1983	1.046
1984	1.098
1985	1.153
1990	1.468
1995	1.870
2000	2.381

An example of a gasoline price projection using this approach uses the following assumptions: (1) the ceiling price for a 42-gal barrel of synthetic crude oil in 1979 dollars is $45; (2) the price of crude is 45 percent of the price of gasoline. Therefore, the ceiling price of gasoline is $2.38 per gallon; and (3) the ceiling price is obtained in the year 2000. Using these assumptions with Eqs. 17, 18, and 19 produces the gasoline price projection in Table 22.

The nonshortfall gasoline price projections presented in this report are national averages. In particular, they assume national average per gallon gasoline taxes. Therefore, an analyst may consider adjusting the prices to account for the difference between local and national average tax rates and other local conditions.

The prices also may be adjusted to reflect tax policies for encouraging energy conservation. An increase in per gallon taxes is the most straightforward situation. Prices would simply be adjusted upward by the amount of the tax increase. Some states are considering, or have implemented, a gasoline tax based on percentage of sales. The projections presented in this report could be adjusted to reflect this policy in the following way:

$$\text{New price} = (1 + r)\ (\text{Old price} - g) \qquad (20)$$

where new price is the price under proportional taxation; old price is the price under per gallon taxation; r is the proportional tax rate; and g is the per gallon tax rate. (For the 1979 base period used in the gasoline price projections, national average per gallon tax rate was $0.1176).

The base price is the starting point for deriving price projections for shortfall scenarios. On the basis of standard economic analysis using the price elasticity of demand for gasoline, the shortfall price levels are estimated as follows:

$$\text{Shortage price}_t = \text{Base price}_t \left(1 - \frac{s}{\eta}\right) \qquad (21)$$

where s is the shortfall level (derived from the scenario definition and expressed as a decimal function) and η is the price elasticity (assumed to be -0.2 in the analyses). Therefore, the elasticity becomes the key factor in deriving alternative shortfall price levels.

Input Variables

This subsection discusses possible sources for the specific input requirements for the analysis of Chapter Two for both the work and nonwork trip models.

Work Trip Analyses

The work trip methodology involves the following procedures: (1) classification of total areawide work trips into the six traveler classes; (2) estimation of base modal shares for each class; (3) estimation of base level values for the independent variables for each class; (4) projection of future level values for the independent variables; (5) projection of the future number of work trips in each class; (6) projection of future average fuel economies for auto and transit; and (7) projection of future average occupancies for the three modes.

The most direct way of classifying work trips and estimating base modal shares is by using a recent transportation survey (or a simple survey conducted for use with the forecasting system). Information on work trip length, mode, transit access, and auto availability is necessary. These data requirements are so limited that a low-cost, special survey (e.g., a telephone survey) could be used if existing data were not available.

Given the availability of survey data, the first step is the construction of the traveler classes used in the aggregation procedure. This involves the definition of long and short trips, the use of criteria for determining available modes, and the assignment of trips to classes. In NCHRP Project 8–13, CRA (*11*) suggested that the average or median trip distance could be used to define

short and long trips. For each trip length, the work trip maker in the sample would be assigned to one of three choice set categories. The decision rules used to construct the traveler classes in Chapter Two are as follows: (1) if autos per worker is less than 0.5, the person is assigned to the shared/ride transit class; (2) if autos per worker is greater than 0.5 and distance to transit is greater than 6 blocks, the person is assigned to the drive alone/shared ride class; and (3) all other persons are assigned to the full choice set. Once trip makers are assigned to classes, shares for each class are constructed from reported work trip modes. (It is possible that some anomalous modes would be observed (e.g., a drive-alone trip for a person with low auto availability); however, existing data suggest that few such cases should occur and they can be ignored in estimating base modal shares.)

If survey data are not available, the classes and base shares can be constructed from secondary data sources. For example, the distributions of work trip lengths for several cities are presented in the reference volume, "Characteristics of Urban Travel Demand" (*84*). The distribution of trip makers across choice sets can be estimated as follows. Since only 2 percent of the trip makers in the low automobile availability segment constructed from Nationwide Personal Transportation Study (NPTS) data actually had an available auto (*12*), it appears that the proportion of zero auto households reported in census data for the area is a reasonable approximation of the proportion of households in the shared ride/transit classes. The proportion of households greater than six blocks from transit is a statistic generally available from a transit agency. Also, it can be inferred from route maps and census housing information for tracts in the service area. The distribution of households across classes is then estimated as:

Shared ride/transit = proportion of zero auto households;

Drive alone/shared ride = proportion of households greater than six blocks from transit (there may be some zero auto households more than six blocks from transit; however, this is likely to be a very small proportion, which should not substantially affect the results); and

Full choice set = 1 − proportion of zero auto households − proportion of households greater than six blocks from transit.

The number of work trips per household is likely to vary by traveler class. Charles River Associates (*11*) suggests that a data source such as the NPTS can be used to estimate these trip rates. For example, in the NCHRP Project 8–13 Phase II report (*11*), information on work trip rates was produced for non-center-city households in SMSAs of 1,000,000 population. (This information was produced directly from the data tapes for the 1969 NPTS study. Similar procedures could be applied to develop trip rates for other types of urban areas. Data from the 1977 NPTS survey could also be used when the tapes become available. See the NCHRP Project 8–13 Phase II report (*11*) for details.)

The rates for round-trip work trips constructed from these data are 0.93, 0.96, and 0.30 for the full choice set, drive alone/shared ride, and shared ride/transit classes, respectively. Each of these rates would then be applied to the proportion of households in the corresponding class to produce the proportion of trip makers by class.

The joint distribution of trip makers across trip distance/choice set classes is likely to be different from a distribution constructed by assuming independence between the separate trip distance and choice set distributions. For example, the NPTS data indicate that transit is less likely to be available for long trips. Therefore, the joint distribution may have to be constructed artificially using the iterative proportional fitting methodology described in the NCHRP Project 8–13 Phase II report (*11*). The procedure involves adjusting a joint distribution from another area with the separate trip distance and choice set distributions from the area in question. The procedure is analogous to adjusting a trip distribution table so that it produces row and column totals that match independently supplied control totals. (The procedure is described in the NCHRP 8–13 Phase II report (*11*) and in standard transportation planning texts such as Stopher and Meyburg (*85*).) For example, the joint distribution from the classes constructed from the NPTS data, given in Table 23, can be used with the separate marginal distributions from the area in question.

The base modal shares can then be estimated by applying the mode choice model (in its conventional, rather than incremental, form) using the base level of service variables to be described next. Model coefficients and alternative specific constants would be necessary. If estimates of areawide modal shares are available, the alternative specific constants can be adjusted so that predicted modal shares match observed modal shares. (This procedure involves an iterative process similar to that used in estimating a modal choice model.)

Because of the relative simplicity of obtaining survey data for the area, indirect construction of traveler classes and their modal shares is recommended only as a back-up strategy to be pursued when survey data are not available.

Base values of the independent variables are either available directly from the survey data or can be constructed from the definitions of the classes. In the former case, average values for each class would be estimated.

TABLE 23

JOINT DISTRIBUTION OF TRIP DISTANCE/ CHOICE SET

	Trip Distance*	
Choice Set	Short	Long
Full	.302	.145
Drive Alone/Shared Ride	.244	.205
Shared Ride/Transit	.075	.028

*The average round trip distances derived from the data used to construct this table were approximately 8.5 miles for short drive alone trips and 33.5 miles for long trips. The distances for the other two modes were somewhat different. Average distances for particular urban areas would likely differ from these national averages.

Since the modeling procedures discussed in Chapter Two emphasize trip cost, in-vehicle time, and walk time, procedures are described for constructing these variables when survey data are not used. The variables are average values for the traveler classes used in the aggregation procedure. The discussion is organized by mode.

For drive alone, the round-trip cost is estimated as:

$$\text{Cost}_{Dj} = TL_{Dj}\left[\frac{\text{Gas price}}{\text{MPG}} + OC\right] = TL_{Dj} \cdot (\text{Cost per mile}) \quad (22)$$

where Cost_{Dj} is the drive alone round-trip cost for class j; TL is the trip length; and OC is the nongasoline auto costs (oil, tires, and maintenance).

The round-trip in-vehicle travel time is estimated as:

$$\text{IVTT}_{Dj} = TL_{Dj}/\text{Auto speed}_{Dj} \quad (23)$$

where IVTT is the in-vehicle travel time. Auto speed may vary by trip length. Knowledge of local conditions would be useful in selecting values for speed for the segments. Walk time is likely to be a fairly small value, representing typical access and egress times for auto trips.

Transit cost is determined by the local fare structure. In-vehicle time (which includes waiting and transfer time in this model) can be determined by assuming a bus speed (which may vary by trip length) and adding typical wait and transfer times. Walk time includes access and egress times. For the home end of the trip, round-trip walk time can be estimated by:

$$\text{Walk time}_{Tj} = 2 \times \text{Distance to transit}_j \,/\, \text{Walk speed} \quad (24)$$

For example, if distance to transit is 3 blocks (about 0.3 miles) and walk speed is 1/19 miles per minute, round-trip home to transit walk time is about 11 min. To this is added round-trip transit to work walk times.

Shared ride times are the most complicated because they depend on carpool size. As explained in Appendix C, an average occupancy of 2 (driver and passenger) is assumed in constructing shared-ride level-of-service variables.

Shared ride costs are estimated as:

$$\text{Cost}_{Sj} = TL_{Sj}\ (\text{Cost per mile})/LF_j \quad (25)$$

where LF denotes average occupancy and the subscript S denotes shared ride. The trip length for carpool is likely to be longer than the corresponding drive alone length because of picking up and dropping off passengers. For example, CSI (*9*) assumes a circuity factor of 0.5 miles per carpool member. Shared ride in-vehicle round-trip time is estimated as:

$$\text{IVTT}_{Sj} = TL_{Sj}/\text{Auto speed}_{Sj} + \text{Wait time}_{Sj} \quad (26)$$

Auto speed may be somewhat slower than that for drive alone because of neighborhood driving in the picking up and dropping off of passengers. The wait time involves delays in coordinating among passengers. For example, Cambridge Systematics, Inc. (CSI) (*9*) assumes a delay of 5 min per carpool member. Walk time for shared ride may be somewhat longer than that for drive alone, but would still be a small value.

Values for future period level-of-service variables are constructed in a similar manner. Inasmuch as gasoline and other automobile operating costs are projected to increase, new cost per mile estimates would be necessary. In addition, any cost incentives or disincentives would be included.

Future time variables would reflect the effects of policy actions. Table A–15 gives a list of actions likely to affect the various level-of-service variables. The actual level of change would be determined by the nature of the action and local conditions. For example, in Chapter Two it was assumed that an exclusive bus lane would reduce transit line-haul time by 20 percent.

When base level modal shares for the traveler classes are available and the incremental logit model is used, it is not strictly necessary to estimate both base level and future period values for the independent variables. Rather, the changes in the variables can be estimated directly without necessarily referencing base levels. This feature could be advantageous when the changes can be estimated more easily than the base and future levels.

Projections of the future number of work trips in each class should reflect changes in the work force in the area and any changes in work trip lengths, auto, or transit availability. For example, if no major changes in the relative sizes of the classes are anticipated, the future sizes can be estimated by factoring the current distribution to account for labor force changes. If it is assumed that increasing energy costs are encouraging people to live closer to work, some trip makers would be shifted from long to short trip classes.

Fuel economy projections can be obtained from this report and other sources. For example, the New York State Department of Transportation (*86*) has produced fuel economy estimates through 1995, and a number of alternative projections are available in the Transportation Energy Conservation Data Book (*87*). Transit fuel economies should reflect the type of equipment used in the local area.

Average occupancies should also reflect local conditions. By definition, the drive alone occupancy is 1. A factor of 2.5 was used for shared ride. (Note that this is different from the factor used in estimating level-of-service variables. The reasons for the difference are explained in App. C.) The transit average occupancy should be consistent with local occupancy for work (mainly peak) trips.

Nonwork Trip Analysis

Application of the nonwork trip models requires the following areawide inputs: (1) base period average household VMT and transit ridership; (2) base period average values on the 13 independent variables in the model; (3) forecast period values for the independent variables; (4) forecast period estimates of the number of households; (5) projections of fuel economies; and (6) projection of a factor converting transit trips to bus miles.

Base period nonwork VMT and transit ridership are likely to be available from standard sources such as

transportation surveys and transit ridership counts or surveys. Because the model forecasts 4-day values for these variables, it is necessary to translate the available information, which is probably daily averages, to 4-day averages.

The independent variables in the model are of three types: (1) area characteristics, (2) average household characteristics, and (3) level-of-service variables. The area characteristics are the broad population size categories defined in Table 7. Because they are unlikely to change over the forecast period, they do not affect the forecasts produced with the incremental form of the model.

The household characteristics include average household size, average number of household members 5 years of age and older, average household income, and average number of licensed drivers per household. The first three variables are generally available through regional demographic and economic estimates or forecasts. Estimation of the second variable requires forecasts of population by 5-year age groups. The variable is calculated as the number of people 5 years and older divided by the number of households.

The age group estimates and forecasts can also be used to derive the number of licensed drivers per household. The Federal Highway Administration (*88*) defines the eligible driving population as people 15 years of age and older. Licensed drivers are approximately 85 percent of eligible drivers (*88*) Because this proportion may be close to a saturation level, total licensed drivers could be estimated as 85 percent of the population 15 years and older. Alternatively, proportions specific to the area in question may be used. The estimated number of licensed drivers is then divided by the number of households.

Six level-of-service variables appear in the model. The average nonwork trip auto time per mile is simply the inverse of the average speed. It can be determined from data and projections of traffic flow conditions. This estimate would then be multiplied by the average household wage rate in cents per minute to obtain the average travel time by wage rate variable. (In the model, household wage per minute (measured in cents per minute) is calculated by dividing household income (measured in dollars per year) by 1,200.)

The cost per mile divided by wage variable is constructed from gasoline price, private vehicle fuel economy, and household income variables. All of these factors have already been discussed.

Information on the percentage of nonwork trips for which free parking is available for the base period should be available from travel or parking surveys. The forecast period value is, in part, a policy outcome. If the incremental form of the model is used, only the change in the variable is needed. In many cases it may be more reasonable to estimate the change resulting from a policy without having to estimate accurately the base period value.

Average nonwork transit trip time for the base period should be readily available from transportation or transit survey data. Again, the forecast period value is affected by level-of-service policy changes.

Finally, the average percentage of nonwork trips served by transit for the base period can be estimated from travel survey data. It should be noted that this percentage is smaller than the number of households within six blocks of transit because some of the trips from these households would have trip ends further than six blocks from transit. Because this variable is likely to be the most difficult to estimate for both the base and forecast periods, it may be necessary to rely on a judgmental estimate of the magnitude of change in transit availability in place of estimating the difference between forecast and base period values.

Estimates of the number of households are necessary to convert household averages to areawide totals. This information should be readily available from standard demographic sources.

Private vehicle and bus fuel economies were discussed when work trip inputs were described. The factor that converts bus ridership to bus miles would account for average trip length and occupancy factors. The factor should be chosen to reflect local conditions.

Behavioral Parameters

To apply the forecasting system, coefficients are necessary for the work trip and nonwork trip models. The work trip model requires coefficients for round-trip in-vehicle time, walk time, and cost. The analyst has several options in selecting the coefficients.

First, on the basis of the scenario tests in Chapter Two, one of the sets of coefficients presented there could be selected. It appears that the second set of linear coefficients yielded the most reasonable results. However, sensitivity analysis involving alternative sets of coefficients is also recommended.

Second, the analyst could select a set of coefficients from other existing work trip mode choice models. For example, the work trip models developed in the Urban Travel Demand Forecasting Project (*89*) are prominent examples of another model set. Some consultants (e.g., CSI (*9*)) actually recommend transferring the coefficients of their modeling system to other regions.

The selection of the coefficients from an existing model would be based on the assumption that the model in question is reasonably transferable to the region in question. Therefore, the analyst would benefit from a thorough knowledge of available models. Several sources described existing models (*90, 91, 15*). In addition, Koppelman (*19*) presents a useful comparison of models with alternative functional forms for level-of-service variables.

Third, the analyst could estimate a new model with data from his/her area. The data either could be from an existing transportation survey or collected specifically for adapting the forecasting system to this region. For example, if new survey data are being used to construct the traveler classes, it also may be appropriate for mode choice model estimation. Again, knowledge of the choice modeling literature would be highly useful.

Since many prominent work trip model choice models were estimated with data at least 10 years old, the estimation of new models with newer data sets is highly desirable, particularly for energy policy analyses. The forecasting capabilities of such models very well may be better than those of existing models. For example, model estimation with the recently available Baltimore Disaggregate Data Set (*92*) may be an important research development. Models estimated with data collected during energy shortage periods also may be an important contribution. Appendix E presents suggestions for data collection during such periods.

Elasticity analysis is an alternative to the incremental logit analysis methodology work trip analysis. A description of the methodology and sample applications are presented in Appendix C. Several sources have been consulted for estimates of the appropriate elasticities. Table 24 gives the ranges of likely values for these elasticities.

As described in Chapter Two, there is much less information on the range of likely coefficients for the nonwork trip models. Also, the coefficients used in this project appear to produce reasonable forecasts. Therefore, the existing model is recommended for the types of quick response policy analyses described in this report.

Future research on the estimation of new nonwork trip models would be highly desirable. The Baltimore data set and the 1977 version of the Nationwide Personal Transportation Study would be useful data sources. Data collected during energy shortage periods would also be useful. The estimation of new models would contribute to knowledge on the likely range of the travel parameters (coefficients) of nonwork trip models and would indicate whether sensitivity analysis is an important component of nonwork travel forecasting.

TABLE 24

ELASTICITY ESTIMATES

	Lower Bound	Upper Bound
Auto Demand Elasticities:		
Variable		
Auto line haul operating cost	-.10	-.30
Auto parking charge	-.30	-.50
Auto out-of-vehicle time	-.80	-1.00
Bus line-haul travel time	+.10	+.30
Bus out-of-vehicle time	+.30	+.40
Bus fare	+.05	+.15
Carpool Demand Elasticities:		
Variable		
Carpool total trip cost*	-.06	-.10
Carpool out-of-vehicle time	-.10	-.30
Bus line-haul travel time	+.02	+.04
Bus out-of-vehicle time	+.09	+.10
Bus fare	+.05	+.15
Bus Demand Elasticities:		
Variable		
Bus line-haul travel time	-.30	-.50
Bus out-of-vehicle time	-.60	-.80
Bus fare	-.15	-.35
Auto total trip cost*	+.40	+.60
Auto out-of-vehicle time	+.30	+.40
Carpool total trip cost*	+.03	+.04
Carpool out-of-vehicle time	+.10	+.20

*Elasticity estimates for separate cost components were not available.

SOURCES: Y. Chan and F. L. Ou, "A Tabulation of Demand Elasticities for Urban Travel Forecasting," Pennsylvania Transportation Institute, August 1977; J. R. Pucher and J. Rothenberg, "Pricing in Urban Transportation: A Survey of Empirical Evidence on the Elasticity of Travel Demand," Center for Transportation Studies, Massachusetts Institute of Technology, September 1976; Paul Dygert et al., "Public Transportation Fare Policy," Peat, Marwick, Mitchell and Company, prepared for U.S. Department of Transportation, May 1977.

Integrating Qualitative and Quantitative Analyses

Guidelines for applying the quantitative travel behavior forecasting system have been presented in the preceding subsections. The outputs from applying this system should be supplemented with the qualitative analysis activities described in Chapter Three.

There are a number of important uses for qualitative analyses. First, long-run impacts, such as changes in residential and employment location patterns, are complex. Quantitative predictions are difficult to produce and of uncertain accuracy. However, because most travel behavior models, including the ones used in this study, require information on longer range decision variables, the analyst must address these longer run impacts if medium-to-long-range forecasts are desired. Sensitivity tests based on insights from qualitative analysis are an attractive source for these inputs. For example, although the magnitude of adjustment of home-to-work-trip distances resulting from the changing energy situation is difficult to forecast, location theories, empirical evidence, and common sense suggest a range of likely outcomes. The two 1990 scenarios tested in Chapter Two—one based on no long-run location changes and the other based on the assumption of shorter work trips—illustrate this approach. In a similar way, an analyst can develop alternative work trip length distribution assumptions based on local conditions and the issues discussed in Chapter Three.

Second, even though the quantitative forecasting system appears to produce reasonable results, there may not be enough detail on specific travel behavior impacts. In order to develop a practical system, simplification is necessary. Hence, summary variables such as VMT and fuel consumption have been emphasized. Even though these variables are clearly policy relevant, many interesting adjustments in travel behavior may not be explicitly revealed by them.

Therefore, sources such as survey data and gaming methodology can provide more information on specific adjustments in travel behavior. By combining these data (which often provide the direction, but not magnitude, of behavioral changes) with reasonable assumptions about the amount of travel saved per adjustment, the relative contribution of various behavioral adjustments to energy conservation can be estimated. The work of the New York State Department of Transportation (*25*) in this area is a valuable resource. The examples given in Chapter Three illustrate a similar approach.

Similarly, qualitative analysis provides the opportunity to consider impacts not necessarily addressed by the quantitative analysis. For example, although travel demand models can be used to produce quantitative estimates of the distributional impacts of transportation policies, the increased detail may make applications more cumbersome. Quantitative analysis of areawide travel impacts complemented by a qualitative discussion of the benefits and costs to particular groups may be an attractive alternative. Also, quantitative estimates tend to become less reliable as they are applied to smaller and smaller groups.

Finally, good qualitative insight can serve as an important check on the reliability of the quantitative results. Because available models were estimated with data that may not represent travel behavior during fuel supply shortfalls and travel behavior theories have not been fully developed, a given available model does not always produce reliable results, especially in unusual situations such as fuel supply limitations. Qualitative knowledge of previous responses to fuel shortages and/or likely responses to future shortages can be used to test the plausibility of quantitative forecasts and to adjust such forecasts so that they are more plausible. In a sense, qualitative information gives the analyst more knowledge to update information from the model, which may be based on nonshortage assumptions. It should be noted that any such adjustments involve assumptions that can be subjected to sensitivity analysis.

CHAPTER FIVE

CONCLUSIONS AND SUGGESTED RESEARCH

CONCLUSIONS

The research approach of NCHRP Project 8–23 was guided by two major considerations. First, available methods were used in the development of practical procedures for analyzing the travel behavior impacts of fuel supply shortages. The major product of this effort is the quantitative forecasting system. Second, it was apparent that understanding of travel responses to energy shortfalls was incomplete. Better understanding would require ongoing research both to improve conventional travel behavior models and to develop and apply some of the emerging concepts such as activity choice analysis, gaming, and simulation data collection and analysis. Therefore, this project examined state-of-the-art issues in travel behavior research and incorporated some of the important findings into the qualitative analysis procedures.

The quantitative forecasting system is based on an incremental approach to both work and nonwork trip estimation. This approach facilitates estimation by hand, with a hand calculator, or with a small computer program.

The traveler classification aggregation approach for the work trip logit model consists of six classes defined in terms of trip distance and choice set availability. The small number of classes makes data requirements fairly small. Similarly, the linear form of the nonwork trip model is conducive to easy and economical application.

The forecasting system was applied to four fuel shortfall scenarios. The outputs of the system are plausible. Furthermore, they are generally consistent with the gasoline shortfall and price levels established independently in the definitions of the scenarios. Thus, the forecasting system appears to perform well in analyzing short-run travel responses to fuel supply limitations.

Quantitative results must be supplemented with insights from qualitative analysis. Because there is little direct experience with fuel supply limitations (and no recent experience with major disruptions) and fundamental behavioral research is still developing, there is a great deal of uncertainty in analyzing the impacts of fuel shortage situations. Sensitivity analysis, which was used with the work trip scenario tests, is one way to deal with uncertainty in this analysis. For other impacts (e.g., the assessment of long-run impacts such as residential location choices), practical quantitative analysis is very difficult because of model complexity, lack of data, or other factors. In these cases, qualitative analysis can yield important insights into impacts that are difficult to address, but should not be ignored.

The qualitative analysis approach used in this report was to use sources such as basic theoretical concepts, existing models, and empirical evidence to establish the range of possible outcomes for various phenomena related to fuel supply limitations. For example, survey data collected during previous energy shortfall periods can be used to establish patterns of adjustments in travel behavior not easily uncovered by existing models. Similarly, studies of residential location decisions provide some evidence on the likely residential location consequences of gasoline price increases and/or supply limitations.

In summary, travel behavior responses to energy supply and price conditions are very complex phenomena that require continuing fundamental research. However, because practical decision-making cannot be delayed by the lack of complete information, it is important that the available approaches for comprehensive analysis be identified and illustrated. The combination of the quantitative forecasting system for work and nonwork travel and qualitative analysis of other impacts has been motivated by these considerations.

SUGGESTED RESEARCH

Recommendations for further research are organized into three major categories: (1) applications, (2) improvements to existing approaches, and (3) fundamental research.

Applications

The approaches developed in this report have been tested with hypothetical case examples. Further testing of the approaches with case studies from actual urban areas would be an important demonstration of the capabilities of the methodology and the usefulness of the results produced by the procedures.

A case study would address issues such as the availability of suitable existing data, the practicality of collecting new data, the specification of energy shortfall scenarios for the particular urban area in question, the performance of the quantitative forecasting system, and the usefulness of the material in this report for qualitative analysis.

A case study could be performed either as a special demonstration with a cooperating region or as part of an ongoing transportation energy conservation planning activity. In either case, the results should be disseminated widely. Ideally, the approaches presented in NCHRP Project 8–23 should be compared to other approaches in terms of reliability, data requirements, and the like.

Improvements in Existing Methods

Although existing models, such as those used in this study, appear to be quite useful in energy policy analysis, research should continue on model improvements. Two important activities are the use of more recent data and the testing of alternative model specifications.

Almost all well-known travel behavior models are estimated with data that are at least 10 years old. This results in application of behavioral relationships established during a period of declining real energy prices to periods of price increases and supply shortages. This fact may introduce the danger of extending the models beyond their reasonable ranges.

Fortunately, the long awaited Baltimore Disaggregate Data Set and the new Nationwide Personal Transportation Survey, both 1977 data, have recently become available and have received limited research use. These data sets would allow the reestimation of existing models with post-1973–1974 oil embargo data. Other data sets might include conventional transportation surveys conducted after the 1973–1974 gasoline shortage. This activity would be an important test of the reliability of existing models in new situations and might also serve as a test of the temporal stability of travel behavior models.

Alternative specifications should also be considered. For example, the nonwork transit trip equation used in the quantitative analyses might be modified so that private vehicle VM and/or level-of-service characteristics affect transit travel. Also, nonlinear functional forms for the independent variables in travel behavior models might be considered.

New Approaches

In addition to research resulting in modifications to existing methodology, fundamental research should proceed on some of the newer approaches to understanding travel behavior. As illustrated in Chapter Three, information from this type of research already can be used in qualitative analysis, and newly emerging concepts should continue to be incorporated into both quantitative and qualitative approaches.

Promising areas of research include both substantive areas and data collection and analysis procedures. The former category includes analysis of complex travel patterns (trip chaining), nonmotorized modes, and travel behavior under resource constraints. Studies of time allocation to daily activities also may be relevant. These research areas are discussed in Appendix D.

Newer methodological approaches include gaming and laboratory simulation methods and the use of attitudinal survey data to analyze responses to previous or potential fuel supply shortages. The use of these approaches was described and illustrated in Chapter Three. Appendix E presents guidelines for collecting data of this nature.

Basic research of this nature has the potential to develop better explanations of the motivations for travel. These insights could be very valuable in analyzing new situations (e.g., severe constraints to travel or attractive alternatives to travel, such as telecommunications).

Finally, the availability of high quality data collected during fuel shortage periods would contribute to better understanding of the effects of fuel supply limitations on passenger travel. Systematic identification and analysis of data available from the 1979 gasoline shortage (and, perhaps, the 1973–1974 shortage) would be a useful first step. In addition, data collection efforts should be designed for rapid implementation at the onset of any future fuel shortages. Data collection activities, such as those described in Appendix E, would provide information for monitoring the performance of the transportation system during the shortfall. In addition, definitive explanations of travel behavior during periods of fuel supply limitations can only be completely developed with empirical evidence on actual behavior during such periods.

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APPENDIX A

SCENARIO DEFINITIONS

The energy shortfall scenarios developed in this study are defined in terms of variables characterizing the fuel markets. Government policies implemented to control fuel distribution and prices in response to energy supply

shortages are also important features of long-run energy scenarios. This appendix presents a brief overview of the transportation fuel market. Projections of key variables that define the baseline (nonshortage) against which energy shortfalls are considered and described. The energy shortfall scenarios are defined. Finally, government contingency planning actions in response to energy shortfalls are presented.

TRANSPORTATION FUEL MARKET

The Supply of Crude Oil

The most important single cause of current oil price increases and temporary shortages is the behavior of the OPEC members in producing, pricing, and distributing crude oil. Popular opinion notwithstanding, the major oil companies have had relatively modest roles over the past 10 years in setting world oil prices and controlling crude oil production. (This point was made forcefully by Adelman (*A-1*) and is even more true today. See also Stoubaugh and Yergin (*A-2*). Moreover, it can be demonstrated that over the long run urban transportation planning horizon (e.g., 20 years), total world resource constraints are much less important than the behavior of oil producing countries in determining crude oil supply and price.

The following subsections highlight the issues of oil availability and OPEC behavior. This serves two purposes: first, it sets the framework for gasoline price forecasts and energy shortfall scenarios; second, it provides background for understanding the limitations and impacts of government involvement in transportation fuels markets.

Resource Availability

The endowment of oil in the earth's crust is limited, but it is not likely to be a constraint on consumption for the remainder of this century. In order to test this hypothesis, an analysis performed by Adelman (*A-3*) in 1976 is presented. This test makes liberal assumptions about demand and conservative assumptions about resource availability in order to show that physical constraints to oil production are much less important than institutional constraints.

The trend in oil markets has been for oil prices to rise, causing less consumption than would otherwise have occurred. In fact, since 1973, world oil production, including communist countries, has increased at less than 2 percent per year, which is well below the post-World War II experience (*A-4*).

As shown in Figure A-1, cumulative oil consumption of the noncommunist world can be liberally assumed to be 540 billion barrels from 1980 to 2000. This figure results from a relatively high autonomous growth rate of 5.8 percent (the growth rate that would have occurred if oil prices remained at pre-1973 levels); a low, assumed long-run price elasticity of —0.3 (most uses of oil seem to have long-run elasticities closer to minus unity); and a price of oil equal to $30 per barrel, in 1979 constant dollars, by the year 2000. (If the supply is running out faster, this price should be higher.) The effect of these

CUMULATIVE CONSUMPTION 1980–2000 → 540 billion bbl.

ASSUMES: Autonomous Demand Growth = 5.8%

Long Run Demand Elasticity = —0.3

Average Annual Price Increase = 7% (1973–2000)

THEN: Average Annual Consumption Growth = 3.7% (that is $1.058 \times (1.07)^{-.3} - 1$)

Cumulative Consumption = 540 billion bbl. (that is $17.5 \int_1^{21} e^{.03t}\, dt$ where 17.5 billion bbl. is estimated 1979 consumption)

EXPECTED RESERVES → 1600 billion bbl.

INCLUDES: Proved Reserves in Known Reservoirs = 600 billion bbl.

Additions in Known Reservoirs = 400 billion bbl.

Expected Discoveries (1980–2000) = 600 billion bbl.

EXCLUDES: Deep Offshore, Unexplored (1250 billion bbl.)

Secondary and Tertiary Recovery (50% of oil in place)

Shale, Tar Sands and Coal

Figure A-1. Noncommunist oil availability under worst case assumptions. (Sources: Adelman (A-3) *and Ref.* A-4)

assumptions is a relatively high growth rate of consumption at about 3.7 percent and a cumulative consumption of 540 billion barrels through the rest of this century.

On the supply side, conservative estimates of resources available in noncommunist countries are about 1600 billion barrels, which is about three times consumption over this period. This excludes such nontraditional oil sources as deep offshore deposits, secondary and tertiary recovery, shale and tar sands. Thus, geological resource availability is not likely to be a major constraint over the next two decades.

OPEC Behavior

Though overall resource availability is not a major problem, the geographic distribution of these resources has been, and is likely to continue to be, the major source of domestic energy availability constraints. To oversimplify somewhat, the concentration of economically minable reserves in a relatively small number of countries has had two somewhat related effects: first, it allows the formation of a viable cartel that can set prices at monopolistic levels; second, short-run disruptions in supply to the United States are likely from time to time because of the political instability in the areas holding substantial economically minable reserves.

There are three major factors that need to be considered in transportation fuel price and availability scenarios:

1. OPEC has sufficient market power to set oil prices at high levels over the foreseeable future.
2. The largest oil-producing members of OPEC are politically unstable and can cause short-term disruptions in domestic crude oil supplies.
3. Domestic government involvement in the crude and refined oil product markets causes further uncertainty in gasoline allocation and cost to consumers.

All of these factors are interrelated, but an attempt will be made to discuss each separately. The first two aspects of OPEC behavior are presented next. The third factor, governmental policies, is discussed in a later section of this appendix.

OPEC's Price Setting Behavior

The market behavior of OPEC has become reasonably apparent over the past decade. Briefly stated, crude oil price and production levels are set in such a way as to maximize their long-run profits. Though many factors can go into the decision as to what price level will be set, a rough approximation of the long-run price of crude oil is that price at which alternative plentiful sources of energy are foreclosed from the market. That is, OPEC tends to price somewhat below the cost of domestic synthetic crude oil products such as shale oils and coal liquefaction. The particular level at which they will set the price also depends on other factors such as their internal financial discount (or interest) rate, the anticipated lead times needed to bring alternative fuels onstream, the elasticity of demand for oil generally, and the cost to the countries of finding and exploiting reserves to replace those now being depleted.

From the standpoint of transportation planning, it is reasonable to presume that OPEC will persist in maintaining high price levels over the planning horizon of most state and local authorities. Though prices may fluctuate, historically there has been sufficient discipline among members to restrain supplies and thereby ensure that prices well above the costs of production will be maintained. This condition will probably obtain as long as Saudi Arabia has large amounts of excess capacity. The Saudi Arabians can enforce adherence to established OPEC production limits because they have the capacity to erode the market share of any other member that would increase output beyond these mutually agreed upon limits.

Under conditions of political stability among OPEC countries and nongovernmental interference in the United States, one could assume that oil would be continuously available through the end of this century albeit at a high price. Supply disruptions are not inherent in the functioning of a cartelized market but are, rather, the result of political factors.

Crude Oil Supply Disruptions

Restrictions in oil supply, resulting recently in lines at gas stations, have always arisen out of political crises in the Middle East. This syndrome of supply instability dates back to the closing of the Suez in 1956, which created a tanker shortage due to the longer hauls of crude and residual oil around the Cape. With the decline of domestic production and refining reserve capacity in the late 1960s, temporary disruptions in the Middle Eastern fields recently have been translated quickly into domestic refined product shortages.

Current analyses of the institutional framework within and among Middle East countries indicate that this pattern of instability should continue through the indefinite future (*A-2*). As a working hypothesis, transportation planners should anticipate that supply disruptions, as occurred in 1973–1974 and in 1979, will continue to occur periodically. Though the magnitude and timing of such episodes is not knowable, the following seems to have been the pattern:

1. Revolutions and wars causing temporary oil stoppages from major fields occur about every 5 to 6 years.
2. Taking up to 3 months for some amount of supply relief, usually in the form of extra production from nonaffected fields, to overcome the supply shortage.
3. The cartel using this period to institute an upward adjustment in oil prices.
4. The supply-demand gap created during a shortage resulting more from the secular increase in demand than from there being an absolute decline in imports. Stated another way, there is usually only a modest decline in imports and this is smaller than the increase in demand. Thus, the energy emergency is caused less by an absolute decline in oil availability and more by oil supplies not keeping up with the demand growth that would have occurred at preshortage prices.

Given that the foregoing characterization of energy emergencies is based on relatively few observations, it is quite possible that disruptions that occur in the future will be somewhat different. Of greatest concern would be shortages that occur with more frequency, last longer, and are of greater magnitude. Each of these three parameters is discussed in the following.

Frequency. At this time, there is very little information on the frequency of those episodes that will lead to supply cutoffs. Certainly, political unrest is the rule rather than the exception in the Middle East, even though many, if not most, political disruptions do not lead to decreased oil production. At this time, the best estimate of frequency of occurrence of shortages as happened in 1979 is about once every 5 years.

Duration. The duration of a shortage depends on the length of time it takes to increase production in alternative oil fields in such magnitude as to offset the lost production in the disrupted area. Over the next several years there appears to be sufficient extraction capacity, especially in Saudi Arabia, to make up for the lost production in any other single field. Whether there is sufficient refining capacity or whether there will be sufficient extraction capacity in the 1990s to provide such a reserve margin is an open question. Also, there appears to be little short-run margin to counteract a potential Saudi Arabian cutoff. Although Saudi Arabia has been viewed as a stabilizing

influence in international oil politics, there is a real possibility that internal strife could cause a major oil disruption in that country sometime between now and the year 2000. In summary, it is likely that any isolated shortage will last less than 3 months, but that either a disruption with less than adequate excess extraction and refining capacity or a disruption in Saudi Arabia is a significant possibility sometime over the next 20 years.

Magnitude. The actual shortfall between supply and demand at preshortage prices is also very difficult to forecast. Moreover, there has been little analysis on why gasoline shortfalls appear to be more severe in some states rather than others and why some states have shortfalls at different times from others. Crude oil shortages have been difficult to document and, in fact, world crude production increased during 1979 when there was a domestic shortage. (The first half of 1979 average noncommunist oil flow was 5.8 percent higher than the same period in 1978 (*A-4*).) However, most of this increase came from the Saudi Arabians who anticipated the shortage caused by the Iranian revolution. Other producing countries were straining their capacity to make up for the Iranian shortfall. In the absence of sufficient backup capacity that can come on-stream in anticipation of a supply disruption, the severity of shortfalls could increase in the future. Also, if Saudi Arabian production were cut, the impact on world oil supplies would be particularly severe. In general, the same issues that affect the duration of supply disruptions also affect their magnitude. Consequently, a crude oil shortage triggering gasoline shortages typically would be as severe as or less than that which occurred in 1973–1974 and 1979, unless the shortage was caused by a Saudi Arabian cutoff or the shortage happened when there was already little excess capacity. Although the likelihood of any particular shortage being of greater magnitude than previous experience is small, there is a significant chance that a more major shortfall could occur within the next two decades.

BASELINE PROJECTIONS

Baseline projections are developed for two scenarios: the base case and increasing conservation. The base case represents an extension of trends established in the last 5 years. This scenario assumes that awareness of the energy problem will remain fairly stable. Travelers' behavior will be based on expectations of periodic energy shortages and a continuation of recent gasoline price trends. The increasing conservation scenario assumes that although the private vehicle will be the dominant mode for personal travel, increasing awareness of the energy problem and willingness to conserve gasoline will lead to revised vehicle purchasing behavior. Consumers are expected to purchase more fuel-efficient vehicles. It is also assumed that because of consumer awareness of the differential between certified and on-road fuel economy, vehicle purchasing decisions will be based on desired on-road fuel economy. To represent this scenario, on-road fuel economy for both autos and light trucks after 1985 is projected to increase at a rate 50 percent greater than the rate of improvement between 1975 and 1985.

For each scenario, projections are provided through year 2000 for personal automobile on-road fuel economy, personal automobile fleet size, personal light truck on-road fuel economy, personal light truck fleet size, average personal vehicle on-road fuel economy, personal vehicle fleet size, and average operating costs for the fleet. Projections for fuel economy and fleet size for the base case scenario and for the conservation scenario are given in Tables A-1 and A-2, respectively. Projections for operating costs are given in Tables A-3 through A-6. Descriptions of the scenarios are provided in the following.

Personal Automobile On-Road Fuel Economy

Base Case Scenario

The TECNET base case projected certified fuel economy for the automobile stock in 1985 and 2000 is 22.0 and 27.3 miles per gallon (9.53 and 11.61 kilometers per liter (kpl), respectively (*A-5*). On-road fuel economy has been shown to be lower than certified fuel economy. Hence, the projections for certified fuel economy are adjusted to obtain on-road fuel economy as follows (*A-6*):

$$\frac{1}{\text{On-road mpg}} = 0.76 * \frac{1}{\text{Rated mpg}} + 0.0237 \qquad \text{(A-1)}$$

where mpg is miles per gallon; and rated mpg is certified fuel economy. The projected on-road fuel economies for 1985 and 2000 are 17.17 and 19.4 mpg (7.30 and 8.25 kpl), respectively.

There is some controversy over the discrepancy between rated and on-road fuel economy. McNutt's (*A-6*) equation produces a fairly large gap that grows as rated mpg increases. The estimated discrepancies are even larger than those estimated in his previous work. However, other work has produced much smaller discrepancies. For example, the New York State Department of Transportation (*A-7*) has produced fuel economy projections based on an assumption that on-road fuel economy averages 89.3 percent of rated fuel economy.

The use of a more optimistic relationship between on-road and rated fuel economies would certainly produce different private vehicle fuel economies and transportation fuel consumption estimates. However, for any particular year, the percentage reduction in fuel consumption resulting from fuel supply restrictions probably is not very sensitive to the assumed on-road fuel economy. Of course, the base levels and the absolute amounts of reduction are clearly sensitive to the fuel economy assumptions.

In 1975 the observed on-road fuel economy for the automobile stock was 13.52 mpg (5.75 kpl) (*A-8*). Projected fuel economy for years 1979 through 1984 is obtained by assuming a constant annual rate of growth in fuel economy as follows:

$$\text{On-road MPG}_t = 13.52\left(\frac{17.17}{13.52}\right)^{\frac{t-75}{10}} \qquad \text{(A-2)}$$

where $t = 79, \ldots, 84$. Similarly, projected fuel economy for 1990 and 1995 is obtained by assuming constant annual growth as follows:

TABLE A-1

ON-ROAD FUEL ECONOMY PROJECTIONS—BASE CASE

	Personal Autos		Personal Light Trucks		Personal Vehicle Fleet	
Year	On-Road Fuel Economy* (Miles per Gallon)	Fleet** (Millions)	On-Road Fuel Economy+ (Miles per Gallon)	Fleet+ (Millions)	On-Road Fuel Economy++ (Miles per Gallon)	Fleet# (Millions)
1975 ##	13.8	84.8	12.2	10.3	13.6	95.1
1979	14.9	90.8	13.5	13.6	14.7	104.4
1980	15.2	92.4	13.8	14.6	15.0	107.0
1981	15.6	94.0	14.1	15.7	15.4	109.7
1982	16.0	95.6	14.5	16.8	15.8	112.4
1983	16.4	97.2	14.9	18.1	16.1	115.3
1984	16.8	98.9	15.2	19.4	16.5	118.3
1985	17.2	100.6	15.6	20.8	16.9	121.4
1990	17.9	107.3	17.0	22.6	17.7	129.9
1995	18.6	113.5	17.7	25.4	18.4	138.9
2000	19.4	113.9	18.4	26.9	19.2	145.8

*Based on TECNET Base Case projections for 1985 and 2000 certified fuel economy (A5) and McNutt's (A9) adjustment to on-road fuel economy.

**1985, 1990, 1995, 2000 projections from Knorr and Millar (A8).

+Projections from Knorr and Millar (A8); On-road fuel economy updated to reflect McNutt's (A9) latest findings.

$$^{++}\text{Fleet MPG} = \left(\frac{\text{Fleet Autos}}{\text{Auto MPG}} \quad \frac{\text{Fleet Light Trucks}}{\text{LightTruck MPG}} \Big/ \text{Fleet Autos} + \text{Fleet Light Trucks}\right)^{-1}$$

#Personal vehicle fleet is equal to the sum of the personal automobile and personal truck fleets.

##1975 data are observed (A7).

Note: 1 mile per gallon = .425 kilometers per liter.

$$\text{On-road MPG}_t = 17.17\left(\frac{19.4}{17.17}\right)^{\frac{t-85}{15}} \qquad \text{(A-3)}$$

where $t = 90, 95$. These projections are given in Table A-1.

The personal use automobile fleet differs from the automobile stock in several ways that may affect fuel economy. Personal use automobiles tend to be older, smaller, and less intensively used. In 1975, the on-road fuel economy for personal use automobiles was 13.79 miles per gallon (5.86 kpl) (*A-8*). Knorr and Millar (*A-8*) project that the difference between on-road fuel economy for the personal use auto fleet and the automobile stock will decrease over time. In the year 2000 the personal fleet fuel economy is projected to be less than one-half of 1 percent larger than the automobile stock fuel economy. Therefore, the difference in fuel economy is ignored in this analysis.

Conservation Scenario

This scenario assumes that after 1985 the average annual rate of improvement in on-road fuel economy will be 50 percent greater than the rate between 1975 and 1985. The average annual rate between 1975 and 1985 is equal to:

$$\left(\frac{17.17}{13.52}\right)^{1/10} = 0.0242 \qquad \text{(A-4)}$$

After 1985, the rate of improvement is assumed to be 0.0363. On-road fuel economy of personal automobiles after 1985 is projected as follows:

$$\text{On-road MPG}_t = 17.17\ (1.0363)^{t-85} \qquad \text{(A-5)}$$

where $t = 90, 95, 100$. These projections are given in Table A-2.

Personal Automobile Fleet Size

In 1975, the personal automobile fleet was comprised of 84.8 million in-use vehicles. (This estimate differs from the number of vehicles registered in 1975 (106.5 million) because of nonpersonal use vehicles, scrappage during the year, and multiple registrations because of used car sales.) Knorr and Millar (*A-8*) provide projections of the personal automobile fleet for 1985, 1990, 1995, and 2000. The personal automobile fleet for 1979 through 1984 is projected by assuming constant annual growth as follows:

$$\text{Fleet}_t = 84.8\left(\frac{100.6}{84.8}\right)^{\frac{t-75}{10}} \qquad \text{(A-6)}$$

where Fleet_t is the size of the personal auto fleet in millions; 100.6 is the projected fleet size in 1985; and t is 79, . . . , 84. These projections appear in Table A-1.

TABLE A-2

ON-ROAD FUEL ECONOMY PROJECTIONS—CONSERVATION SCENARIO

Year	Personal Autos: On-Road Fuel Economy* (Miles per Gallon)	Personal Autos: Fleet** (Millions)	Personal Light Trucks: On-Road Fuel Economy*** (Miles per Gallon)	Personal Light Trucks: Fleet† (Millions)	Personal Vehicle Fleet: On-Road Fuel Economy†† (Miles per Gallon)	Personal Vehicle Fleet: Fleet††† (Millions)
1975#	13.8	84.8	12.2	10.3	13.6	95.1
1979	14.9	90.8	13.5	13.6	14.7	104.4
1980	15.2	92.4	13.8	14.6	15.0	107.0
1981	15.6	94.0	14.1	15.7	15.4	109.7
1982	16.0	95.6	14.5	16.8	15.8	112.4
1983	16.4	97.2	14.9	18.1	16.1	115.3
1984	16.8	98.9	15.2	19.4	16.5	118.3
1985	17.2	100.6	15.6	20.8	16.9	121.4
1990	20.5	107.3	18.7	22.6	20.2	129.9
1995	24.5	113.5	22.5	25.4	24.1	138.9
2000	29.3	118.9	27.1	26.9	28.9	145.8

*Annual rate of growth through 1985 is equal to 0.0242; after 1985 annual rate of growth is equal to 0.0363.

**1985, 1990, 1995, 2000 projections from Knorr and Millar (A8).

***Annual rate of growth through 1985 is equal to 0.0249; after 1985 annual rate of growth is equal to 0.0374.

†1985, 1990, 1995, 2000 projections from Knorr and Millar (A8).

††
$$\text{Fleet MPG} = \left(\frac{\text{Fleet Autos}}{\text{Auto MPG}} + \frac{\text{Fleet Light Trucks}}{\text{Light Truck MPG}} \Big/ \text{Fleet Autos} + \text{Fleet Light Trucks}\right)^{-1}.$$

†††Personal vehicle fleet is equal to the sum of the personal automobile and personal light truck fleets.

#1975 data are observed (A8).

Note: 1 mile per gallon = .425 kilometers per liter.

TABLE A-3

NATIONAL AVERAGE PUMP PRICE OF GASOLINE

(Cents per Gallon* in June 1979 Dollars)

Year	Pump Price
1979	86.24
1980	99.27
1981	110.84
1982	113.22
1983	115.66
1984	118.15
1985	120.71
1990	134.40
1995	149.79
2000	167.06

*1 cent per gallon = .26 cents per liter.

TABLE A-4

PERSONAL AUTOMOBILE OPERATING COSTS

(Cents per Mile* in June 1979 Dollars)

Year	Operating Costs**: Base Case	Operating Costs**: Conservation Scenario	Costs Excluding Gasoline†
1979	10.77	10.77	4.98
1980	11.69	11.69	5.16
1981	12.46	12.46	5.35
1982	12.62	12.62	5.54
1983	12.79	12.79	5.74
1984	12.98	12.98	5.95
1985	13.20	13.20	6.17
1990	14.88	13.93	7.37
1995	16.86	14.92	8.81
2000	19.14	16.23	10.53

*1 cent per mile = .62 cents per kilometer.

**Based on Tables A-1, A-2, A-3, and Column 4 of this Table.

†Costs included for repairs and maintenance, replacement tires, oil, and tax on tires based on FHWA operating cost data (A10).

Personal Light Truck On-Road Fuel Economy

Base Case

In 1975 the on-road fuel economy for the personal light truck fleet was 12.2 miles per gallon (5.17 kpl) (*A-8*). Knorr and Millar (*A-8*) provide projection of the on-road fuel economy for personal light trucks for 1985, 1990, 1995, and 2000. These projections were based on earlier work by McNutt (*A-9*). They were revised to reflect McNutt's most recent findings (*A-6*).

On-road fuel economy for 1979 through 1984 is projected by assuming a constant annual rate of improve-

TABLE A-5

PERSONAL LIGHT TRUCK OPERATING COSTS

(Cents per Mile* in June 1979 Dollars)

Year	Operating Costs** Base Case	Operating Costs** Conservation Scenario	Costs Excluding Gasoline†
1979	12.59	12.59	6.20
1980	13.66	13.66	6.47
1981	14.62	14.62	6.76
1982	14.89	14.89	7.06
1983	15.13	15.13	7.37
1984	15.46	15.46	7.69
1985	15.77	15.77	8.03
1990	17.88	17.16	9.97
1995	20.84	19.04	12.38
2000	24.46	21.54	15.38

*1 cent per mile = .62 cents per kilometer.

** Based on Tables A-1, A-2, A-3, and Column 4 of this Table.

† Costs included for repairs and maintenance, replacement tires, oil, and tax on tires based on FHWA operating cost data (A10).

TABLE A-6

PERSONAL VEHICLE OPERATING COSTS

(Cents Per Mile** in June 1979 Dollars)

Year	Operating Costs† Base Case	Operating Costs† Conservation Scenario	Costs Excluding Gasoline†
1979	11.01	11.01	5.14
1980	11.96	11.96	5.34
1981	12.75	12.75	5.55
1982	12.94	12.94	5.77
1983	13.18	13.18	6.00
1984	13.40	13.40	6.24
1985	13.63	13.63	6.49
1990	15.41	14.47	7.82
1995	17.60	15.68	9.46
2000	20.12	17.20	11.42

$$*COST_t = \frac{Pgas_t}{\text{Fleet MPG}_t} + \frac{\text{Fleet Autos}_t * \text{Auto OC}_t + \text{Fleet Light Trucks}_t * \text{Light Truck OC}_t}{\text{Fleet Autos}_t + \text{Fleet Light Trucks}_t}$$

**1 cent per mile = .62 cents per kilometer.

†Based on Tables A-1 through A-5 and Column 4 of this table.

ment between 1975 and 1985. The revised on-road personal light truck fuel economy projection for 1985 is 15.6 miles per gallon (6.63 kpl). Fuel economy in year t, where t = 79, . . . , 84, is calculated as follows:

$$\text{On-road MPG}_t = 12.2 \left(\frac{15.6}{12.2}\right)^{\frac{t-75}{10}} \qquad \text{(A-7)}$$

These projections appear in Table A-1.

Conservation Scenario

Between 1975 and 1985 the average annual rate of improvement in personal light truck on-road fuel economy is equal to:

$$\left(\frac{15.6}{12.2}\right)^{1/10} = 0.0249 \qquad \text{(A-8)}$$

Under this scenario, the rate of increase after 1985 is assumed to be 50 percent greater (i.e., 0.0374). On-road fuel economy after 1985 is projected as follows:

$$\text{On-road MPG}_t = 15.6(1.0374)^{t-85} \qquad \text{(A-9)}$$

where $t = 90$, 95, 100. The projections are given in Table A-2.

Personal Light Truck Fleet Size

In 1975 10.3 million light trucks were in personal use (*A-8*). Knorr and Millar (*A-8*) project the personal light truck fleet size for 1985, 1990, 1995, and 2000. To obtain projected fleet size for 1979 through 1984, constant annual growth between 1975 and 1985 is assumed as follows:

$$\text{Fleet}_t = 10.3 \left(\frac{20.8}{10.3}\right)^{\frac{t-75}{10}} \qquad \text{(A-10)}$$

where Fleet_t is the size of the personal light truck fleet in millions in year t; 20.8 is the projected size in millions for 1985; and t is 79, . . ., 84. These projections are presented in Table A-1.

Personal Vehicle On-Road Fuel Economy

To measure the average on-road fuel economy for the personal vehicle fleet, the harmonic mean of the personal automobile and personal light truck fleet is calculated as follows:

$$\text{Total fleet on-road MPG}_t = \left(\frac{\dfrac{\text{Auto fleet}_t}{\text{Auto MPG}_t} + \dfrac{\text{Light truck fleet}_t}{\text{Light truck MPG}_t}}{\text{Auto fleet}_t + \text{Light truck fleet}_t}\right)^{-1} \qquad \text{(A-11)}$$

where $t = 1975, \ldots, 2000$. Projections for the base case and conservation scenarios are given in Tables A-1 and A-2, respectively.

Personal Vehicle Fleet Size

The personal vehicle fleet size is the sum of the personal automobile and light truck fleets as follows:

$$\text{Total fleet}_t = \text{Auto fleet}_t + \text{Light truck fleet}_t \qquad \text{(A-12)}$$

where $t = 1975, \ldots, 2000$.

Personal Automobile Operating Costs

To calculate the costs of operating an automobile, costs for gasoline and oil, repairs and maintenance, and replacement tires are included. These costs are estimated by the Federal Highway Administration (*A-10*) for subcompact, compact, and standard cars as given in Table A-7. Taxes for registration and titling are excluded because they repre-

sent ownership costs rather than operating costs. Gasoline taxes are included in the pump price of gasoline and tax on oil is negligible. Tax on tires is relatively constant over time, assumed to be .03 cent per mile in June 1979 dollars.

Pump Price of Gasoline

The pump price of gasoline after 1979 is projected using the following formulas:

$$P_{1980} = (P_{1979}(1 + r)) + \tfrac{1}{2}\,\mathrm{DC} + \tfrac{7}{12}\,\mathrm{Tax}$$
$$P_{1981} = (P_{1979}(1 + r)^2) + \mathrm{DC} + \mathrm{Tax}$$
$$P_t = (P_{t-1} - \mathrm{Tax})\ (1 + r) + \mathrm{Tax}, \text{ for } t > 1981 \qquad \text{(A-13)}$$

where P is the average pump price of regular gasoline; r is the real annual rate of growth; DC is the impact of decontrol of domestic crude oil on the pump price; and tax is the impact of the import fee on the pump price expected to become effective in May 1980. (Since this was written there has been a court-ordered delay in implementing the import fee.)

The real growth rate for the pump price has been characterized by a saw-tooth pattern. Periods of rapid price increase, associated with supply disruptions, have been followed by periods of price stability or even decline. Rather than project pump prices based on this pattern, a smooth trend is predicted to represent the baseline projection. The trend rate is assumed to be equal to the average annual real rate of growth prevailing between 1969 and 1979. This rate is calculated below. The 1969 current price of gasoline is equal to 34.84 cents per gallon (9.20 cents per liter) (*A-10*). Thus, in June 1979 dollars, this price (the consumer price indices for 1969 and June 1979 are 109.8 and 215.4, respectively) is equal to

$$34.84 \times \left(\frac{215.4}{109.8}\right) = 68.35 \text{ cents per gallon}$$

The average 1979 pump price (in June 1979 dollars) is 86.24 cents per gallon (22.78 cents per liter) (based on the pump price for the week of July 3, 1979 (*A-11*)). The average annual growth rate between 1969 and 1979 is equal to:

$$\left(\frac{86.24}{68.35}\right)^{0.10} - 1 = 0.0235$$

The impact of decontrol is expected to add 11 cents per gallon (2.91 cents per liter) (in June 1979 dollars) by the end of 1981, relative to an extension of price controls. In 1980 the impact of decontrol is expected to be half the total impact, 5.5 cents (1.45 cents per liter), reflecting phased decontrol.

The recently announced import fee is expected to add 10 cents to each gallon in current dollars, or approximately 9.5 cents (2.51 cents per liter) in June 1979 dollars. Because the fee is expected to become effective in May 1980, the impact of the fee on average 1980 pump prices is only 5.5 cents ($\tfrac{7}{12} \times 9.5$) (1.45 cents per liter). Because both decontrol and the import fee represent a new direction in federal pricing policy, the growth rate is calculated excluding the effects of these policies on price. After 1981, however, it is assumed that the pump price is fully adjusted to reflect decontrolled prices. Hence, the annual growth rate is applied to a base price including the 11 cents increase. Because the import fee represents a tax and because decontrolled domestic crude prices are expected to rise to the price level of imported crude, the 9.5 cents (2.51 cents per liter) tax is added to the projected pump price in each year. The pump price projections are given in Table A-3.

TABLE A-7

MODEL YEAR 1976 OPERATING COSTS (EXCLUDING TAXES)—10-YEAR AVERAGE

Standard Size	(Cents Per Mile)*
Repairs and maintenance	3.67
Replacement tires	0.45
Gasoline	3.19
Oil	0.17
Total	7.48
Gasoline = 42.65% total cost	
Gas and oil = 44.92% total cost	
Total excluding gas and oil	4.12
Compact Size	
Repairs and maintenance	2.96
Replacement tires	0.39
Gasoline	2.28
Oil	0.17
Total	5.80
Gasoline = 39.3% total cost	
Gas and oil = 42.24% total cost	
Total excluding gas and oil	3.35
Subcompact Size	
Repairs and maintenance	2.66
Replacement tires	0.35
Gasoline	1.65
Oil	0.15
Total	4.81
Gasoline	
Gas and oil	
Total excluding gas and oil	3.01

*1 cent per mile = .62 cents per kilometer.

SOURCE: Transportation Systems Center, *National Transportation Statistics Annual Report*. Cambridge, Mass., Tables 41, 42, 43, pp. 105-107, September 1978.

Total Operating Costs

To represent average costs excluding gasoline, costs for compact cars are used. Costs excluding gasoline and oil

(in real terms) are assumed to increase at the average annual rate of increase between 1972 and 1976. This rate is equal to 0.037, as given in Table A-8. The real cost of oil is assumed to increase at the same rate as the pump price of gasoline, 0.0235 annually.

The 1976 operating cost excluding gasoline and oil is 4.23 cents per mile (2.63 cents per kilometer) in June 1979 dollars. Assuming an average rate of increase of 3.7 percent, 1979 operating cost excluding gasoline and oil is 4.72 cents per mile (2.93 cents per kilometer). The 1976 cost of oil per mile is 0.215 cents per mile (0.134 cents per kilometer) in June 1979 dollars. At an annual rate of increase of 2.395 per cent, the cost of oil in 1979 is 0.231 cents per mile (0.144 cents per kilometer). Tax on tires is assumed to remain constant at 0.03 cent per mile (0.019 cent per kilometer). Using these assumptions, the projected costs excluding gasoline through year 2000 are calculated as follows:

$$OC_t = 4.72(1.037)^{t-79} + 0.231(1.0235)^{t-79} + 0.03 \qquad \text{(A-14)}$$

where OC is cost excluding gasoline expressed in cents per mile; and t is 80, . . ., 100.

To estimate gasoline cost per mile, the pump price of gasoline (cents per mile) is divided by the personal automobile fleet on-road fuel economy (miles per gallon). Costs, excluding gasoline and total operating costs, for the base case and conservation scenarios are presented in Table A-4.

Personal Light Truck Operating Costs

Costs of operating a standard size automobile are assumed to represent costs of operating personal light trucks (see Table A-7). Costs (in real terms) excluding gasoline and oil are assumed to increase at the average annual rate of increase in these costs between 1972 and 1976 of 0.045, as given in Table A-9. The cost of oil in real terms is assumed to increase at the same rate as the pump price of gasoline, 0.0235. Tax on tires is assumed to remain constant in real terms at 0.03 cents per mile (0.019 cents per kilometer).

In June 1979 dollars, the 1976 costs of operating light trucks, excluding gasoline and oil, were 5.20 cents per mile (3.23 cents per kilometer). The 1976 cost of oil in June 1979 dollars was 0.215 cents per mile (0.134 cents per kilometer). 1979 costs, excluding gasoline and oil, were 5.94 cents per mile (3.69 cents per kilometer) and the 1979 cost of oil was 0.231 (0.144 cents per kilometer). Adding tax of 0.03 cents (0.019 cents per kilometer), operating cost, excluding gasoline, in 1979 was 6.20 cents per mile (3.85 cents per kilometer).

Operating cost excluding gasoline is calculated as follows:

$$OC_t = 5.94\ (1.045)_{t-79} + 0.213\ (1.0235)_{t-79} + 0.03 \qquad \text{(A-15)}$$

where OC is cost excluding gasoline expressed in cents per mile; and t is 80, . . ., 100. To estimate gasoline costs, the pump price is divided by the personal light truck on-road fuel economy. Total operating costs and cost excluding gasoline are given in Table A-5.

Personal Vehicle Operating Costs

To measure the average cost of operating personal vehicles excluding gasoline, the weighted average of operating cost excluding gasoline for personal automobiles and light trucks is calculated as follows:

TABLE A-8

TEN-YEAR AVERAGE COST OF OPERATING COMPACT SIZE AUTOMOBILE (EXCLUDING TAXES)

(Cents per mile* in 1978 Dollars)

Year	CPI For All Items (1967 = 100)	Operating Costs	Operating Costs Excluding Gasoline and Oil	Average Annual Increase In Costs Excluding Gasoline and Oil (percent)
1972	125.3	5.33	2.90	---
1974	147.7	6.13	3.11	3.6
1976	170.5	5.8	3.35	3.8
Four Year Average:				3.7

*1 cent per mile = .62 cents per kilometer.

SOURCES: Column 2: U.S. Department of Labor, Bureau of Labor Statistics, Handbook of Labor Statistics, p. 241, 1976. Columns 3 and 4 Transportation Systems Center, National Transportation Statistics, Annual Report. Cambridge, Mass., Tables 36, 39, 42, pp. 100, 103, 106, September 1978.

$$OC_t = \frac{\text{Fleet autos}_t{*}\text{Auto } OC_t + \text{Fleet light trucks}_t{*}\text{Light truck } OC_t}{\text{Fleet autos}_t + \text{Fleet light trucks}_t} \quad \text{(A-16)}$$

where OC is average operating cost excluding gasoline for the personal vehicle fleet, and t is 1979, . . ., 2000. Average gasoline cost for the personal vehicle fleet is a function of the harmonic mean on-road fuel economy (see Tables A-1 and A-2) and the pump price of gasoline. Cost is calculated as follows:

$$\text{Cost}_t = \left(\frac{P_{\text{gas}_t}}{\text{Fleet MPG}_t}\right) + OC_t \quad \text{(A-17)}$$

where Cost_t is average total operating cost for the personal vehicle fleet; P_{gas} is the pump price of gasoline; fleet MPG is the harmonic mean on-road fuel economy for the personal vehicle fleet; OC is the weighted average operating cost excluding gasoline for the personal vehicle fleet; and t is 1979, . . ., 2000. Both total operating cost and cost excluding gasoline are presented in Table A-1.

TABLE A-9

TEN-YEAR AVERAGE COST OF OPERATING STANDARD SIZE AUTOMOBILE

(Cents per mile* in 1976 dollars)

Model Year	CPI for All Items (1967=100)	Operating Costs	Operating Costs Excluding Gasoline and Oil	Average Annual Increase in Costs Excluding Gasoline and Oil (Percent)
1972	125.3	6.31	3.46	--
1974	147.7	7.55	3.83	5.2
1976	170.5	7.48	4.12	3.7
Four Year Average:				4.5

*1 cent per mile = .62 cents per kilometer.

SOURCES: Column 1: U.S. Department of Labor, Bureau of Labor Statistics, Handbook of Labor Statistics, p. 241, 1976.

Column 2: Transportation Systems Center, National Transportation Statistics, Annual Report. Cambridge, Mass., Tables 35, 38, 41, pp. 103, 105, September 1978.

ENERGY SHORTFALL SCENARIO

Six fuel supply price and shortage scenarios are presented in this section. These scenarios are defined in terms of the following variables: (1) pump price of gasoline; (2) magnitude of shortage (percent shortfall); (3) duration of shortage; (4) frequency of shortage; and (5) governmental allocation actions.

These scenarios are designed to establish alternative "base cases" to be used in analyzing the effects of fuel supply limitations on passenger travel. That is, for a state or local official or planner, the scenarios establish possible alternative futures determined by market forces and actions of higher levels of government. These scenarios are the exogenously set contexts for analyses of likely actions available to state and local governments in the form of contingency plans using the forecasting system of this project. (See App. C for a description of the forecasting system.) These local actions would, in turn, affect the market by altering the demand for gasoline and therefore lead to a change in the price of gasoline and ration coupons.

The approach is, of course, not new. For example, Dorfman and Harrington (*A-12*) assumed a shortfall of 7 percent as a base case and then analyzed the costs and benefits of governmental actions to reduce the shortfall. However, the scenarios here consider higher shortfall levels. These scenarios also differ from those considered by the National Academy of Sciences (*A-13*) in that the former focus on price, shortfall levels, and government actions, while the NAS scenarios emphasize only economic variables such as fuel prices and income levels. This is because the purpose of the scenarios in this report is to establish alternative shortage environments, while the NAS report establishes alternatives with no shortfalls assumed.

Because fuel shortfalls are key to the scenario definitions and to the entire project, the term "shortfall" should be clearly defined for the immediate purposes of this study. A shortfall can thus be defined to occur when the amount of fuel available is less than the normal amount, which can be estimated through the use of projections such as those presented earlier or in similar studies (i.e., *A-8*). This definition differs from that implicit in economic analysis. For example, if gasoline pump prices were decontrolled during a shortage period, supply and demand would eventually equilibrate at a higher price. Hence, although there would be no shortage as defined by the difference between supply and demand, there would be a shortage as defined by the difference between the otherwise "normal" and the resulting "equilibrated" fuel supplies made available through demand and supply responses to higher prices.

In the following subsections, the scenario definitions and assumptions are presented. Then, the interactions among shortage levels, price levels, and governmental actions are discussed. Because of its prominence in current federal legislation, particular attention is given to the operation of white markets for ration coupons. Finally, estimates for the pump price of gasoline (and the price of ration coupons) under each shortfall scenario are presented.

SCENARIO DEFINITIONS AND ASSUMPTIONS

Six scenarios, defined in terms of alternative assumptions for five criteria (pump price, shortage magnitude, shortage duration, shortage frequency, and government allocation) are given in Table A-10. Each of the five criteria is discussed in turn in the following.

Pump Price

Both a low and a high price are assumed in Table A-7 in order to bound the likely range of values for gasoline pump price. The low value is based on the assumption that the average annual rate of increase in gasoline prices for the

TABLE A-10

DEFINITIONS OF THE SCENARIOS

	Pump Price	Shortage Assumptions: Magnitude (Percent)	Duration*	Frequency	Government Allocation
A	Low	10-15	3 months	5-year intervals (1985, 1990, 1995, 2000)	Actions that do not involve price decontrol taxes, or rationing**
B	High	10-15	3 months	5-year intervals	Decontrolled pump price
C	Low	20-25	3 months	10-year intervals (1990, 2000)	Rationing with white markets
D	High	20-25	3 months	10-year intervals	Rationing with white markets
E	Low	20-25	1 year	1990	Rationing with white markets
F	High	20-25	1 year	1990	Rationing with white markets

*For scenarios where rationing is implemented, duration refers to the period during which rationing is in effect.

**These actions likely include measures used in previous shortages such as the odd-even gasoline sales plan and Sunday gasoline sales ban as well as some of the actions described in the Standby Federal Emergency Energy Conservation Plan (DOE, (A17). These actions include: 1) public information; 2) minimum fuel purchase requirements; 3) odd-even; 4) employer-based commuter and travel measures; 5) speed limit enforcement; 6) compressed work week; 7) vehicle use sticker plan; and 8) recreational vehicle use restrictions.

last 10 years will continue through the year 2000. It is assumed that real gasoline prices (in June 1979 dollars) increase at the average historic rate (1969–1979) of 2.35 percent per year from a base of $0.8624 ($0.2278 per liter) for regular gasoline. (This is an average rate of increase. The historical pattern has been years of real price increase followed by periods of constant or slightly declining real prices. Hence, in using the average rate of increase, a smooth trend is predicted for future prices rather than the more likely saw-tooth pattern.) The anticipated effects of decontrol of domestic petroleum and the recently announced petroleum import tax on the pump price are also included. By the year 2000, this results in a real price increase of about 94 percent over June 1979.

The high values are assumed to equal the price that would prevail in a free market (pump price of gasoline decontrolled). In order to derive the market-clearing price, it is assumed that the price will rise above the low (controlled) value to the point at which demand (determined by the demand associated with the controlled price) is reduced to meet the level supplied (determined by the quantity demanded at the controlled price and the shortfall assumed). An immediate price adjustment is assumed to the supply level for analytic convenience. In reality, because of imperfect information and lags in behavioral adjustments, there will be a lag between the supply shortfall and price adjustment. However, it is assumed that the short-run equilibrium price will be attained within the shortage period duration.

Given the price elasticity of demand and assumption that supply is fixed in the short run, the market-clearing price can be calculated. Assume a linear relationship between price and demand and solve for price as follows:

$$P_1 = P_0\left(1 - \frac{S}{\eta}\right) \qquad \text{(A-18)}$$

where S is the shortfall level (expressed as a decimal function); P_0 is the low (controlled) price; P_1 is the market-clearing price; and η is the price elasticity.

The linear demand relation can be compared to the multiplicative relation used by Dorfman and Harrington (*A-12*). Their alternative expression for the market clearing price is:

$$P_1 = P_0(1 - S)^{1/\eta} \qquad \text{(A-19)}$$

For small shortfalls, the linear and multiplicative formulas yield similar results. However, for shortfalls in the ranges considered in the scenarios, the multiplicative formula is much more sensitive to shortfalls. For example, a price elasticity of −0.15 to −0.20 and a 20 percent shortfall imply a price increase of 2 to 2.33 times the controlled price, if the linear relation is assumed. With the multiplicative formula, the corresponding multipliers range from 3.05 to 4.43. Because the price increases implied by the linear relation appear to correspond more closely to those generated in other analyses of fuel shortages, the linear analysis is used. (On the basis of prevailing gasoline price levels, elasticity estimates in the range −0.1 to −0.2, and assumed shortages in the 15 to 25 percent range, a number of sources have reported coupon price levels under rationing with white markets that are consistent with the linear demand relation (*A-14*; *A-15*; *A-16*). The coupon price level can be shown to be equal to the price increase resulting from decontrol.)

Shortage—Magnitude

Table A-10 shows shortfalls of two magnitudes: 10 to 15 percent and 20 to 25 percent. The discussion of the magnitude of future shortfalls presented earlier concluded that a repeat of the 1973–1974 crisis was most likely. A shortfall of 10 to 15 percent is similar to that experience. For two reasons, a more severe shortfall of 20 to 25 percent is also considered. First, the current legislation provides for rationing at shortages of at least 20 percent; hence, this scenario allows one to consider realistically the impacts of rationing. Second, one has not yet faced a shortage of this magnitude and therefore there is greater uncertainty surrounding the impacts of such an energy future. The use of scenarios allows the evaluation of this uncertainty. Moreover, current developments in the Middle East (foreign policy of the current government in Iran and its internal problems, and the growing tension between the United States and many OPEC nations) indicate that a shortfall of this magnitude is more likely than had been previously anticipated.

Scenarios with relatively minor shortfalls of less than 10 percent are not explicitly considered. Such scenarios would be similar to the 10 to 15 percent shortfall, with a lower level of conservation actions. There is less uncertainty regarding the results of this scenario because such a

shortfall has been experienced in recent history (spring 1979).

Shortage—Duration

Following the reasoning established earlier, shortages lasting 3 months are assumed in the scenario of lesser magnitude in Table A-10. In addition, a sustained shortage lasting 1 year is considered. Because a sustained shortage would likely involve a shift in behavior on the part of Saudi Arabia, this duration probably would be accompanied by a shortage of severe proportions (20 to 25 percent). It is expected that shortages of this magnitude would be preceded by less severe shortages.

Shortage—Frequency

Shortages of the lesser magnitude (10 to 15 percent) scenarios in Table A-10 are assumed to occur with a frequency of every 5 years beginning in 1985, following the historical pattern of energy supply disruptions. Shortages of larger magnitudes (20 to 25 percent) and short duration (3 months) are assumed at 10-year intervals. A large magnitude (20 to 25 percent) shortfall of sustained duration (1 year) is treated as a one-time occurrence. The year 1990 is chosen arbitrarily as the midpoint of the forecast period.

Government Allocation

Because there is no federal government allocation scheme for shortages of less than 20 percent, it is assumed that at controlled prices state governments will adopt the policies used under similar conditions in the past, such as odd-even gasoline sales plans and Sunday sales bans, and will include actions in state conservation plans similar to some of the measures described in the standby Federal Emergency Energy Conservation Plan (*A-17*). (Specific actions are given in Table A-10.) Under decontrolled prices, gasoline is allocated through the market mechanism. Because of the legislation providing for presidential power to institute rationing with white markets if the shortfall exceeds 20 percent, all scenarios with shortages of 20 to 25 percent in Table A-10 show such an allocation scheme. Rationing for a 3-month period and 1-year period is considered. The analysis of responses during rationing is unaffected by the duration of an energy shortfall of less severe proportions which is likely to precede and perhaps occur subsequent to the institution of rationing. One year is assumed to represent the maximum duration for a rationing scheme; longer durations appear to be less likely to occur.

Alternative Assumptions

There is a large amount of uncertainty that must be considered in developing energy shortfall scenarios. This uncertainty becomes a larger factor for longer run projections. Given this inherent uncertainty, assumptions other than those used in this appendix clearly could be used to develop additional scenarios.

Franssen (*A-18*) suggests that three critical factors affecting energy availability and price are economic growth, political stability of oil-producing nations, and the lead time necessary for bringing new energy sources on-line. The political stability factor probably contributes the most to uncertainty. Some analysts are apparently more pessimistic regarding the future political stability of oil-producing nations, especially in the Persian Gulf area, than previously. For example, at the 1980 National Energy Users Conference for Transportation Kilgore stated that the 1979 fuel shortage suggests that there may be less slack energy production capacity and more incentives (including political instability) for oil-producing nations to hold down production. He believes that these factors are likely to lead to more severe future shortfalls in terms of shortfall level, duration, and frequency than have been previously experienced. He presents no specific numerical assumptions however.

Greater instability of supply would likely lead to increases in the base (nonshortage) price levels (e.g., the real annual growth rate could be higher than previous historical rates. (Alternative price projections can be produced by changing the growth rate factor, r, in the equations for projecting gasoline price presented in the previous section.) Further, the perception of the possibility of chronic or frequent shortfalls may lead to permanent changes in travel and location behavior (e.g., people may live closer to work and/or purchase fuel-efficient vehicles). Longer term behavioral adjustments of this nature will be examined in the tests of the forecasting system developed for this project.

Although these considerations could result in many additional scenarios, the six scenarios presented in this study represent a reasonable sample of possible shortfall futures. Further, the forecasting system that was designed for examining the impacts of alternative fuel shortage scenarios can be used for other scenarios as well as for the six presented here.

ANALYSIS OF INTERACTIONS AMONG SHORTAGE LEVEL, PRICE, AND ALLOCATION POLICIES

This section is organized by the three types of governmental allocation actions used to define scenarios. The discussion proceeds in order of analytical complexity: (1) market clearing price (decontrol at the pump); (2) governmental actions not involving price decontrol, rationing, or taxes; and (3) rationing with a white market for coupons.

Market-Clearing Price (Decontrolled Pump Price)

The market is the allocation mechanism when the price is allowed to rise to the market-clearing level. By definition, this price reduces the demand for gasoline to the level of supply available. The process is shown in Figure A-2, where p_1 is the market clearing price and q_1 is the available supply.

The market mechanism allocates gasoline according to willingness to pay for gasoline. To the extent that the current distribution of income is perceived to be inequi-

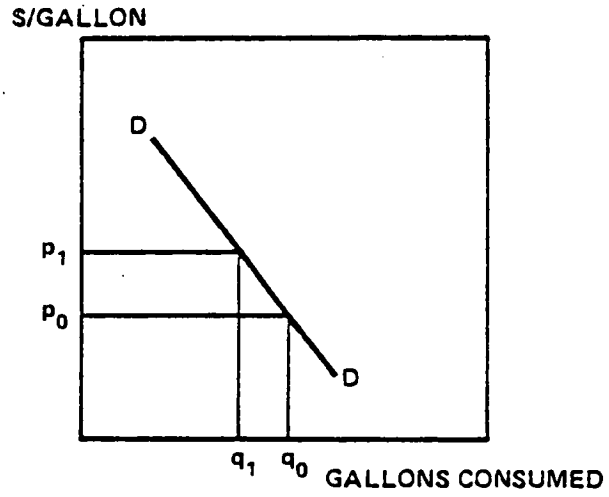

Figure A-2. Analysis of market clearing price.

table, this allocation scheme may have adverse equity impacts. In this case, the government may attempt to redistribute income by lowering regressive taxes to counteract the regressive nature of high gasoline prices.

It should be noted that the market-clearing price will still lead to greater consumption of gasoline than is optimal. Because there are external diseconomies associated with gasoline, such as oil spills and political and economic risks currently associated with dependence on oil imports, the free market price will be less than the true social cost of gasoline consumption. Because the market for gasoline does not consider these external costs, government imposition of a tax is necessary if the level of consumption is to be reduced to its efficient level (*A-2*).

Governmental Actions not Involving Price Decontrol, Rationing, or Taxes

Under a controlled price scenario, the imposition of an odd–even plan, Sunday sales ban, and other fuel conservation actions probably provides only a partial means of allocation of gasoline. The basic mechanism for allocating the insufficient supply will be gas station queues.

An odd–even plan for gasoline will have several effects: shortening the gas queues faced by consumers, hoarding of gasoline, and reducing demand because of foregone travel opportunities. Gasoline is likely to be hoarded in the form of maintaining a full tank as often as possible because of the inability to buy gasoline at all times. There will also be some increase in demand because of the gasoline used in the process of purchasing gasoline. Limited opportunities to buy gasoline will lead also to reduced demand for gasoline because some travel opportunities will be foregone, especially overnight travel. In other cases, other modes will be substituted for automobile travel, such as plane, train, and bus.

The Sunday sales ban will have the same effect as the odd–even plan in terms of hoarding and foregone automobile travel. Because gasoline can be stored only to a limited extent, however, the net impact of the odd–even plan and Sunday ban will most likely be to reduce demand for gasoline in the short run.

The odd–even plan and the Sunday sales ban are actions that directly affect the condition of gasoline sales and purchases. These measures are implemented to provide more order in retailing gasoline as well as to suppress the demand for gasoline. Other actions, such as employer-based plans for encouraging high-occupancy vehicle use and the vehicle sticker plan (in which all vehicles in a household are not to be used on day of the week specified by the sticker), are designed to lower demand for gasoline. Dorfman and Harrington (*A-12*) present an analysis of the costs and benefits of these types of actions.

In the absence of these government allocation actions, the effect of a controlled price is represented in Figure A-3. The difference between the market-clearing price, p_1, and the controlled price, p_0, is paid in the form of waiting time in gasoline lines. In the aggregate, this cost is equal to the average value of the time spent waiting in queues.

In addition, the factors leading to increases or decreases in demand, such as hoarding or reduced travel demand, are relevant. With no governmental allocation actions, it may also be hypothesized that uncertainty costs cause an upward shift in demand (i.e., consumers are willing to pay a higher price—mainly in the form of waiting time—for a given quantity of gasoline because possession of the gasoline reduces uncertainty). This effect is represented by the higher demand curve, D'-D'. The uncertainty cost is p^*-p_1.

If the government actions are to have an effect relative to the "do-nothing" option, there must be a downward demand shift. A possible impact is that such policies reduce uncertainty over the "do-nothing" alternative, perhaps resulting in a downward demand shift to the original curve *D-D*.

Rationing with White Markets

Since white markets are a prominent part of the federal rationing legislation, they will be analyzed in detail. The

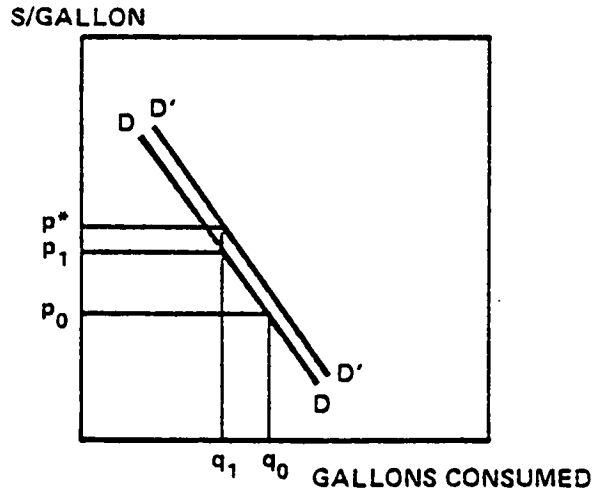

Figure A-3. Analysis of odd-even allocation with Sunday closings (controlled price).

analysis is organized into four parts: (1) simple economic analysis, (2) coupon market, (3) income and distributional effects, and (4) policy issues.

Simple Economic Analysis

The analysis is basically the same as that of the market-clearing price (see Fig. A-1). The controlled price of gasoline is represented by p_0. The quantity demanded before the supply disruption is equal to q_0. After the supply disruption, only q_1 gasoline is available. The notation p_1 represents the controlled price plus the price of coupons.

The price of coupons, then, is equal to p_1 minus p_0. It should be clear from this diagram that p_1 is the market-clearing price, that is, the price at which demand is equal to the available supply. Given the assumptions of the analysis, there is virtually no difference between rationing with white markets given controlled prices and allocation by allowing the price of gasoline to rise to the market-clearing level.

However, the simple analysis hides potentially important differences between rationing and pricing. This issue is discussed in the following subsections.

The Coupon Market

(The discussion in this subsection is primarily a theoretical economic analysis of a white market coupon market. It is not essential for understanding the specific scenarios presented here. Therefore, the reader may wish to go directly to the following subsection.)

The analysis of the coupon market involves segmentation of the aggregate gasoline demand curve into groups with demand below and above the number of ration coupons. In the simplest case, these two segments are represented in Figure A-4(A).

The left demand curve for the above-average segment in Figure A-4(A) determines the demand curve for coupons, while the coupon supply curve is determined by the gasoline demand curve for the below-average segment. Specifically,

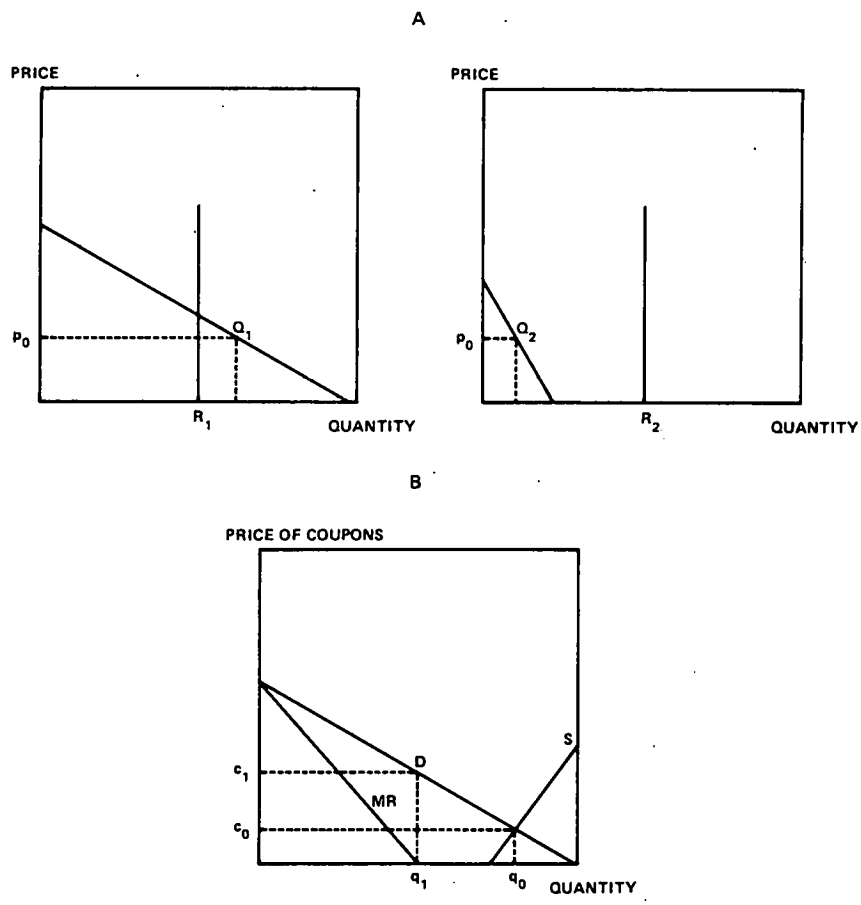

Figure A-4. Analysis of the ration coupon market.

$$D(c) = Q_1\ (p + C) - R_1 \qquad \text{(A-20)}$$

and

$$S(c) = R_2 - Q_2\ (p + c) \qquad \text{(A-21)}$$

where p is the pump price of gasoline; c is the coupon price; $D(c)$ is the demand for coupons at price c; Q_1 is the gasoline demand curve for the above-average segment; R_1 is the number of coupons (where each coupon equals 1 gallon of gasoline) allocated to the above-average segment; $S(c)$ is the quantity supplied at c; and R_2 and Q_2 are analogous to R_1 and Q_1. The coupon market clears when $D(c) = S(c)$, if it is assumed that it is a free market. The price of the coupon, c, is the same as the price determined by the simple economic analysis. The coupon market is represented in Figure A-4(B).

An interesting result emerging from this analysis is that when the prerationing price is already at the market-clearing price, the coupon price is zero. That is, under free market assumptions, excess coupons have no value to their holders. Because this result may be counterintuitive and because the high-price ration coupon situation is one of the scenarios in this study, some discussion of this result is warranted.

The coupon market-clearing price assumes perfect information, zero transaction costs, and equilibrium. Because coupons in excess of the amount of gasoline that would be consumed at the market price are of no value to the coupon suppliers in and of themselves (they allow the purchase of gasoline at a price higher than willingness to pay), they should be willing to accept any positive price for them. This means the equilibrium price of coupons can approach zero.

The assumptions of perfect information, no transaction costs, and equilibrium may not be realistic for determining the coupon price. Hence, at least a small positive price would probably prevail when p_0 is the market-clearing price. In addition, it is possible that coupon suppliers could attain some market power (e.g., through the use of brokers). This possibility suggests the consideration of monopolistic situations.

In the case of a single price monopoly, the quantity of coupons sold is determined by the intersection of the supply curve with the marginal revenue curve, MR, which is always below the demand curve. In Figure A-4(B) this leads to q_1 coupons sold at price c_1. That is, fewer coupons are sold at a higher price. In the case of p_0 being the market-clearing price, coupons would sell for a positive amount.

If the coupon suppliers approximated a price discriminating monopolist (i.e., each consumer of coupons was charged his or her full willingness to pay), q_0 coupons would be sold. Suppliers would realize revenues equal to c_0 times q_0, plus the triangular area above this rectangle.

Income and Distributional Effects

Although pricing and rationing may have similar impacts in terms of gasoline consumption and total cost of gasoline (price plus coupon value), they may have substantially different distributional consequences. Pricing results in a transfer of income from gasoline consumers, as a whole, to suppliers. On the other hand, rationing leads to a transfer from heavy to light consumers of gasoline. To the extent that the latter transfer tends to favor lower income people, it may be preferred on equity grounds (*A-15, A-19, A-20*).

The transfer of income can influence both gasoline consumption and the consumption of other goods. To analyze the former situation, consideration of the income elasticity of gasoline demand is necessary. It appears that the elasticity lies between 0 and 1 (*A-21, A-22, A-23*). Because the amount of income transferred through ration coupons is likely to be a small fraction of total income, elasticities in this range imply very small consumption shifts. However, simple hypothetical examples (which are not presented here) suggest that even these small shifts can have nontrivial impacts on the coupon prices and on the total transfer of income. (As income elasticity increases, the number of coupons sold appears to decrease slightly, but the coupon price and the total income transfer appears to increase.)

The consumption of other goods is also affected. To the extent that the price of coupons is likely to be considerable, the additional income to coupon sellers will affect the consumption patterns of these households. Hence, demand for all other goods by these households will increase, and demand for all other goods by coupon purchasers will decrease. Because the two groups of households are likely to demand a different mix of goods, the pattern of total consumption in society will change.

It should be noted, however, that rationing may be an inefficient means of redistributing income from high-income to low-income groups. It generally has been true in the past that higher income households consume more gasoline because they purchase larger vehicles, own more vehicles per driver, and use each vehicle more. Because of these factors, Lee (*A-15*) and Goodman (*A-19*) have estimated that there would tend to be a moderate transfer of income to low-income households given current vehicle ownership and travel patterns. Using a simulation model with a very low (in absolute value) implicit gasoline price elasticity, Horowitz (*A-20*) estimated very large income transfers to people with household income less than $11,500 in the Washington, D.C., area. (Under the assumptions of gasoline rationing with white markets and a 15 percent shortfall, Horowitz's model estimated that the income remaining after out-of-pocket transportation expenses for this income group would increase by 52 percent. The total gasoline price (pump price plus coupon price) was estimated to increase by 630 percent.)

However, during periods of shortages or in anticipation of future shortages, the relationship between income and gasoline consumption may change. In many cases, low-income individuals may be heavy consumers of gasoline by necessity (e.g., they own older, less fuel-efficient vehicles; they are provided inadequate transit service; and they have long work trip journeys). Similarly, higher income households are often able to conserve gasoline because they face more choices, such as substituting air travel for automobile travel, purchasing new fuel-efficient

vehicles, and substituting at-home activities for out-of-home activities. In contrast, low-income households often have few choices available. Therefore, one can imagine how, in many instances, the coupon market may lead to income transfers from low-income to high-income households. Moreover, to the extent that information about the coupon market provides the opportunity to increase the price of coupons, high-income individuals are more likely to be offered this opportunity because they are more likely to have access to the necessary information.

Policy Issues

Rationing may be preferred to pricing for other reasons than distributional considerations. These reasons may justify rationing even at the high, or market-clearing price assumed in some of the scenarios in this study. First, in the real world prices change relatively slowly; hence, there will be a lag between the supply shortage and the price adjustment, causing overconsumption at the outset. Second, rationing leads to absolute certainty of the level of total consumption. To the extent that the administrative costs of rationing are perceived to be less than the costs of uncertainty of the amount of consumption, rationing may be preferred under any pricing policy. Moreover, rationing serves to regulate consumption over time. Even at the market-clearing price, the existence of lags in price adjustments may result in an inefficient temporal pattern of gasoline consumption that can produce improper signals to consumers, producers, and the government. Finally, because externalities exist, the market-clearing price results in a higher level of consumption than is efficient for society. During a shortfall, the need to maintain the efficient level of consumption may be perceived to be great due to abnormally high political and economic external costs; rationing would allow this level to be maintained.

Although rationing provides certainty of total consumption, there is no assurance that the amount consumed in any single area will be equal to the coupons issued in that area. Because gasoline allocations provide a fixed supply for each area and coupons are mobile, both spot shortages and gluts can be expected. These imbalances will be played out in the price of coupons. In cases of spot shortages, the coupon price will rise and/or gasoline lines will form; in cases of spot gluts, the coupon price will fall.

An alternative plan to rationing and pricing that combines price decontrol, a tax on gasoline, and lump sum rebates (mainly distributed through the withholding tax system) to consumers is suggested by Difiglio (*A-24*). In theory, this system can be designed to have gasoline consumption and distributional impacts similar to a rationing system. Difiglio claims that his system is preferable to rationing because it is easier and less costly to implement and the price system is more capable of responding to changing supply/demand conditions than is the governmental mechanism for distributing coupons. Since current legislation specifies a rationing plan and since the major difference between rationing and Difiglio's proposal involves implementation feasibility rather than the consequences of a successfully implemented program, this study analyzes rationing. However, more analysis and discussion of implementation issues are definitely important subjects for future research.

PRICE PREDICTIONS

In this section four price estimates are derived for the relevant time periods of each scenario: (1) the base (nonshortage) price, (2) the pump price of gasoline, (3) the price of ration coupons in the white market (relevant to Scenarios C through F), and (4) the total price of gasoline. These estimates are given in Tables A-11 through A-14 for the years 1985, 1990, 1995, and 2000, respectively.

TABLE A-11

1985 PRICE PREDICTIONS

(In 1979 dollars)†

Scenario	Base Price††	Pump Price†††	Coupon Price#	Total Price##
A	1.21	1.21	NA	1.02
B	1.21	2.11	NA	2.11
C	*	*	*	*
D	*	*	*	*
E	*	*	*	*
F	*	*	*	*

*Scenario not defined for 1985.

†$1.00 per gallon = $.26 per liter.

††Base prices are defined and presented in Table A-3.

†††For low price scenarios, this is the base price. For high price scenarios, Equation A-1 with an elasticity of -.2 is used to estimate pump price.

#Estimation assumes a free market for ration coupons. Factors such as transaction costs or acquisition of market power by coupon suppliers could lead to coupon price increases.

##Pump price plus coupon price.

TABLE A-12

1990 PRICE PREDICTIONS

(In 1979 dollars)†

Scenario	Base Price††	Pump Price†††	Coupon Price#	Total Price##
A	1.34	1.34	NA	1.15
B	1.34	2.35	NA	2.35
C	1.34	1.34	1.68	3.02
D	1.34	3.02	0	3.02
E	1.34	1.34	1.68	3.02
F	1.34	3.02	0	3.02

†$1.00 per gallon = $.26 per liter.

††Base prices are defined and presented in Table A-3.

†††For low price scenarios, this is the base price. For high price scenarios, Equation A-1 with an elasticity of -.2 is used to estimate pump price.

#Estimation assumes a free market for ration coupons. Factors such as transaction costs or acquisition of market power by coupon suppliers could lead to coupon price increases.

##Pump price plus coupon price.

TABLE A-13

1995 PRICE PREDICTIONS

(In 1979 dollars)†

Scenario	Base Price††	Pump Price†††	Coupon Price #	Total Price##
A	1.50	1.50	NA	1.50
B	1.50	2.62	NA	2.62
C	*	*	*	*
D	*	*	*	*
E	*	*	*	*
F	*	*	*	*

*Scenario not defined for 1995.

†$1.00 per gallon = $.26 per liter.

††Base prices are defined and presented in Table A-3.

†††For low price scenarios, this is the base price. For high price scenarios, Equation A-1 with an elasticity of -.2 is used to estimate pump price.

#Estimation assumes a free market for ration coupons. Factors such as transaction costs or acquisition of market power by coupon suppliers could lead to coupon price increases.

##Pump price plus coupon price.

TABLE A-14

2000 PRICE PREDICTIONS

(In 1979 dollars)†

Scenario	Base Price††	Pump Price†††	Coupon Price #	Total Price ##
A	1.67	1.67	NA	1.67
B	1.67	2.92	NA	2.92
C	1.67	1.67	2.09	3.76
D	1.67	3.76	0	3.76
E	*	*	*	*
F	*	*	*	*

*Scenario not defined for 2000.

†$1.00 per gallon = $.26 per liter.

††Base prices are defined and presented in Table A-3.

†††For low price scenarios, this is the base price. For high price scenarios, Equation A-1 with an elasticity of -.2 is used to estimate pump price.

#Estimation assumes a free market for ration coupons. Factors such as transaction costs or acquisition of market power by coupon suppliers could lead to coupon price increases.

##Pump price plus coupon price.

In estimating the various prices prevailing under shortfall conditions, free market conditions are assumed. Therefore, the market-clearing prices are estimated with Eq. A-18, and the white market price of coupons is simply the difference between the market-clearing price and the pump price.

Application of Eq. A-16 requires a base price (nonshortage) level for the year in question, a shortfall level, and an elasticity estimate as inputs. The first two variables are already defined; the former variable is presented in the section on "Baseline Projections" and the latter variable is part of the scenario definition. (The high end of the shortage range is used.)

To determine the appropriate value for the short-run price elasticity, the available estimates were reviewed. The estimates were quite consistent and ranged between —0.10 and —0.30 (*A-25, A-26*). However, these estimates were based on data prior to 1973, excluding the effects of rapid increases in price associated with recent years. When consumption of goods represents only a small share of personal income, it is likely that demand is quite inelastic with respect to price. Although pre-1973 gasoline prices met this criterion, the pump prices of the future are likely to represent a larger share of income. Similarly, prior to experience with periods of gasoline shortages, individuals may have perceived fewer alternatives to gasoline use than they have come to realize since experiencing shortages and rapid price increases. Therefore, one would expect the price elasticity to be somewhat higher than the estimates characterizing gasoline demand in earlier years. However, because a "worst case" price scenario is of interest here, an elasticity of —0.2 is used to forecast price through the year 2000. This estimate results in a likely upper bound for gasoline prices for the forecast period.

Since several assumptions are necessary to derive price estimates, uncertainty is definitely a factor. For example, if there are factors such as transaction costs and market power of suppliers in a coupon white market, the coupon price could be higher than the free market price. Therefore, the estimates are indicative of the likely magnitude of prices rather than of precise values.

The actual years in which shortages occur cannot be predicted. The years represented in the scenarios reflect assumptions about the likely frequencies of shortfalls and are chosen for convenience.

Because the research project emphasizes fuel supply limitations, primary emphasis is placed on shortage periods. The analysis presented here considers the effect of these short-term shortages relative to a baseline of adequate supplies. However, the behavior of prices between shortage periods is also of some interest. The low price assumptions based on the historic average annual real growth rate of gasoline prices are designed to incorporate the effects of shortfalls on subsequent real gasoline price levels. That is, as explained in the section on "Baseline Projections," the use of a constant real growth rate is a smooth trend approximation to the historic pattern of major price jumps (resulting from supply shortfalls), followed by a few years of real price erosion attributable to secular inflation. Consequently, the base price levels are appropriate for nonshortage periods, although governmental actions during a shortfall could affect the timing of price responses. For example, a pump price decontrol policy may require a longer period for prices to return to the "normal" trajectory than would a policy involving price controls; that is, because oil suppliers enjoy at least some market power, gasoline prices are likely to decrease at a rate slower than that at which they increase. The fact that in the past gasoline prices have decreased as a result of secular inflation rather than as a result of declines in the nominal price supports this assumption. Hence, for scenarios of frequent shortages, sufficient time may not elapse between shortages for the pump price to return to the "normal" trajectory.

While this suggests that the base prices may be higher than assumed in this analysis, other factors suggest that the base price in future years may be lower than indicated by historical evidence.

The increasing incidence of periods of supply shortfalls and rapid price increases may cause a downward shift in the long-run demand for gasoline. This shift will affect the base price in future years to the extent that gasoline pricing policy is sensitive to demand. Shifts in demand may be caused by consumer-initiated changes such as purchasing more fuel-efficient vehicles, changing work and residential locations to conserve gasoline, substituting at-home activities for out-of-home activities, and substituting closer destinations for certain trips.

Similarly, government policies can shift the demand for gasoline by providing more attractive alternatives to the automobile (e.g., improved transit service), putting restrictions on the automobile, imposing more stringent standards for vehicle fuel economy, and encouraging the production of economical synfuels. The result of this downward shift in long-run demand for gasoline is likely to be lower future base prices relative to prices used in this appendix. (This argument assumes petroleum suppliers behave in a conventional manner—they lower their price when demand slackens. The recent softening in retail gasoline prices suggests that retailers fit the conventional pattern. Some have argued, however, that petroleum exporting nations would increase price if world demand slackened so as to preserve revenues.) The balancing of these two forces on the base price of gasoline in future years suggests that the prices used in this analysis represent a reasonable estimate of actual prices, given the information available at this time.

ENERGY CONTINGENCY PLANNING

As noted earlier, the energy shortfall scenarios are defined as futures to which governments must respond. Because government actions during transportation energy shortfalls are inextricably linked to traveler response to fuel supply limitations, these actions are an important element of the forecasting system. The contingency planning process and contingency plans are described in the following.

Definition of Contingency Packages

Because no single energy conservation action is capable of fulfilling all the requirements of governmental responsibility during an energy shortfall, packages of actions are developed to represent a more realistic policy response. It is expected that local governments will take the lead in implementing contingency actions. Although the optimal contingency plan for each urban area may be unique, it is useful to develop general plans for prototypical urban areas. These general plans should, of course, be refined to meet the special needs of any given area. A typology of urban areas is developed which controls for those factors likely to have the greatest impact on the design of contingency plans. In addition, plans are specified in terms of the magnitude of the shortfall.

Three parameters were selected as controls for developing the typology: size of population, set of dominant travel modes, and modal split. Based on a suggestion made in an early Voorhees (*A-28*) report on energy conservation packages, urban areas are categorized into the following sizes: small (population of 50,000 to 250,000), medium (population of 250,000 to 1,000,000), and large (population of 1,000,000 and over). As noted in the Voorhees report, the cost-effectiveness (energy savings per dollar) and feasibility of implementation of contingency actions often vary by area size. Because the modal choice set affects both travel behavior and opportunities for energy conservation, two choice set categories were established: automobile and bus; and automobile, bus, and rail. The availability of less conventional modes, such as demand-responsive transit and taxis, and identification of specific transit modes, such as express bus or streetcar, would impose a level of detail not necessary for the general purposes of this exercise. Finally, the existing modal split for work trips was included because it is roughly related to both the level of service of modes and the capacity of modes. Three modal split categories were identified: relatively even, high automobile, and high transit (rail and/or bus).

The resulting set of prototypical urban areas is based on the categories previously identified and those "cells" representing the types of urban areas encountered by most planners. The cells representing prototypical areas are identified with an x in the following matrix:

	Typology of Urban Areas			
	Small Auto/Bus	Medium Auto/Bus	Large Auto/Bus	Large Auto/Bus/Rail
Even		x	x	x
High Auto	x	x	x	x
High Transit				x

For each type of urban area, three contingency plans are described for each of the following energy shortfall scenarios: 5 to 10 percent; 10 to 20 percent; and 20 to 25 percent. These packages are labeled minimum, medium, and maximum, respectively. Contingency plans should be capable of meeting the needs of changing energy scenarios and should have both "tear-down" and "build-up" capabilities. To meet these requirements, contingency plans are designed as incremental stages. Therefore, packages for levels above minimum shortfall include actions identified in previous levels as well as actions initiated at the prevailing level.

Criteria for Combining Actions

Contingency plans were put together on the basis of several criteria:

- Applicability of individual actions to a given urban area.
- Institutional and technical feasibility of implementation.
- Public reaction.
- Energy cost-effectiveness.

The first criterion, applicability of actions to a given area, is determined independently of the magnitude of the energy shortfall. For example, the number of taxis in small urban areas is generally so small that prohibiting taxi cruising seems inappropriate. Similarly, in a small area the creation of an auto-free zone is likely to create severe problems in terms of congestion along the periphery because there are fewer travel alternatives. Moreover, opposition from store owners in small urban areas is not easily ignored by government officials. In both small- and medium-size urban areas, the level of transit crowding and highway congestion is probably not sufficient to encourage 4-day work weeks. If the factors discouraging travel are not strong enough, 4-day work weeks may result in increased travel rather than reduced travel.

Institutional feasibility of implementation is better described in terms of institutional obstacles to implementation. These obstacles include administrative problems such as the need for a new agency or office, new personnel, or coordination among agencies—especially across several levels of government; legal problems such as the need for legislative action or whether legal authority exists to implement the action; and funding problems such as whether new money must be raised and whether available money can be diverted to the action. To some extent, institutional feasibility may vary with the magnitude of the shortfall. Concern over the effects of a more severe shortage may minimize bureaucratic inertia and foster greater cooperation between and within agencies.

Technical feasibility refers to the need for quick implementation; that is, minimal planning and construction requirements. All actions included in the minimum shortfall plans must be capable of being implemented in 3 months or less. Actions requiring the longest lead times are only considered for the maximum shortfall packages. Although technical feasibility does not vary with the level of shortfall, the need for short lead time does.

Favorable public reaction to actions is important in two respects. First, favorable public reaction generally reduces the need for enforcement because individuals are more likely to cooperate voluntarily. Second, anticipation of an unfavorable reaction is likely to cause institutional obstacles because bureaucracies are hesitant to alienate their constituencies. For these reasons, although the most restrictive energy actions have the greatest conservation potential, they are only included in maximum shortfall packages. Public reaction to restrictive actions is likely to be more favorable (or less unfavorable) if the energy shortage is more severe.

Energy cost-effectiveness refers to the energy conservation per unit cost. Given the need to conserve a given amount of energy and the need to meet other criteria, the least costly actions are preferred. The cost-effectiveness of actions often varies by urban size, modal alternatives, and modal split. Moreover, as the level of energy to be saved increases, the marginal cost of that saving is likely to increase.

Description of Contingency Packages

The energy contingency packages described in Table A-15 represent a first cut at developing generalized plans. The specific actions included in the plans were selected from the list of contingency actions presented in the literature reviewed (*A-27* through *A-61*). The actions were evaluated according to the criteria in a qualitative fashion. Although these criteria provided guidelines for combining actions, a substantial degree of personal judgment was involved.

TABLE A-15

ENERGY CONTINGENCY PACKAGES FOR PROTOTYPICAL URBAN AREAS

Small Urban Area: Auto and Bus; High Auto Modal Split

	Energy Contingency Package		
Action Group	Minimum	Medium	Maximum
Auto Ownership Cost	Encourage employer vanpool incentives; encourage employers to offer company vehicles to carpoolers		
Auto Operating Cost		Reduce parking spaces on street; parking surcharges for long-term parking	Reduce parking spaces at work sites; eliminate employer subsidization of parking costs
Auto Drive-Alone Cost			Increase tolls for single-occupant vehicles
Shared-Ride Auto Cost		Offer free or reduced tolls for carpools and vanpools	
Transit Cost			Free transit zones
General Highway Travel Time	55 mph; right turn on red; reserved bus and HOV* lanes		Adjust timing and sequence of traffic lights; off-peak flashing cautions
Auto Travel Time	Preferential parking for carpools and vanpools at work site	Park-n-pool lots	Auto-free zones
Transit Travel Time	Increase transit load standards; double-heading on heavy bus routes; increased turnback operations	Consolidate routes; consolidate E and H** transportation services; expand park-n-ride services	Decrease fleet/spare ratio; increase fleet maintenance; lease or purchase buses from other properties; consolidate school bus routes

TABLE A-15 (Continued)

Action Group	Energy Contingency Package: Minimum	Medium	Maximum
Small Urban Area: Auto and Bus; High Auto Modal Split			
New Modes	Encourage subscription buspools; use taxi service on low-patronage bus routes		
Nonmotorized Modes	Bicycle storage facilities at major trip attractions; bicycle priority regulations at intersections		
Perceptions of Modes	Carpool/vanpool matching; ridesharing promotion; transit promotion; public information campaigns to promote improved driving habits		
General Travel, Temporal and Spatial	Encourage trip planning through information campaigns	Encourage staggered work hours	Encourage home delivery of goods
Automobile, Temporal and Spatial	Shorter hours for gasoline stations		
Transit, Temporal and Spatial	Reduced fares during off-peak		
Public Sector -- Cost of Vehicles	Mandatory standards relating to energy efficiency for procurement of vehicles		
Public Sector -- Activity Allocation		Limit municipal vehicle use	
Medium Area: Auto and Bus; High Auto Modal Split			
Auto Ownership Cost	Encourage employer vanpool incentives; encourage employers to offer company vehicles to carpoolers; third-party sponsored vanpools		
Auto Operating Cost	Parking surcharges for long-term parking	Reduce on-street parking; reduce parking at work sites	Eliminate employer subsidization of parking charges
Auto Drive-Alone Cost			Increase tolls for single-occupant vehicles
Shared-Ride Auto Cost		Free or reduced tolls and parking charges for carpools and vanpools	
Transit Cost		Reduce transfer charges	Free transit zone
General Highway Travel Time	55 mph; right turn on red; reserved bus and HOV* lanes; peak-period contraflow lanes	Adjust traffic lights; change some local buses to express	Bus-activated traffic signals; off-peak flashing cautions

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TABLE A-15 (Continued)

Action Group	Energy Contingency Package: Minimum	Medium	Maximum
Medium Urban Area: Auto and Bus; High Auto Modal Split			
Auto Travel Time	Preferential parking for carpools and vanpools at work site; park-n-ride lots		Auto-free zones
Transit Travel Time	Increase transit load standards; double-heading on heavy bus routes	Increase turnback operations; consolidate routes; consolidate E and H** services; expand park-n-ride services	Decrease fleet/spare ratio; increase fleet maintenance; consolidate school bus routes
New Modes	Subscription buspools; shared-ride taxis	Use taxis on low-patronage routes	Jitneys and fixed-route taxis
Nonmotorized Modes	Bicycle storage facilities; bicycle priority at intersections		Pedestrian malls in high-activity centers
Perceptions of Modes	Carpool/vanpool matching; coordinators at work sites bring carpools/vanpools together; ridesharing and transit promotion; public information campaigns to promote improved driving habits		
General Travel, Temporal and Spatial	Encourage staggered work hours; improve household trip planning		Encourage home delivery of goods
Automobile, Temporal and Spatial	Shorter hours for gasoline stations		
Transit, Temporal and Spatial	Off-peak reduced fares		
Public Sector -- Cost of Vehicles	Mandatory standards relating to energy efficiency for vehicles procurement		Dieselization of school buses
Public Sector -- Activity Allocation			Limit municipal vehicle use
Medium Urban Area: Auto and Bus; Even Modal Split			
Auto Ownership Cost	Encourage employer vanpool incentives; encourage employers to offer company vehicles to carpoolers; third-party sponsored vanpools		
Auto Operating Cost		Parking surcharges for long-term parking; reduce on-street parking; reduce parking at work sites	Eliminate employer subsidization of parking charges
Auto Drive-Alone Cost			Increase tolls for single-occupant vehicles

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TABLE A-15 (Continued)

Medium Urban Area: Auto and Bus; Even Modal Split

Action Group	Energy Contingency Package: Minimum	Medium	Maximum
Shared-Ride Auto Cost		Free or reduced tolls and parking charges for carpools and vanpools	
Transit Cost			Reduce transfer charges; free transit zones
General Highway Travel Time	55 mph; right turn on red; reserved bus and HOV* lane; peak-period contraflow lane; change some local bus service to express	Off-peak flashing cautions; adjust traffic lights	Bus-activated traffic signals
Auto Travel Time	Preferential parking for carpools and vanpools at work site; park-n-pool lots		Auto-free zones
Transit Travel Time	Increase transit load standards; double-heading on heavy bus routes; expand park-n-ride services; decrease fleet/spare ratio	Increase turnback operations; consolidate routes; consolidate E and H** services; increase fleet maintenance	Consolidate school bus routes
New Modes	Subscription buspools; shared-ride taxis	Use taxis on low-patronage routes	Jitneys and fixed-route taxis
Nonmotorized Modes	Bicycle storage facilities; bicycle priority at intersections		Pedestrian malls at high-activity centers
Perceptions of Modes	Carpool/vanpool matching; coordinators at work sites increase ridesharing; ridesharing and transit promotion; public information campaigns to improve driving habits		
General Travel, Temporal and Spatial	Encourage staggered work hours; improve household trip planning		Encourage home delivery of goods
Automobile, Temporal and Spatial	Shorter hours for gasoline stations		
Transit, Temporal and Spatial		Off-peak reduced fares	
Public Sector -- Cost of Vehicles	Mandatory standards for fuel efficiency of vehicles		Dieselization of school buses
Public Sector -- Activity Allocation			Limit municipal vehicle use

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TABLE A-15 (Continued)

Large Urban Area: Auto and Bus; Even Modal Split

Action Group	Energy Contingency Package: Minimum	Medium	Maximum
Auto Ownership Cost	Employer vanpool incentives; encourage employers to offer company vehicles to carpoolers; third-party sponsored vanpools		
Auto Operating Cost	Parking surcharge for long-term parking	Reduce parking spaces on street	Reduce parking spaces at work sites; eliminate employer subsidization of parking costs
Auto Drive-Alone Cost			Increase tolls for single-occupant vehicles
Shared-Ride Auto Cost		Free or reduced parking and tolls for carpools and vanpools	
Transit Cost			Free transit zones
General Highway Travel Time	55 mph; reserved bus and HOV* lanes; right turn on red; peak-period contraflow lanes; change some local bus to express service	Off-peak flashing cautions; adjust traffic lights	Metered access to highways; bus-activated traffic signals
Auto Travel Time	Preferential parking for carpools and vanpools; park-n-pool lots		Auto-free zones
Transit Travel Time	Expand park-n-ride service; double-heading on heavy bus routes; increase fleet maintenance; decrease fleet/spare ratio	Increase turnback operations; consolidate routes; consolidate E and H** services	Reduce number of bus stops; lease or purchase buses from other properties; reduce deadhead miles by leasing downtown lots for bus storage; consolidate school bus routes; prohibit taxi cruising
New Modes	Shared-ride taxis; subscription bus pools	Use taxis on low-patronage bus routes; shuttles to fixed-route transit (bus and taxis)	Jitneys and fixed-route taxis
Nonmotorized Modes	Bicycle storage facilities; bicycle priority regulations at intersections		Pedestrian malls in high-activity centers
Perceptions of Modes	Carpool/vanpool matching; coordinators at work sites bring carpools/vanpools together; ridesharing and transit promotion; information campaign to improve driving habits		

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TABLE A-15 (Continued)

Action Group	Energy Contingency Package: Minimum	Medium	Maximum
Large Urban Area: Auto and Bus; Even Modal Split			
General Travel, Temporal and Spatial	Encourage staggered work hours; improve trip planning through public information campaigns		Home delivery of goods; encourage four-day work week
Automobile, Temporal and Spatial	Shorter hours for gasoline stations		
Transit, Temporal and Spatial	Off-peak reduced fares		
Public Sector -- Cost of Vehicles	Mandatory standards for fuel efficiency in vehicle procurement	Dieselization of school buses	
Public Sector -- Activity Allocation			Limit municipal vehicle use
Large Urban Area: Auto and Bus; High Auto Modal Split			
Auto Ownership Cost	Employer vanpool incentives; encourage employers to offer company vehicles to carpoolers; third-party sponsored vanpools		
Auto Operating Cost	Surcharge on long-term parking; reduce parking spaces on street	Reduce parking spaces at work site	Eliminate employer subsidization of parking charges; mandatory vehicle inspections
Auto Drive-Alone Cost		Increase tolls for single-occupant autos	Parking surcharge for single-occupant autos
Shared-Ride Auto Cost		Free or reduced tolls and parking charges for carpools/vanpools	
Transit Cost	Reduce transfer charges	Free transit zones	
General Highway Travel Time	55 mph; reserved bus and HOV* lanes; right turn on red; peak-period contraflow lanes; change local bus to express	Adjust traffic lights	Metered access to highways; bus-activated traffic signals; off-peak flashing caution
Auto Travel Time	Preferential parking for carpools/vanpools; park-n-pool lots	Auto-free zones	
Transit Travel Time	Increase transit load standards; double-heading on heavy bus routes; expand park-n-ride service	Increase turnback operations; consolidate routes; decrease fleet/spare ratio; increase fleet maintenance; consolidate E and H** services	Reduce deadhead miles by leasing downtown lots; lease or purchase buses from other properties; consolidate school bus routes; reduce bus stops; prohibit taxi cruising
New Modes	Shared-ride taxis; subscription buspools	Use taxi service on low-patronage routes	Jitneys and fixed-route taxis

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TABLE A-15 (Continued)

Action Group	Energy Contingency Package: Minimum	Medium	Maximum
Large Urban Area: Auto and Bus; High Auto Modal Split			
Nonmotorized Modes	Bicycle storage facilities; bicycle priority at intersections	Pedestrian malls at high-activity centers	
Perceptions of Modes	Carpool/vanpool matching; ride-sharing coordinators at work sites; ridesharing and transit promotion; information campaign to improve driving habits		
General Travel, Temporal and Spatial	Encourage staggered work hours; encourage improved household trip planning		Four-day work week; encourage home delivery of goods
Automobile, Temporal and Spatial	Shorter hours for gasoline stations		
Transit, Temporal and Spatial	Reduced fares during off-peak		
Public Sector -- Cost of Vehicles	Mandatory standards for fuel efficiency of vehicles	Dieselization of school buses	
Public Sector -- Activity Allocation			Limit municipal vehicle use
Large Urban Area: Auto, Bus, and Rail; Even and High Auto Modal Split			
Auto Ownership Cost	Employer vanpool incentives; encourage employers to offer company vehicles to carpoolers; third-party sponsored vanpools		
Auto Operating Cost	Surcharge on long-term parking; reduce on-street parking spaces	Reduce parking spaces at work	Eliminate employer subsidization of parking charges; mandatory vehicle inspections
Auto Drive-Alone Cost		Increase tolls for single-occupant autos	Parking surcharge for single-occupant autos
Shared-Ride Auto Cost		Free or reduced tolls and parking for carpools/vanpools	
Transit Cost	Reduced transfer charges	Free transit zones	
General Highway Travel Time	55 mph; reserved bus and HOV* lanes; right turn on red; peak-period contraflow lanes; change local bus to express	Off-peak flashing caution; adjust traffic lights	Metered access to highways; bus-activated traffic signals
Auto Travel Time	Preferential parking for carpools/vanpools; park-n-pool lots	Auto-free zones	

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TABLE A-15 (Continued)

Large Urban Area: Auto, Bus, and Rail; Even and High Auto Modal Split

Action Group	Energy Contingency Package: Minimum	Medium	Maximum
Transit Travel Time	Increase transit load standards; double-heading on heavy bus routes; expand park-n-ride services; decrease fleet/spare ratio; increase fleet maintenance	Increase turnback operations; consolidate routes; consolidate E and H** services	Reduce deadhead miles by leasing downtown lots; lease or purchase buses from other properties; consolidate school bus routes; reduce bus stops; prohibit taxi cruising
New Modes	Shared-ride taxis, subscription buspools; shuttles to fixed-route transit	Use taxi service on low-patronage bus routes; demand-responsive bus service to and from rail stations	Jitneys and fixed-route taxis
Nonmotorized Modes	Bicycle storage facilities; bicycle priority at intersections	Pedestrian malls at high-activity centers	
Perceptions of Modes	Carpool/vanpool matching; ridesharing coordinators at work sites; ridesharing and transit promotion; information campaign to improve driving habits		
General Travel, Temporal and Spatial	Encourage staggered work hours; encourage improved household trip planning		Four-day work week; encourage home delivery of goods
Automobile, Temporal and Spatial	Shorter hours for gasoline stations		
Transit, Temporal and Spatial	Reduced fares during off-peak		
Public Sector -- Cost of Vehicles	Mandatory standards for fuel efficiency of vehicles	Dieselization of school buses	
Public Sector -- Activity Allocation			Limit municipal vehicle use
Large Urban Area: Auto, Bus, and Rail; High Transit			
Auto Ownership Cost	Employer vanpool incentives; encourage employers to offer company vehicles to carpoolers; third-party sponsored vanpools		
Auto Operating Cost	Surcharge on long-term parking; reduce on-street parking spaces	Reduce parking spaces at work	Eliminate employer subsidization of parking charges; mandatory vehicle inspections
Auto Drive-Alone Cost		Increase tolls for single-occupant autos	Parking surcharge for single-occupant autos
Shared-Ride Auto Cost		Free or reduced tolls and parking for carpools/vanpools	

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TABLE A-15 (Continued)

Large Urban Area: Auto, Bus, and Rail; High Transit

Action Group	Energy Contingency Package: Minimum	Medium	Maximum
Transit Cost		Reduced transfer charges	
General Highway Travel Time	55 mph; reserved bus and HOV[1] lanes; right turn on red; peak-period contra-flow lanes; change local bus to express	Adjust traffic lights	Metered access to highways; bus-activated traffic signals; off-peak flashing caution
Auto Travel Time	Preferential parking for carpools/vanpools; park-n-pool lots	Auto-free zones	
Transit Travel Time	Increase transit load standards; double-heading on heavy bus routes; expand park-n-ride services; decrease fleet/spare ratio; increase fleet maintenance	Increase turnback operations; consolidate routes; consolidate E and H** services; lease or purchase buses from other properties; reduce bus stops; prohibit taxi cruising	Reduce deadhead miles by leasing downtown lots; consolidate school bus routes
New Modes	Shared-ride taxis; subscription buspools	Shuttles to fixed-route transit; use taxi service on low-patronage bus routes; demand-responsive bus service to and from rail stations	Jitneys and fixed-route taxis
Nonmotorized Modes	Bicycle storage facilities; bicycle priority at intersections		Pedestrian malls at high-activity centers
Perceptions of Modes	Carpool/vanpool matching; ridesharing coordinators at work sites; ridesharing and transit promotion; information campaigns to improve driving habits		
General Travel, Temporal and Spatial	Encourage staggered work hours; encourage improved household trip planning	Encourage four-day work week	Encourage home delivery of goods
Automobile, Temporal and Spatial	Shorter hours for gasoline stations		
Transit, Temporal and Spatial		Reduced off-peak fares	
Public Sector -- Cost of Vehicles	Mandatory standards for fuel efficiency of vehicles	Dieselization of school buses	
Public Sector -- Activity Allocation			Limit municipal vehicle use

*High-occupancy vehicle lane.
**Elderly and handicapped transportation service

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APPENDIX B

EVALUATION OF METHODOLOGIES FOR ANALYZING THE EFFECTS OF FUEL SUPPLY LIMITATIONS ON PASSENGER TRAVEL

This appendix discusses existing methodologies for forecasting the impacts of energy policies. Several different approaches are presented. For each approach, the essentials are outlined, the conceptual soundness of the approach is discussed, examples of applications are given, and the approach is evaluated in terms of the six criteria previously established in this project for assessing the applicability of methodologies for analyzing fuel supply policies.

The evaluation criteria are as follows:

1. *Energy market and policy sensitivity.* Are the data elements and variables consistent with the policies being tested, the outputs needed, and the requirements for a reliable forecasting system?

2. *Forecast relevance.* Are the predicted output variables the same as, or easily linked to, the forecast system impacts?

3. *Accuracy and reliability.* Are there errors or biases in the data? Does the methodology forecast well? Are the

data and data analysis generalizable across different areas?

4. *Data requirements.* Are data readily available to support a methodology? What are the resources required to gather the appropriate data? Are costly transportation experiments required to generate observations over a sufficient range?

5. *Manpower and computation requirements.* What are the manpower and computer resources required to perform the procedures? What specific skills are required?

6. *Operational availability.* What is the level of experience with the methodology among state and local planning agencies? Does the methodology require further development and testing before it has demonstrated accuracy and reliability?

The remainder of this appendix is organized into two major sections. First, existing analytical approaches are described in detail. Following this, these approaches, as well as the state-of-the-art approaches described elsewhere in this report, are evaluated with respect to the six criteria.

DISCUSSION OF EXISTING METHODOLOGIES

The discussion of existing travel methodologies is organized into the following subsections: (1) application of elasticities; (2) work mode choice models; (3) nonwork trip models; (4) models of long-run mobility choices; (5) attitudinal models; (6) findings from studies performed during energy shortage periods; and (7) time-series studies.

Application of Elasticities

An elasticity is a measure of the responsiveness of travel demand to a given change in some variable with all else held constant. Two types of elasticities are of interest to transportation planners. Direct elasticities measure the response in demand for some travel option to change in a characteristic of that travel option. Cross-elasticities measure the change in demand for a travel option in response to change in a characteristic of some other travel option.

There is considerable variation among elasticity estimates. An understanding of the sources of variation is necessary if elasticities are to be correctly applied. The major areas of differences are discussed in the following.

Measurement

Three different measures of elasticity have been developed which, as a general rule, are not interchangeable. To illustrate the differences, transit demand elasticity is used with respect to fare with the following notation: q represents ridership, f represents fare, the subscript 1 indicates the value before the change, and the subscript 2 represents the value after the change.

Point elasticity is estimated from the demand curve. It indicates the ridership response to a marginal change in either direction. The point elasticity is calculated at a given point along the demand function as follows:

$$\eta_{\text{point}} = \frac{\partial q}{\partial f} \cdot \frac{f_1}{q_1} \qquad \text{(B-1)}$$

Because no actual change in fare is marginal or infinitesimal, the point elasticity is an abstract concept. It is meaningful as a means for comparing demand sensitivity to different variables or comparing different groups' responsiveness to the same variable.

Arc elasticity is calculated from two points observed on the demand curve. The arc elasticity estimated for a fare increase is likely to differ from the estimate based on a fare decrease. The following equation is used to calculate the arc elasticity:

$$\eta_{\text{arc}} = \frac{\dfrac{q_1 - q_2}{q_1 + q_2}}{\dfrac{2}{}} \cdot \frac{\dfrac{f_1 + f_2}{2}}{f_1 - f_2} \qquad \text{(B-2)}$$

The arc elasticity represents a linear approximation of the relevant arc on the demand curve. Information is used on fare and ridership both before and after the fare change.

Shrinkage ratio or loss ratio is a measure of the percentage change in ridership in response to a 1 percent change in fare. It is calculated by relating the changes to the base or "before" values, as follows:

$$\eta_{\text{SR}} = \frac{\Delta q}{\Delta f} \cdot \frac{f_1}{q_1} \qquad \text{(B-3)}$$

The shrinkage ratio is an approximation of the point elasticity for discrete changes. It is a cruder measure of demand responsiveness than the point and arc elasticities.

Short Run Versus Long Run

It has been found that elasticity estimates based on models calibrated with cross-section data are consistently larger than elasticities based on before-and-after studies. The reason is that cross-section data reveal long-run demand relationships and, hence, long-run elasticities; before-and-after data reveal short-run elasticities. The demand response to a given change will generally be larger the longer the change has been in effect. Because certain changes evolve more slowly over time, behavior can be adjusted along more parameters.

Aggregate versus Disaggregate

Elasticities estimated from disaggregate travel demand models must be adjusted in several ways before they can be appropriately applied to forecast aggregate travel responses. For example, if a travel choice is not available, the demand elasticity for that choice will be zero. The disaggregate elasticity can only be applied to the proportion of trips for which that choice is an option (*B-1*). In the short run, riders with only one travel option also have a demand elasticity of zero for work trips. In addition, induced demand must be handled separately for elasticities calibrated with disaggregate choice models because these reflect the adjustment in the probability of an individual choosing some travel option rather than adjustments of trip frequencies. Finally, the results of disaggregate models must be aggregated using an unbiased procedure. (For a discussion of aggregation procedures for multinomial logit,

see Koppelman (*B-2*).) The direct elasticity estimated with a logit model is equal to

$$(1\text{-}P_t)b_x x \qquad \text{(B-4)}$$

where P_t is the probability of accepting choice t; x is the independent variable; and b_x is the coefficient. The naive approximation of aggregate elasticity, using the average value for x across the population, yields an upwardly biased estimate of the aggregate elasticity. A better approximation involves segmenting the population into homogeneous groups and taking the weighted average of the segment elasticities (*B-3*).

Implied Demand Function

Elasticity values depend on the demand function; the corollary to this is that an elasticity implies a certain demand function. The more similar the demand functions are for populations, the more transferable are elasticities. It was noted earlier that the level of service of travel-choice substitutes influences the demand for a given travel choice. This effect has been empirically supported. Forecasts of automobile travel in Great Britain reveal that when gasoline prices are doubled, automobile VMT is reduced about 15 percent in central London, but less than 5 percent in smaller cities where public transportation is less readily available (*B-4*). The affect of the modal choice structure on bus demand elasticity can be seen by comparing elasticities before and after the opening of BART in San Francisco. Before the availability of rail, bus demand elasticities with respect to line-haul time and cost were —0.46 and —0.45, respectively. After BART opened, the bus demand elasticities were —0.60 and —0.58 (*B-4*).

Another implication of this relationship between elasticity and the demand function concerns the use of elasticities outside the range of observed values. Just as forecasting with a demand function outside the range of values observed imposes uncertainty, so does application of elasticities. As a given level-of-service attribute is assumed to have values further and further from the range of values used to estimate the elasticity, the less certain are the results.

Policy Applications

Those travel demand models that use aggregate cross-section data have for the most part provided estimates of demand elasticities with respect to price and service variables such as service miles and headway frequency. Before-and-after studies based on aggregate time-series data have yielded a wider set of elasticity relationships; these estimates tend to be less reliable, however, because less rigor is applied in model specification. In general, aggregate data produce less accurate estimates because important disaggregate variation is obscured by the aggregate data; before-and-after services such as express bus, demand-responsive transit, buspools, and vanpools; auto-area-restraint schemes; bus priority treatments; user-side subsidies; and variable work-hour programs. Unfortunately, the models used to examine travel response to these policies have been restrictive so that potentially important spatio-temporal and interpersonal linkages in behavior have not been observed (spatio-temporal linkages refer to interdependencies of travel decisions made at different times and places; interpersonal linkages refer to interactions among members of a decision-making unit, usually a household). The degree of bias imposed by this restrictiveness is determined by the significance of the secondary linkages. Policies affecting travelers' perceptions, such as transit and ridesharing promotion, have been studied to a limited extent. Because such policies are only crudely measured, their effect on behavior can only be hypothesized.

Therefore, policy applications of elasticities are in part limited by both the range of elasticity estimates and the reliability of the estimates. Appropriate application of available estimates requires an understanding of the differences among elasticity values and techniques such as sensitivity analysis to evaluate the uncertainty underlying most estimates. Part of the difficulty in using elasticities lies in the fact that much of the published literature fails to specify which measure of elasticity is used and how the elasticity was estimated. Given these limitations, however, application of elasticities provides the policy maker with an inexpensive and quick turnaround method of forecasting the impacts of a number of policy changes.

Use of previously estimated statistical models is a closely related alternative to application of elasticities. Because elasticities are often derived from estimated models, guidelines for transferring models are the same as for elasticities. Because elasticities reveal the percentage change in the dependent variable, models may be easier to use when a number of changes are being considered simultaneously. Policy applications involving both elasticities and models are discussed in the following.

Work Mode Choice Models

Modal choice studies based on disaggregate cross-section data have produced a sizable body of evidence on demand elasticities with respect to price and travel time. Many of these models have focused on a single trip purpose, such as work trips, or a travel choice segment, such as noncaptive riders. Typically, the models are of the multinomial logit form, although regression techniques have been used to estimate "direct demand models." As noted previously, the functional form of the model implies a given elasticity function; for example, the logit model specifies a variable elasticity.

The functional form of the multinomial logit work mode choice model is well known. It is

$$P(\text{Mode } i) = \exp\ (X_i B)/\sum_j \exp(X_j B) \qquad \text{(B-5)}$$

where X_i is a vector of modal characteristics (and sometimes socioeconomic characteristics) such as travel times and costs by mode; and B is a vector of coefficients (weights).

Probability model choice models are well suited to predicting the impacts of policies involving a change in modal costs and travel times. An example of such an application is a study by Charles River Associates (*B-5*) of the effects

of various Transportation Control Plan (TCP) proposals on work travel for Boston's North Shore. Using a model estimated on 1967 Pittsburgh work trip data (from Domencich and McFadden (*B-3*)), adjustments were made to account for secular inflation and the constant term was recalibrated on a sample from a 1974 Boston North Shore survey. The effects of policies on each individual were simulated for a sample of local households, and the results were expanded using 1970 Census data to tabulate aggregate travel demand for the North Shore corridor. A $0.75 toll increase, a $1.50 parking cost increase, and a 75 percent increase in gasoline tax were evaluated. The disaggregate demand model was also used to estimate the impact of the introduction of an express bus with own collection, with minibus feeder service, with minivan feeder service, and with taxi feeder service. The demand for each of these new modes and the resulting area mode split were estimated.

Work mode choice models typically do not account for nonwork trips that are part of trip chains involving the work trip (e.g., a shopping stop on the way home from work). These trip chains are a somewhat significant proportion of total work travel (*B-6, B-7*) and could be even more important during energy shortages. Improvement of existing work trip demand techniques to account for trip chains may be an important future research task in developing energy policy tools.

The major limitation of these models is that only modal splits can be examined. Several joint probability choice models have been developed that permit examination of a wider range of behavioral responses. Two examples of such models are Adler and Ben-Akiva's (*B-8*) joint frequency, modal choice, destination choice logit model for shopping trips and Lerman's (*B-9*) joint location, housing, automobile, and mode-to-work logit model. Both of these models can be used to forecast the impacts of policies affecting modal cost and travel time parameters.

Nonwork Trip Models

The models reviewed in this section explain daily nonwork travel patterns given residential location and automobile ownership. The key output from these models for purposes of energy forecasting is VMT by mode. Two types of models will be discussed: (1) probability choice models that explain individual trip patterns; and (2) models that use summary measures of travel patterns, such as VMT, to describe travel behavior (simplified models).

Probability Choice Models

The two most prominent examples of policy applications of nonwork probability choice models are the application of the CRA disaggregate demand model (*B-3*) to analyze pollution control policies in Los Angeles (*B-10, B-11*) and the application of the Cambridge Systematics modeling system to analyze carpooling policies (*B-12, B-13, B-14*). The following discussion centers on general features of the approach, CRA and CSI applications, and finally assessment of nonwork probability choice models.

Nonwork Probability Choice Models. Because the number of alternatives available for nonwork trips is fairly large, existing models have used multinomial logit analysis. The models explain choices among alternative nonwork trips, where trips are defined by alternative frequency, destination, and modal characteristics. These models typically deal with round trips defined as a movement between home, a nonwork destination, and home. More complicated travel patterns are not represented.

The general form of the models is represented by the following equations:

$$P_{fdmi} = \exp\ (U_{fdmi}) / \sum_{f'} \sum_{d'} \sum_{m'} \exp\ (U_{f'd'm'i'}) \quad \text{(B-6)}$$

$$U_{fdmi} = X_{fdmi}\beta_1 + Y_{fdmi}\beta_2 + Z_{fi}\,\beta_3 \quad \text{(B-7)}$$

where P_{fdmi} is the probability of individual i making a trip with frequency f to destination d by mode m. The range of possible frequencies is usually limited to 0 or 1, and destinations are often defined in terms of traffic zones or larger aggregates. U is the systematic component of the probabilistic utility for the particular alternative. It is assumed to be a function of vectors of characteristics that vary by individual, frequency, mode, and destination X; by individual, frequency and destination Y; and by individual and frequency Z. Examples of the first class of variables are transportation level-of-service variables such as times and costs. Variables in the vector Y might include destination charactristics such as number of employees per zone, and Z might contain socioeconomic variables such as income. β_1, β_2, and β_3 are vectors of coefficients.

Although it is possible to estimate a simultaneous frequency, destination, and mode choice model, it is also possible to separate the model into frequency, destination, and mode choice components. These components are as follows:

$$P_{mi/fd} = \exp\ (X_{fdmi}\ \beta_1) / \sum_{m'} \exp\ (X_{fdm'i}\ \beta_1\ \text{(mode)} \quad \text{(B-8)}$$

$$P_{di/f} = \exp\ (Y_{fdi}\ \beta_2 + \alpha_1\ I_{fdi}) / \sum_{d'} \exp\ (Y_{fd'i}\ \beta_2 + \alpha_1\ I_{fd'i})\ \text{(destination)} \quad \text{(B-9)}$$

where:

$$\mathrm{I}_{fdi} = \log \sum_{m'} \exp\ (X_{fdm'i}\,\beta_1);\ \text{and}$$

$$\alpha_1 = \text{a scalar coefficient}$$

And

$$P_{fi} = \exp\ (Z_{fi}\ \beta_3 + \alpha_2\ I'_{fi}) / \sum_{f'} \exp\ (\mathrm{Z}_{f'i}\,\beta_3 + \alpha_2\,\mathrm{I}'_{f'i})\ \text{(frequency)} \quad \text{(B-10)}$$

where:

$$I'_{fi} = \log \sum_{d^1} \exp\ (Y_{fd'i}\,\beta_2 + \alpha_1\,I_{fd'i});\ \text{and}$$

$$\alpha_2 = \text{a scalar coefficient.}$$

$P_{mi/fd}$ explains the choice of mode for individual i given a fixed frequency f and destination d; $P_{di/f}$ explains the destination choice given frequency, and P_{fi} is the frequency choice probability.

If the coefficients α_1 and α_2 are constrained to equal 1, it

can be shown that the component structure is mathematically equivalent to the joint choice structure.

CRA Applications. The CRA model, a shopping trip model, contains separate frequency, destination, and mode choice components. In the Los Angeles application, it was assumed that pollution control policies would not change trip frequencies (*B-10*, *B11*). Therefore, frequencies are fixed and only the destination and modal choice components are used. The nonwork trip models were used with a work trip mode choice model in this policy analysis.

The CRA model is relatively simple in that it contains a small number of independent variables. The conditional mode choice model contains three types of level-of-service variables (trip costs by mode, in-vehicle times by mode, and out-of-vehicle times by mode), and an automobile availability variable (autos per worker). The destination choice model contains measures of retail employment by zone and a linear approximation to the I_{fdi} term.

The model was used to analyze the impacts of auto disincentives, such as parking taxes, gasoline taxes, and per-mile emissions taxes, and transit incentives on automobile VMT and, hence, on pollution emissions. These policy instruments directly affect the level-of-service variables of the model (auto costs are increased and/or transit times are decreased). The analysis demonstrated that all of the instruments would be effective in reducing VMT, although the parking policies are less effective because they equally penalize long and short trips.

This particular application has implications for the study at hand. First, it illustrates the relative ease with which policies affecting conventional level-of-service variables can be analyzed. It was noted that the application was much less demanding of time and monetary resources than conventional aggregate models (*B-11*). Although there are several steps to applying the models, they can easily be documented (*B-10*). Such documentation will be produced if models of this type are selected for the forecasting system.

Second, the modeling system was adapted to handle the inclusion of new modes. The original model (*B-3*) contained only auto driver and transit modes. With the aid of several assumptions, various carpool modes (determined by size) were defined. The capability of handling new modes in this manner is a direct consequence of the structure of the logit model. Although applications of this type probably place more demands on the model than do simple level-of-service changes, the capability of the model for handling new modes is important for energy policy analyses. The key issue is how accurate the resulting estimates are.

Third, the application involved the transfer of a model estimated with 1967 Pittsburgh data to 1974 Los Angeles conditions. Although the degree of transferability of such models is an unresolved issue (a very optimistic assessment of the prospects for model transferability is given by Atherton and Ben-Akiva (*B-15*); a less optimistic assessment is given by Kirshner and Talvitie (*B-16*)), this particular application seems to have yielded reasonable results. It is possible that transferred models can yield reasonable order of magnitude estimates of the impacts of various policies. Therefore, they may be very useful for comparison of the relative desirabilities of policy alternatives.

It should be noted that subsequent research by CRA has resulted in the modification of the modeling system to contain the exact values of the I and I' variables rather than linear approximations (*B-17*). This modification resulted in substantial changes in some of the derived point elasticities.

Elasticities estimated from this modeling system can also be used for determining the degree to which some policy change will affect different aspects of the travel decision. An example of such an application uses conditional probability models for mode choice, time-of-day choice, destination choice, and frequency choice (*B-17*) for shopping trips. The elasticity for any travel decision (e.g., frequency) can be defined as a multiplicative function of the other conditional probabilities, the independent variable of interest, and the relevant coefficients. Using this approach, point elasticities with respect to transit reveal that the order of sensitivity of travel choice, from least responsive to most responsive, is as follows: frequency choice, time-of-day choice, destination choice, and mode choice. This sequence suggests that evaluation of policies affecting variables such as transit time can ignore certain travel choices because of the small degree of sensitivity.

CSI Applications. The CSI modeling system (*B-12*, *B-13*, *B14*) contains auto ownership and work mode choice components as well as a nonwork trip model. There are direct links between the nonwork trip models and the other components in that the auto ownership variables in the nonwork models are affected by auto ownership levels and work mode choice.

The nonwork trip model, again a shopping trip model, is a joint frequency, destination, and mode choice model. The model was estimated simultaneously rather than sequentially like the CRA model. The independent variables were similar to those used by CRA (i.e., trip times and costs, destination characteristics such as employment, and socioeconomic characteristics were included).

The carpooling policies included auto disincentives such as parking charges and/or restrictions and gasoline taxes, carpool and transit incentives that improve trip times on these modes, and introduction of a new vanpool mode. As in the CRA model, policies were analyzed by changing either the choice sets or the level-of-service variables in the model.

A major finding from the research involved the interdependency between work and nonwork travel. Policies that focused exclusively on the work trip had their effectiveness reduced by increasing auto availability for nonwork travel. On the other hand, policies that affected both work and nonwork travel were especially effective because of the apparently greater sensitivity of nonwork travel to level-of-service changes.

The policy analyses were performed for several cities. In some of the applications, the incremental form of the logit model was used in place of the usual form (*B-13*, *B-14*). This form of the model is

$$P'_j = P_j \exp(\Delta u_j) / \sum_k P_k \exp(\Delta u_k) \qquad \text{(B-11)}$$

where:

P'_j = the probability of selecting alternative j after a change in the transportation system;
P_j = the probability before the change; and
Δu_j = the change in the systematic component of the utility function.

Alternative j could be either a simple alternative such as a mode or a composite alternative such as a mode-destination combination.

The incremental form of the logit model can be applied to estimate changes in aggregate shares for homogeneous market segments. The procedure requires the identification of suitable segments, aggregate shares for the segments, average changes in the relevant variables, and the coefficients of these variables. It should be noted that the information requirements for this approach are similar to the requirements for applying elasticities. This is advantageous in that the demand model would be used in its exact form rather than in the approximate form implicit with elasticities.

Assessment of Nonwork Probability Choice Models. The preceding examples indicate that probability choice models can be used to analyze policies that change level-of-service variables and, possibly, policies that introduce new alternatives. Compared with conventional aggregate models, these models are sensitive to a wider range of potential policies and are easier to apply.

There are some features of these models that suggest alternative approaches, however. First, the definition of the home-based round trip excludes a substantial proportion of travel that does not fit the definition (fewer than half of the households that made shopping trips fit the round-trip definition in the CSI data set; see Adler and Ben-Akiva (*B-8*)). Recent research to model more complex trip chaining behavior is an attempt to make such models more complete (*B-18–B-20*). Second, the models are designed to yield a degree of spatial specificity that might be unnecessary for energy policy analysis of regional impacts. In particular, the representation of travel patterns involving specific destinations may include more detail than necessary to derive VMT estimates.

A simplified modeling approach to nonwork travel might address both of these problems. The definition of variables that summarize key features of travel patterns (e.g., daily VMT or time allocation) could implicitly include more information on daily trip patterns than does the round trip variable of existing models. At the same time, the suppression of spatial detail may make such models easier to apply.

The other approach to improving existing models is to explicitly define more complex travel patterns. Because this approach has only recently been attempted by transportation researchers (*B-21*) and because it complicates rather than simplifies the resulting models, it is not anticipated that it will be used in this project.

Simplified Models

Variables that summarize complex travel patterns include number of trips, average trip distance, VMT, and time allocated to travel. Simplified models explain these summary variables rather than choices of particular alternatives. The general nature of this approach is illustrated below by a CRA simultaneous equation nonwork trip model (*B-22*) and recent studies of time allocation (*B-7, B-23*).

CRA Simultaneous Equation Nonwork Trip Model. (Most of this section is from Charles River Associates (*B-24*).) Charles River Associates has developed simultaneous equation models of household VMT and numbers of auto and transit trips, and auto trip length for nonwork travel over a 4-day period. The models are estimated using two-stage least squares on the Nationwide Personal Transportation Study (NPTS). NPTS records the trip-making behavior and automobile ownership in four gross categories, as well as geographic and socioeconomic information. Because these models are not as well known as probability choice models, they are presented in more detail; the equation specifications are given in Table B-1.

VMT is modeled as a function of transportation system and demographic and geographic variables. System variables include the time and cost of transportation. The money cost of travel accounts for the fuel economy variations among auto categories. Demographic variables include the number of drivers, people over the age of four per household, and household income. Geographic variables are the size of the urban area, SMSA, and place of residence.

Number of auto nonwork trips is estimated as a function of the number of automobiles available; the number of workers, drivers, and people over the age of four in the household; household income; and time and money costs of transportation. The size of the SMSA is also included.

Trip length is modeled as a function of the number of trips, travel costs, income, and urban and residential area size.

It is interesting to note that the number of autos available is not found to influence total VMT, but it did shift the frequency of trips. This implies that households have some flexibility in the timing of nonwork travel, and may postpone trips until autos become available. Travel costs and demographics all have effects on VMT that are of the expected magnitude. The geographic variables show an inverse relationship between VMT and both SMSA size and residential area size; but they show a positive relationship with urban area size. Because urban centers attract auto trips from surrounding areas, as the urban area increases, trips from residences to the urban center become longer, increasing VMT. For the larger census-defined residential areas and SMSAs, however, there are more potential destinations satisfying a trip purpose, decreasing trip length.

The CRA model is appealing because it models VMT for nonwork travel in a behavioral way; yet it is analytically solvable. In future studies, it may be useful to update a model of this nature by reestimating the model on a regional, rather than national, data set (e.g., the Baltimore disaggregated data set) or by reestimating the model with the later version (1977) of the NPTS data.

Time Allocation Models. Time allocation models tend to emphasize the travel-related activities that people engage in rather than the travel per se. Time allocation then becomes

TABLE B-1(a)

ESTIMATED NONWORK TRAVEL EQUATIONS CHARLES RIVER ASSOCIATES MODEL—VMT

Variable	Equation
VMT	Dependent
Constant	162.5
	(4.842)
#T.TRP	-24.24*
	(2.209)
D.TM/MI	- 7.838
	(2.609)
D.V.HH.TM/MI	- .4751
	(1.572)
D.CO/MI.V.HH	-51.01
	(2.244)
#PPL>4	4.966
	(1.855)
URBAN	- 3.394
	(2.042)
SM.SZE	- 2.897
	(1.0468)
PLCSZE	- 1.979
	(1.671)
#LIC.D	15.14
	(2.738)
D.PKAV	-20.04
	(0.921)
HH$	-----
#CARS	-----
R^2 (corrected)	.1059

Number of observations = 638

*Indicates jointly dependent variable.

TABLE B-1(b)

ESTIMATED NONWORK TRAVEL EQUATIONS CHARLES RIVER ASSOCIATES MODEL—NUMBER OF AUTO TRIPS

Variable	Equation
#D.TRP	Dependent
Constant	11.44
	(5.702)
#T.TRP	-1.589*
	(3.894)
D.DIST	-----
D.TIME	- .05269*
	(1.063)
D.TM/MI	-----
D.CO/TRP.V.HH	-0.1085*
	(0.7509)
D.CO/MI.V.HH	-----
H.H.$	.00009403
	(1.380)
SM.SZE	- .4051
	(2.136)
#PPL>4	.8122
	(4.385)
#LIC.D	1.711
	(3.514)
#EMPLY	- .7778
	(1.992)
#CARS	1.313
	(2.713)
D.PKAV	-5.695
	(3.597)
R^2 (corrected)	.1710

Number of observations = 638

*Indicates jointly dependent variable.

TABLE B-1(c)

ESTIMATED NONWORK TRAVEL EQUATIONS CHARLES RIVER ASSOCIATES MODEL—AVERAGE AUTO TRIP DISTANCE

Variable	Equation
D.DIST	Dependent
Constant	28.65
	(7.703)
#D.TRP	- .5890*
	(5.323)
D.TM/MI	-1.582
	(8.019)
D.CO/MI.V.HH	-6.116
	(1.718)
H.H.$	- .0001472
	(0.9301)
URBAN	- .3713
	(1.650)
PLCSZE	- .3136
	(1.932)
R^2 (corrected)	.0928

Number of observations = 638

*Indicates jointly dependent variable.

TABLE B-1(d)

ESTIMATED NONWORK TRAVEL EQUATIONS CHARLES RIVER ASSOCIATES MODEL—NUMBER OF TRANSIT TRIPS

Variable	Equation
#T.TRP	Dependent
Constant	1.444
	(1.158)
T.TIME	-0.009959*
	(0.711)
T.V.HH.TIME	-----
TAVL.D.T.TRP	1.707*
	(1.666)
H.H.$	-.00006254
	(1.365)
HH.SZE	-.3722
	(1.377)
#PPL>4	.7377
	(2.357)
F.H>HH	-----
R^2 (corrected)	.0942

Number of observations = 108

*Indicates jointly dependent variable.

TABLE B-1(e)

ESTIMATED NONWORK TRAVEL EQUATIONS CHARLES RIVER ASSOCIATES MODEL—VARIABLE DEFINITION FOR NONWORK TRAVEL MODELS

Variable Name	Variable Definition
VMT	Vehicle miles traveled by a household for nonwork trips over a four-day period
#D.TRP	Number of nonwork automobile trips by a household over a four-day period
D.DIST	Average distance of each nonwork automobile trip by a household over a four-day period, in miles
#T.TRP	Number of nonwork transit trips by a household over a four-day period
D.CO/MI.V.HH	Average gasoline price per mile of a nonwork auto trip for a household divided by the household wage per minute in minutes/miles
D.CO/TRP.V.HH	Average gasoline cost per nonwork auto trip for a household divided by the household wage per minute, in minutes
D.TIME	Average travel time for an auto nonwork trip by a household, in minutes
D.TM/MI	Average travel time per mile for an auto nonwork trip by a household, in minutes/mile
D.V.HH.TIME	Average travel time for an auto nonwork trip by a household multiplied by the household wage per minute, in cents
D.V.HH.TM/MI	Average travel time per mile for an auto nonwork trip by a household multiplied by the household wage per minute, in cents/mile
T.TIME	Average travel time for a transit nonwork trip by a household, in minutes/mile
T.V.HH.TIME	Average travel time for a transit nonwork trip by a household multiplied by the household wage per minute, in cents
D.PKAV	Fraction of household's nonwork auto trips for which free parking was available
TAVL.D.T.TRIP	Fraction of household's nonwork auto and transit trips for which transit was available within 6 blocks
H.H.$	Household income, in dollars/year
#CARS	Total number of cars owned by the household
#LIC.D	Total number of licensed drivers in the household
HH.SZE	Total number of household members
#PPL>4	Number of household members aged 5 or older
#EMPLY	Number of employed persons in household
F.H>HH	Dummy variable equal to one if a female head of household and zero otherwise
URBAN	Coded variable indicating population of urban area ranging from 1, for largest area, to 8, for smallest area
SM.SZE	Coded variable indicating population of SMSA ranging from 2, for smallest area, to 7, for largest area.
PLCSZE	Coded variable indicating population of household residence place ranging from 0, for smallest, to 15, for largest

a measure of activity choice behavior. This line of research is relatively new to the transportation research community. Consequently, it is anticipated that it will be more suggestive of research approach than definitive.

Two recent time allocation studies are briefly reviewed here. Damm (*B-7*) developed models of time allocation to five daily periods (before work, on the way to work, at work, on the way home, and after work). For purposes of this review, the explanatory variables can be categorized into socioeconomic variables, transportation systems variables, and variables indicating time constraints. For policy analysis purposes, the middle category of variables is the most relevant. In particular, accessibility variables can be varied to analyze the effects of transportation systems changes on time allocation. These variables are composite variables of the form of the I and I' variables discussed in the section on probability choice models. The time constraint category contains variables indicating starting and ending time for work. Those variables might be useful in analyzing the impacts of policies involving work-hour changes on activity time allocation.

Charles River Associates (*B-23*) also has applied the time allocation approach in NCHRP Project 8-14. Up to now, the modeling effort has emphasized demographic and socioeconomic variables in the explanation of activity choice behavior. Therefore, the models are not sensitive to energy policy instruments and the results are not directly applicable to this study.

Because time allocation models emphasize activity choices and not travel per se, they do not produce outputs of direct relevance for energy policy analysis. For them to be policy-relevant, it would be necessary to convert time allocations into variables such as VMT (e.g., an auxiliary model relating VMT to time allocated for travel could be estimated). Investigations of this type are necessary if time allocation models are to become useful for energy policy analysis purposes.

Long-Run Mobility Choice Models

Auto ownership and residential location are longer-term choices that have implications for energy consumption. Relative to work and nonwork travel models, much less research has been performed. Recently, however, models of automobile ownership and residential location choices have been developed. Examples of these models are evaluated here.

Vehicle Demand Models

Since private motor vehicles account for most of the passenger travel in this country, vehicle ownership information is important in analyzing the impacts of energy policies. In recognition of this fact, there has been a large amount of research to develop better vehicle demand models. This work has resulted in models for explaining the number of vehicles owned by a household (see, for example, Lerman and Ben-Akiva (*B-25*) and Burns et al. (*B-26*)) and in models for explaining the type of vehicle chosen (Lave and Train (*B-27*), Cardell and Dunbar (*B-28*), Boyd and Mellman (*B-29*), Beggs and Cardell (*B-30*), and Manski and Sherman (*B-31*)).

Models that explain number of vehicles owned by households often contain variables such as income and household size as explanatory variables. Disaggregate models also contain accessibility variables so that the effects of automobile and transit accessibility on auto ownership can be explored. Models of vehicle type choice focus on socioeconomic variables and characteristics of vehicles such as price, fuel economy, and size in explaining the choice of a household among alternative vehicle types. This kind of vehicle demand model is especially useful for examining changes in fleet fuel economy resulting from changes in ownership patterns among vehicle types.

In the context of this project, probably the most important output from models of this nature are estimates of fleet fuel economies and levels of vehicle ownership. Because much of the work on vehicle demand models is quite recent and because these models require fairly heavy data, computer, and technical resources, it is likely that state and local transportation analysts will rely on published vehicle ownership and fuel economy forecasts as has been done in developing the scenarios in Appendix A. Therefore, detailed reviews of particular models are not presented. The interested reader may consult Train (*B-32*) for a review of aggregate and earlier disaggregate vehicle demand models and Tardiff (*B-33*) for a review of later disaggregate models.

Studies of Residential Location

Residential location choice processes have been an important concern of researchers from many different disciplines. A number of different approaches, discussed in three broad categories, have been used. These include microeconomic approaches to location theory, large-scale urban simulation models, and probability choice models.

Location Theory. The location theory approach (*B-34*) results in an abstract representation of residential land-use patterns based on a number of simplifying assumptions (e.g., all jobs located in the CBD, households with similar tastes). Households are assumed to choose the most satisfactory combination of housing and journey to work subject to a budget constraint. Analytical solution of the abstract problem yields information on density patterns, rent gradients, and commuting distances.

Although the approach is useful in gaining insight into the general nature of cities, it is doubtful it can be used for specific policy applications. First, the focus may be too abstract to apply to real urban areas. Second, the simplifying assumptions may result in serious deviations from reality. For example, this approach was used to conclude that a $0.10 per gallon increase in gasoline prices would lead to about an 8.5 percent reduction in work trip travel in the long run (*B-35*). Although responses to the recent price increases may be considered short-run, this estimate appears to suggest a much greater sensitivity to price than seems apparent from current behavior.

Urban Simulation Models. Although a large amount of research effort has been devoted to urban simulation models, particularly in the 1960s, the results have been far from successful. (Reviews of these modeling efforts are presented by Goldman (*B-36*), Lee (*B-37*), Senior (*B-38*),

and Putnam (*B-39*).) These models tend both to require large amounts of data, time, and monetary resources and to be specific to particular cities. Therefore, they are inconsistent with the goals of this project, which emphasize quick response, policy-sensitive tools.

Probability Choice Models. There has been increasing research interest in developing probability choice models of residential location (*B-9, B-40–B-43*). Probably the study best known to the transportation research community is Lerman's (*B-9*) joint housing type, location, auto ownership, and mode-to-work model. As mentioned earlier, this model is an extension of Lerman and Ben-Akiva's (*B-25*) auto ownership and work mode choice model.

The joint choice structure has the same basic form as the joint choice nonwork trip models. The independent variables characterizing the alternatives include: (1) transportation level-of-service variables, (2) auto ownership costs, (3) housing and locational characteristics, and (4) socioeconomic characteristics. Twenty-five individual variables were included in the four categories.

Both the complexity of the alternatives and the number of independent variables inhibit the use of this model as a quick-response policy tool. As in the case of nonwork travel models, a model that uses specific spatial locations in defining alternatives may contain unnesessary detail for certain types of policy analyses. In addition, the joint choice structure further increases the size of the choice sets used in the model. Therefore, although the model was a pioneering study of long-run spatial choice processes, its particular features make it an unlikely candidate for inclusion in a forecasting system emphasizing quick-response methodologies.

Assessment of Residential Location Models. Because of the inherent complexity of location choice processes, it is not surprising that modeling efforts have not progressed as far, theoretically or practically, as have travel models, especially those for work mode choice. It appears that previous research will have little use in developing quantitative tools for predicting residential location impacts of energy policies.

On the other hand, the insight gained from existing studies is useful in qualitative analyses. An approach to such analyses would involve informed judgments on the direction and likely magnitude of changes in residential location choices in response to energy policies (this type of information is used in the qualitative analyses of Chap. Three). For example, a review of a variety of location choice studies might produce a range of possible sensitivities of distances to work to price of travel. By documenting such information in narrative and tabular form, policy makers could qualitatively consider residential location impacts.

Attitudinal Models

Most of the earlier research on travel behavior emphasized objectively measurable variables such as travel times, costs, and observable socioeconomic variables. These variables are relevant to the types of level-of-service changes traditionally of interest to planners and are also conducive to using the models for forecasting purposes. However, researchers such as Paine et al. (*B-44*) and Gustafson et al. (*B-45*) have recognized that there are variables that may not be measurable with objective scales, but which influence travel behavior. For example, comfort and convenience may be as important as time and cost in explaining mode choice.

Recently there have been several studies of the use of attitudinal variables in models of travel behavior. Most of these have focused on modal choice (*B-46–B-49*). Recker and Kostyniuk (*B-50*) and Koppelman and Hauser (*B-51*) have used attitudinal variables in explaining shopping destination choice, and Dobson and Larson (*B-52*) have applied attitudinal variables in their study of auto ownership choice.

Models of the relationships between travel attitudes and behavior are typically estimated with cross-section data. Discussion of the typical assumptions used in attitudinal modeling is facilitated by use of Dobson's (*B-53*) diagram of relationships among sets of variables. The diagram emphasizes modal choice behavior, but could be modified to explain other transportation choices.

			Perceived
	Behavioral	Modal	Modal
Behavior ←	Intention ←	Affect ←	Attributes

The diagram is useful in clarifying two basic issues. First, the term "attitude" actually involves three different classes of variables. Perceived modal attributes are beliefs about the characteristics of alternative modes (e.g., about how comfortable or safe a bus is). Modal affect is a measure of the overall satisfaction with a mode, and behavioral intention is a measure of a person's intended use of mode in a given hypothetical situation. All three types of variables have been referred to as attitudinal variables.

The second issue is the assumed causal sequence involving attitudes and behavior. The direction of the arrows clearly illustrates the typical assumption that attitudes cause behavior. However, recent research has suggested that the reverse sequence of behavior change leading to attitudinal change should also be specified (*B-54, B-55*). The possible existence of this reverse causality has important implications for planning applications. In addition to direct implications for policy formulation (*B-55*), simultaneous interactions between attitudes and behavior have implications for prediction. Ignoring simultaneous interactions when they, in fact, exist leads to biased predictions. Recognition of this fact complicates the application of attitudinal models. Either a simultaneous equation model or an auxiliary model representing the response of attitudes to behavior would be required in forecasting behavior that is simultaneously determined with attitudes. This complication inhibits the use of attitudinal models for quantitative forecasting.

In addition to possible simultaneous interactions between attitudes and behavior, other characteristics of attitudinal variables are relevant in assessing the predictive capabilities of attitudinal models. In particular, the fact that they are measured with scales with no natural units should be discussed.

The lack of natural scales creates conceptual problems not present with objectively measured variables. In the latter case, it is usually clear whether the variable is measured appropriately (the validity issue), the repeated measurements will yield similar results (the reliability issue), and the researchers in different studies will measure the variable similarly. With attitudinal variables, there are questions with respect to each of the three criteria. First, it is difficult to determine whether a given attitudinal scale actually measures the intended variable. For example, a five-point scale measuring perceived safety may reflect, in part, overall feelings toward a mode (the "halo" effect) or the term "comfort" may mean different things to different people. Second, there has been very little research on the reliability of the attitudinal scales used in transportation studies. Third, it is generally the case that somewhat different attitudinal variable scales are used to measure the same concept in different research applications.

The stability of attitudinal variables is an important consideration. It has not been established whether transportation attitudes are reasonably stable over time or whether they fluctuate fairly rapidly. In the latter case, such variables would present application difficulties even if they could be measured accurately.

The prediction of attitudinal variables for future forecast periods creates a third problem. Unlike objectively measured independent variables (e.g., level-of-service variables or socioeconomic variables), where reasonable predictions can be made, procedures for forecasting attitudinal variables are not available. A possible approach to solving this problem would be to use objective surrogates for the attitudinal variables. This is straightforward for variables such as perceived times and costs (the objective counterparts could be used here). For other variables, the choice of surrogates is less obvious. Until procedures for forecasting attitudinal variables are developed, the use of attitudinal models for forecasting purposes will be limited.

The preceding discussion indicates that there are problems that inhibit the application of attitudinal models for forecasting purposes. However, attitudinal studies of energy issues can yield useful information for qualitative analyses, as illustrated in Chapter Three. For example, behavioral intentions information may be quite useful. Rather than viewing such variables as attitudinal, they would be considered surrogates for behavioral variables not easily measured with standard survey research approaches. For example, existing data may not cover relevant price ranges or shortage situations. In order to obtain behavioral responses to such situations, behavioral intentions data may be necessary. Problems in obtaining behavioral intentions information that reasonably approximates future behavior are discussed in a later section of this report.

Studies Performed During Energy Shortage Periods

During and following the 1973–1974 energy shortage and also during the recent 1979 shortage, a limited number of studies of transportation attitudes and behavior were performed (*B-56–B-65*). The key issues with respect to this project are the following: (1) whether the data are in a form that can be incorporated into a forecasting system; and (2) whether the data yield accurate estimates of likely behavior. In general, the answer to at least one, or maybe both, of these questions is "no" for most existing studies of this nature.

These studies typically collected two types of information of interest: (1) adjustments in travel behavior during the energy shortage; and (2) hypothetical behavior during future energy shortages and/or price increases. The most frequently collected information on previous behavior was checklists of actions taken during the energy shortage. This type of information provides a good qualitative view of the type and complexity of actions taken during the shortage. The general pattern of findings is that such actions tended to be short-run adjustments, some of which involved complex trip chaining patterns. However, little information is available on the magnitude of these adjustments (i.e., how did the stated action contribute to reduced energy consumption). Therefore, although the studies served a useful purpose of identifying patterns for qualitative analyses and suggesting future research directions, they are not directly useful for quantitative forecasting.

The hypothetical behavioral responses also are not directly useful. First, the scenarios presented in the earlier data sets are dated. During the 1973–1974 shortage, $1.00 per gallon of gasoline appeared to be an upper limit, while now it is less than current prices. Second, many of the questions are of the checklist variety, so no estimation of magnitude is possible. Finally, unless hypothetical behavior questions (behavioral intention) are carefully worded, estimated magnitudes of response are likely to be seriously biased. As Jones and his colleagues (*B-66, B-67*) and Stefflre (*B-68*) note, the scenario must be presented in such a way that a direct comparison with existing behavior is made. That is, the relevant issue is how desirable the hypothetical behavior is relevant to its options, including the existing behavior, and not how desirable it is in the abstract. Unfortunately, few behavioral intentions studies, including energy-related ones, structure the questions in the most suitable format.

Time-Series Modeling

Most analytical methods familiar to transportation planners are based on cross-section data. Time-series data may also be useful. Because time-series models are less familiar to transportation planners, several examples are reviewed in some detail here. They include models of Montreal transit ridership (*B-69*), which also illustrate the usefulness of data that might be collected by transportation agencies, time-series models of automobile demand, and gasoline consumption.

Aggregate Time-Series Transit Models

Gaudry and Wills (*B-69–B-71*) have used monthly data to estimate several transit ridership models in Montreal. Their purpose was to demonstrate the usefulness of time-series anaysis and to test alternative econometric techniques. In addition to transit system ridership, aggregate transit level-of-service variables and areawide demographic variables, the time-series approach allows the specification

of variables that change periodically or nonsystematically. For example, the models contain variables such as monthly weather indicators and whether a labor strike occurred.

These models are illustrative of the usefulness of analyzing regionwide time-series data. In addition to defining the effects of level-of-service variables, models of this nature can be used to analyze the effects of seasonal variations and other factors that vary over time. For example, this approach may be useful in separating the effects of price increases from the effects of fuel shortages during the spring-summer 1979 energy shortage. It might be useful to assess the availability of appropriate time-series data for analysis of this type.

Automobile Demand Models

Time-series data have been used to develop models of automobile ownership. These models typically explain auto ownership with independent variables such as price of cars, and economic indicators such as unemployment. To the extent that these models contain variables that can be influenced by energy policies (e.g., cost of ownership), they may be useful for policy planning. However, policies that affect attributes other than ownership costs are difficult to analyze with these models.

An extensive review of these models has been performed in other projects conducted by Charles River Associates (*B-24, B-72–B-74*). Rather than presenting a similar review here, some of the features of this type ot model are illustrated with a rather simple model.

Kulash (*B-75*) estimated a set of auto demand models. One component of the modeling system was a model that estimates the share of new autos by class (small, medium, large). The equation for the small class share is

$$Q_t^s = 1/[1 + \exp(-4.17 - 1.87\, X_t^s + 3.51\, X_t^m + 5.64\, Q^s_{t-1})] \qquad \text{(B-12)}$$

where:

Q_t^s = the market share of small autos in year t;
X_t^s = the ratio of small car ownership costs to average ownership costs; and
X_t^m = the ratio of medium-sized car ownership costs to average ownership costs.

The equations for the other two market shares are similar. National data for the years 1963 to 1973 were used.

These models illustrate two features of the time-series approach. First, policy sensitivity of the model is only available through the cost variables. Second, shares in the preceding year are assumed to affect this year's shares. The use of lagged dependent variables in time-series models, a feature that is obviously not present in cross-section models, is consistent with the assumption that there is some inertia or determinants of choice not explainable by the other independent variables.

Gasoline Demand Models

Gasoline demand studies share some features with auto demand studies. They often have a national scope and also focus on price variables. Because they deal directly with gasoline consumption, they will probably not be used directly in the forecasting system. Rather, as noted in the work plan, they can serve as a useful check on the gasoline consumption outputs from the forecasting system.

An example of a gasoline demand model is given by McGillivray (*B-76*). The following model was estimated on the basis of annual national data from 1951 through 1969:

$$G_t = -111.68 - 1.79P_t + 818.69A_t + 0.32\lambda_t + 0.70G_{t-1} \qquad \text{(B-13)}$$

where G_t is the passenger car per capita gasoline consumption in gallons; P_t is the real gasoline price in cents; A_t is the per capita new car registrations; and λ_t is the average annual gasoline consumption per automobile.

The main features of this model are the price variable and the lagged dependent variable. The model implied a price elasticity of −0.225 at the mean of the independent variables. Analysis of energy policies with the model would involve varying the price of the gasoline variable. Also, automobile fuel efficiency policies may be analyzed indirectly by changing the annual gasoline consumption per automobile variable. However, because this variable captures the effects of both changes in the vehicle fleet and changes in travel behavior, analysis of this sort would probably be quite crude.

EVALUATION OF EXISTING AND STATE-OF-THE-ART METHODS

In this section, the methods described in the previous section are evaluated according to the six criteria presented at the beginning of this appendix. Several state-of-the-art methods are also evaluated with the same criteria. These include estimation of new quantitative models and laboratory simulation and gaming techniques. Next, qualitative analysis approaches are evaluated. Finally, the results of the evaluations are described in a Table B-2 at the end of this appendix.

Elasticities

1. Policy sensitivity. The policy sensitivity of this technique is determined by the demand elasticities available. Given available estimates, this method is best suited for forecasting the effects of policies that affect travel time and cost. As noted in the scenario report, this method is relevant to contingency planning because many energy contingency plans focus on travel time and cost. Since forecasting with elasticities involves factoring the base conditions, aggregate elasticities are more relevant because planners are typically only aware of the aggregate change produced by policies.

2. Forecast relevance. The relevance of the output variables generated with the elasticity method depends on the true domain of response produced by the policy. In general, elasticities are relevant for testing policies that impact the modal split and total travel.

3. Accuracy and reliability. The accuracy of the input data depends on the accuracy of the data originally used to estimate the elasticity and the data used to describe the base conditions. Several other factors influence the accuracy of

the predicted responses: how appropriate the elasticity is to the subject area; whether long- or short-run relationships are revealed; and, if disaggregate elasticities are used, the accuracy of the aggregation procedure employed. Moreover, because elasticities are generally estimated with models based on restrictive assumptions about the travel response domain, if secondary linkages are important, the forecast response may be biased. The elasticity method is best applied to marginal changes, because the larger the change the less accurate is the approximation. Elasticities have been shown to be generalizable across different areas if the guidelines described earlier are followed.

4. Data requirements. Elasticities for common variables such as travel time and cost are widely published and readily available. Typically the base conditions and design conditions are known to the planner at the aggregate level with little or no extraordinary data collection expertise. If the policy involves changes in independent variables far beyond the range of observed values, however, transportation experiments may be necessary to generate reliable estimates of demand relationships over this range.

5. Manpower and computation requirements. Elasticities can typically be applied manually and require little time.

6. Operational availability. Elasticities are widely used among state and local planners, although they are often applied indiscriminately. Because most of the guidelines for use of elasticities are intuitively appealing, planners can quickly acquire the expertise necessary to use this method in the best way.

Work Mode Choice Models

1. Policy sensitivity. These models typically include modal travel time and cost variables and therefore predict well the impacts of policies involving a change in these variables. They are not sensitive to policies involving changes in the variables not included in the models.

2. Forecast relevance. The models are only relevant when the work trip mode choice response is significant. They are not relevant when the impact on other travel decisions or other trip purposes is dominant. Because most contingency plans and the shortage of fuel itself affect travel decisions excluded from this model, the forecast relevance is limited.

3. Accuracy and reliability. These models are fairly reliable and the coefficients have been shown to be transferable across areas. Although the constant term is not transferable, there are simple procedures for updating this term. The work trip model forecasts shifts in work trip modal choice fairly well in most cases.

4. Data requirements. Although the models are readily available, considerable data are required to use the model as a forecasting tool. To produce reliable estimates of aggregate response, data are needed at a level of disaggregation typically not available to planners. Moreover, the estimated response to policies affecting level-of-service variables are applicable only to travelers who have a choice of modes. Planners often do not know the proportion of travelers facing the necessary choice set. Typically, use of this technique will involve a trade-off between accuracy of forecasts and resources for collection of more detailed data.

5. Manpower and computation requirements. Application of this technique is done best with a computer because manual application can become burdensome. Once the technique is understood, the manpower and computer requirements are about average for the techniques available.

6. Operational availability. Although many planners are familiar with the model, the techniques for updating the model and aggregating results are not widely understood. The methodology, however, has been used and tested sufficiently by transportation researchers.

Nonwork Probability Choice Models

1. Policy sensitivity. These models rate high on this criterion because they are sensitive to a wide range of level-of-service, land-use, and choice-set changes. This permits the examination of a number of energy conservation policies, as has been done with previous studies.

The sensitivity of these models to policies not directly affecting level of service (e.g., car pool promotion or allowing lines at gasoline stations) is less clear. Therefore, it may be necessary to supplement the models with other methods for these types of policy analyses.

2. Forecast relevance. These models typically give detailed information on nonwork travel patterns at any desired level of aggregation or disaggregation. This information can be directly converted to VMT. Further, by making reasonable assumptions, impacts like fuel consumption, activity patterns, and consumer expenditures can be indirectly addressed.

A possible weakness of existing nonwork trip models is that they are usually trip specific (typically shopping) in that they do not cover the full range of nonwork travel; some important short-run impacts may not be fully captured.

3. Accuracy and reliability. It is impossible to make absolute statements about forecast accuracy because models are typically applied to hypothetical situations involving no direct verification. However, applications to date seem to offer reasonable insights into the impacts of policies. In addition, outputs seem to be consistent with outside information and intuition.

Since models are usually applied on a regional basis, data are not generalizable across areas. The models may be dependent on the degree of transferability. One way to avoid the regional specificity of typical analyses is to apply the models to prototypical urban areas. The general conclusions of such exercises may then be applicable to real urban areas with similar characteristics.

4. Data requirements. These models typically contain three types of independent variables: (a) transportation level-of-service variables, (b) destination characteristics (land-use information), and (c) socioeconomic variables. Some researchers attempt to make these models more closely representative of choice processes and more policy sensitive by using a large set of independent variables. For example, travel times have been divided into various components. This strategy introduces a trade-off between model accuracy and data requirements. Because it is necessary to forecast values of a large number of independent variables to apply the models (the CRA model (*B-3*) may be an exception—the number of independent variables was in-

tentionally kept small), they rate fairly negatively on this criterion.

It should be noted that if there are errors in the forecasts of the independent variables, a model with more variables might actually forecast worse than a simpler model (*B-77*). In this case the errors in the variables would more than overcome the greater accuracy of the more complex models.

5. *Manpower and computation requirements.* These models are rated somewhat negatively here because of the research necessary to assemble the forecast data bases and because of the rather complex procedures necessary to convert individual predictions to aggregate forecasts. The latter require either complex analytical procedures or sampling methods that inhibit simple desk calculation applications.

6. *Operational availability.* The capabilities of these models have been demonstrated by the research community. However, although some state and local agencies appear to be using probability choice work trip models (*B-78*), the nonwork trip models do not seem to have been used much.

Simplified Nonwork Trip Models

Since the CRA model (*B-22*) appears to be the only example that has been used for policy analysis, the evaluation here refers to that model. It is expected that this model is typical of new models that may develop in this or other studies.

1. *Policy sensitivity.* In general, simplified models can be developed to analyze the same types of policies as probability choice models. They are rated somewhat lower on this criterion because the input variables describe daily travel patterns rather than specific trips. Because the models are simplified, some sensitivity to policies that differentially affect different types of trips may be sacrificed.

2. *Forecast relevance.* These models are designed to forecast directly VMT and number of trips. Therefore, they can be used to obtain quantitative estimates of fuel consumption. Further, secondary impacts, such as activity patterns and consumer expenditures, can be inferred. This type of model may rate slightly higher than probability choice models on this criterion because such a model describes all nonwork travel and not merely particular trip purposes.

3. *Accuracy and reliability.* Because these models do not appear to have been used for forecasting, their forecasting accuracy is unknown. However, elasticities from the CRA model are consistent with those reported elsewhere (*B-22*).

Since the model was developed with national data, its application appears to be quite generalizable. The model could be applied to analyze uniform national policies at a regional (SMSA) level or to analyze prototypical urban areas.

4. *Data requirements.* Because level-of-service variables in the models describe general trip patterns rather than specific trips, data requirements for these models are smaller than for probability choice models. They also do not require specific destination characteristics. Further, the socioeconomic characteristics of the model are generally available from published sources. Therefore, this type of model rates fairly highly on this criterion.

5. *Manpower and computation requirements.* Assembling the forecasting data set appears to be straightforward and not too demanding of staff resources. Because the models are simultaneous linear models, no complex aggregation procedures are necessary. The models probably could be used with a desk calculator, although the simultaneous equation structure introduces some complexity not found in single equation linear models.

6. *Operational availability.* Although the methodology is straightforward to apply, state and local experience, if it exists at all, is limited. Also, because the approach is fairly new, further development and testing may be desirable.

Auto Ownership Models

1. *Policy sensitivity.* No existing auto ownership model completely addresses all relevant issues. The models that predict number of autos owned are sensitive to transportation level-of-service changes and changes in average auto costs. These models, however, are not sensitive to policies designed to lead to more fuel-efficient autos. On the other hand, models explaining the type of auto owned are sensitive to fuel efficiency policies, but are insensitive to changes in the level of service of the transportation system.

2. *Forecast relevance.* Because information on the number of automobiles per household and the types of autos owned is important in explaining gasoline consumption, the outputs from auto ownership models are highly relevant.

3. *Accuracy and reliability.* Although there have been only a few applications of these models, these results appear to be reasonable, especially for the auto type models. The generalizabilty of the procedure depends on the specific model. The models explaining the number of household autos are developed for specific regions. Therefore, the comments on the generalizability of work and nonwork probability choice models apply here. The auto type models are typically estimated with national samples and therefore appear to be generalizable across different areas.

4. *Data requirements.* The models explaining number of autos owned require about the same amount of data as the nonwork probability choice models because they contain accessibility variables that have level of service and some destination characteristics. To the extent that such data are collected for other models, data requirements are lessened. The auto type models require data on the characteristics of particular auto types (e.g., the weight and fuel economy of subcompact autos). Although these data require some effort to assemble initially, because they do not generally vary regionally, data already assembled for studies such as the CRA auto demand studies should be useful for other applications.

5. *Manpower and computation requirements.* These models generally have the same functional form and independent variables similar in scope to those of probability choice nonwork trip models. Therefore, evaluation of this criterion is similar to evaluation of probability choice nonwork models. The CRA Hedonic Demand Model, which is a random coefficient model, is somewhat more demanding in terms of computational resources.

6. *Operational availability*. Again, auto ownership models have been developed and tested within the transportation research community. However, experience at the state and local levels is minimal.

Residential Location Models

1. *Policy sensitivity*. Models of this type typically explain residential location as being determined, in part, by accessibility. Therefore, these models are useful for testing the impacts of changes in accessibility variables (i.e., costs and times of travel) on residential location.

2. *Forecast relevance*. Residential land-use impatcs may be important long-term effects. Therefore, model outputs are relevant for energy policy analyses.

3. *Accuracy and reliability*. Because residential location models have presented large theoretical and practical difficulties, there is little evidence of their accuracy. However, there is reason to suspect their outputs. For example, Boyce et al. (*B-79*) found that the outputs from some of these models were highly insensitive to widely varying inputs (transportation plans). Because models are typically developed for specific regions, generalizability is limited.

4 and 5. *Data, manpower, and computation requirements*. The performance of location models on these criteria is summarized by Lee (*B-37*). Such models tend to be very demanding in terms of data requirements, computation, and manpower. The large level of resources required by these models is a major reason for their low level of success.

6. *Operational availability*. The previously mentioned theoretical and practical difficulties indicate that much more development and testing are required before models of this nature become reliable. Further, there is very little experience at the state or local level with quantitative residential location models. Therefore, they are rated fairly negatively on the operational availability criterion.

General Joint Choice Models

Models in this category subsume both long- and short-run travel choices. Examples include Lerman's (*B-9*) joint housing type, housing location, auto ownership, and work mode choice model and Weisbrod's (*B-42*) housing type, housing location, and auto ownership model.

1. *Policy sensitivity*. These models typically have focused on level-of-service variables and therefore are best suited for testing the impacts of policies affecting the cost of various travel and location decisions.

2. *Forecast relevance*. Because the choice typically involves both long- and short-run decisions, these models are capable of predicting a wider range of responses than the simpler models. Because these models do not reflect interpersonal linkages, however, the full range of potential responses is restricted to some extent. Moreover, the true set of choices facing individuals is often arbitrarily restricted because it is so large. To the extent that the most likely choices are included, the forecast relevance is not significantly eroded.

3. *Accuracy and reliability*. These models have not been widely used or tested. Therefore, the accuracy of the forecasts is unknown.

4. *Data requirements*. Because the number of choices is so large and the model is disaggregate, the data requirements are very large. With respect to other probability choice logit models, there is a trade-off between accuracy of the aggregate response predicted and the input data required.

5. *Manpower and computation requirements*. The computation requirements of this technique are large. Moreover, because the true relationships are not well understood, expertise not generally found in planning agencies is required.

6. *Operational availability*. These models have only been used by researchers and are virtually unknown to planners. They have been tested only to a limited extent and require considerable testing before their accuracy and reliability can be assessed.

Attitudinal Models

1. *Policy sensitivity*. These models are the least policy sensitive because very few policies seek to change travelers' attitudes directly and it is difficult to predict the impacts of a policy on attitudes.

2. *Forecast relevance*. The predicted output variables are somewhat relevant to energy analysis, modal choice being the most common application of attitudinal modeling in transportation.

3. *Accuracy and reliability*. The accuracy of these models has not been tested and is not readily evaluated. The reliability of attitudinal data is even more problematic because the stability of attitudes is not well understood. Because attitudes are not understood, it is unclear whether the attitudinal data and analysis are generalizable.

4. *Data requirements*. Attitudinal data are not readily available, and a survey would most likely be required. Such a survey would require a high level of resources.

5. *Manpower and computation requirements*. Application of this technique would require a high level of manpower and computer resources. Moreover, design of the survey requires special skills as does analysis of the survey data.

6. *Operational availability*. Attitudinal models have not been widely used and very few planners have any experience with them. More development and testing are required.

Energy Shortage Surveys

1. *Policy sensitivity*. Because these surveys are taken during an energy shortage or refer to an energy shortage, they reveal data about the issues with which this study is concerned.

2. *Forecast relevance*. These surveys do not provide data necessary to predict behavioral responses because objective travel behavior data are often not collected. When travel data are collected, they are not measured on an interval scale; rather, the survey is designed to reveal nominal and ordinal scale data such as whether travel increased or decreased. Because the ability to predict behavior with attitudinal data is limited, the output variables are not easily linked to the forecast system.

3. Accuracy and reliability. The surveys are typically administered to a population that is not representative; hence, the survey results are not generalizable. Because the relationship between behavior and attitudes is not known, this technique does not produce reliable forecasts. Of course, the accuracy and reliability of the data depend on the survey instrument and how it was administered.

4. Data requirements. The data collected in these surveys are readily available in the published literature. However, updating the survey results would require a new collection of attitudinal data.

5. Manpower and computation requirements. If these surveys are used for descriptive purposes, the manpower and computation requirements are not large. Simple data analysis techniques can provide a rich body of descriptive data.

6. Operational availability. Most planning agencies are familiar with the descriptive statistics appropriate for these survey data. This level of data analysis generally provides accurate and reliable estimates.

New Cross-Sectional Models—Estimated with Existing Data

1. Policy sensitivity. The existing data sets referred to here include the large disaggregate data bases that have been used in a number of modeling efforts. Because past models have employed all available data, new models are not likely to achieve any substantial advantage with respect to policy sensitivity.

2. Forecast relevance. Barring any development of new techniques to predict a wider range of travel response, new data analysis is characterized by the same degree of forecast relevance as the models previously estimated with the data.

3. Accuracy and reliability. The accuracy of the data depends on the original data collection effort. The accuracy of the forecasts depends further on the way the data are modeled. Therefore, this technique can produce forecasts either more or less accurate than previous modeling efforts.

4. Data requirements. Resources are required to update the data to obtain the values appropriate for the policy and updating the model estimates to better describe the study population. In addition, certain variables may be added that are relevant to the population but were not originally collected.

5. Manpower and computation requirements. Model estimation requires considerable manpower and computer resources. The resource requirements depend, of course, on the complexity of the model, the size of the data set, and the quality of the data. Moreover, computer programming skills may be required.

6. Operational availability. The level of experience with model estimation is typically low among planners. Unlike application of previously estimated relationships, new modeling is best carried out when the theoretical assumptions of the model are understood.

New Cross-Sectional Models—Estimated with New Data

1. Policy sensitivity. The policy sensitivity of models estimated on new data is limited only by the range of values observed in the population and the existence of relevant characteristics. To the extent that the data need to be reliable, the policy sensitivity is also determined by the ability to measure information validly.

2. Forecast relevance. The forecast relevance of this technique is at least as good as for existing models. The relevance of the predicted output variables is limited by current understanding of functional relationships and computational capabilities of existing software.

3. Accuracy and reliability. The accuracy and reliability of the data are determined by the quality of the data collection. The forecasting ability of the model will depend on how carefully the model was estimated and whether the appropriate data were available. The generalizability of the data and data analysis will depend on how the sample was selected, the type of data collected (e.g., level of aggregation), and the range of observed values. In general, this technique should produce accurate and reliable results if the costs are justifiable.

4. Data requirements. The data must of course be collected and the resources required will be large. In some cases transportation experiments may be required if the prevailing conditions do not offer a sufficient range of observations.

5. Manpower and computation requirements. Maximum manpower and computer resources are required because all steps needed to estimate relationships must be carried out. Both data collection and modeling skills are required.

6. Operational availability. Few state and local planning agencies undertake large data collection and modeling efforts. This is especially true when the effort involves collecting a large, disaggregate data set or data outside the agency's jurisdiction.

Time-Series Models

1. Policy sensitivity. Most time-series data handled by planners are highly aggregated and are used to predict total travel or travel by a single mode. Although the variables are consistent with the forecasting system, only a small subset of the forecasting system is reflected in typical time-series models. These models are suitable to test the impacts of changes in travel cost and certain transit service variables such as route miles and headways.

2. Forecast relevance. These models have some degree of relevance in that the output variables are typically at the level of aggregation of interest to planners and can reveal both short- and long-run impacts. To the extent that the range of responses is typically restricted to one or two travel decisions, the relevance is limited.

3. Accuracy and reliability. Because historical data are involved, the reliability is often eroded as reporting practices and measurement conventions are changed over time. The ability to forecast with these models is not known since the predicted impacts are rarely verified. The degree to which the data are generalizable depends on the type of data; for example, auto ownership data are more likely to be generalizable than aggregate transit system data.

4. Data requirements. In many cases the data used are readily available because they are collected on a regular basis. In other cases it is very difficult to obtain a sufficient

number of observations (i.e., when the data are collected annually). In some cases, many time-series studies are quasi-experiments involving a costly demonstration project.

5. Manpower and computation requirements. If new data are to be collected for monitoring purposes, the manpower required can be large. Modeling of time-series data is generally more difficult than modeling cross-section data because time-series data are more likely to violate the assumptions of regression and other estimation techniques.

6. Operational availability. Few planning agencies have sufficient experience with modeling time-series data. Moreover, many analyses of time-series data ignore the econometric problems that lead to biased or unreliable results.

Laboratory Simulations

1. Policy sensitivity. Laboratory simulations can be designed so as to be highly sensitive to a variety of policies.

2. Forecast relevance. Laboratory simulations are unique in that the full range of behavioral responses can be observed. Unlike other models, this method is not based on restrictive assumptions about the structure of travel and nontravel response.

3. Accuracy and reliability. The accuracy and reliability of the data required for this technique are not known because they have been used only to a limited extent. Similarly, these data have not been used for a sample designed to produce generalizable results, so the external validity of the technique is unknown.

4. Data requirements. A large amount of resources is required to collect the data, because a large amount of data are collected for each observation.

5. Manpower and computation requirements. The manpower resources required are large because each observation involves a relatively intensive effort. The computer resources required depend on the level of data analysis, but they are likely to be large because of the amount of data generated with this technique.

6. Operational availability. There is virtually no experience with this method among state and local planning agencies. The method is still in the experimental stages, and considerably more work is necessary before its accuracy and reliability can be evaluated.

Narrative Qualitative Approach

The narrative qualitative approach relies on the informed judgment of the analyst to complement outputs from quantitative methodologies. It has become increasingly important in planning analyses and has been very useful in the current research. Qualitative analysis can benefit from several of the methods identified earlier. For example, results from attitudinal studies may be quite useful even though they may not yield reliable quantitative forecasts. Similarly, findings from large-scale, complex models, such as residential location models, can yield insights for qualitative analysis even though the models themselves may not be practical for quantitative forecasting.

1. Policy sensitivity. Since each policy or set of policies can be evaluated with this approach, the data elements enjoy a high level of consistency with the forecasting system.

2. Forecast relevance. There are no restrictions on the range of predicted output variables, making this technique relevant to the forecasting system.

3. Accuracy and reliability. Because this is a qualitative technique, there is no way to measure objectively the accuracy or reliability of the data or data analyses. The generalizability of the analyses will depend on the issues being considered.

4. Data requirements. In some cases the data necessary to undertake a qualitative analysis are readily available. In other instances a large effort may be required.

5. Manpower and computation requirements. Computer resources are not likely to be necessary except as a way of storing relevant data. The manpower requirements may be quite large if a wide variety of skills is necessary or if a large range of interests must be represented.

6. Operational availability. Most planning agencies have some experience with this technique. The approach, however, has not been standardized and, therefore, requires further development.

SUMMARY

The results of this evaluation are summarized in Table B-2.

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TABLE B-2

EVALUATION OF METHODS

Method	Policy Sensitivity	Forecast Relevance	Accuracy & Reliability	Data Requirements	Manpower & Computational Requirements	Operational Availability
Existing:						
Elasticities	+	+	++	++	++	++
Worktrip Models	+	0	++	+	0	+
Nonworktrip Models:						
a) Joint Choice	++	+	+	-	-	0
b) Simplified	+	++	?	+	+	0
Auto Ownership Models	0	+	+	0	-	0
Residential Models	+	+	-	--	--	-
General Joint Choice Models	++	++	?	--	--	-
Attitudinal Models	-	0	?	--	--	--
Energy Shortage Surveys	+	0	--	+	+	+
Time-Series Models	0	+	?	0	--	--
Proposed:						
Cross-Section Models:						
a) Existing Data	+	0	+	0	--	--
b) New Data	++	++	++	--	--	--
Laboratory Simulations	++	++	?	--	--	--
Narrative Qualitative Approach	++	++	?	0	0	+

Table continued on following page.

Evaluation Scale:
- ++ Very Desirable
- + Desirable
- 0 Neutral
- - Undesirable
- -- Very Undesirable
- ? Unknown

NOTE: Ratings are relative, rather than absolute. Methods that do not rate highly for quantitative analysis may contribute to qualitative analysis.

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APPENDIX C

DEVELOPMENT OF THE QUANTITATIVE FORECASTING SYSTEM

This appendix presents the motivation and justification for the forecasting system described and applied in Chapter Two. Three major sections follow. First, the requirements for ideal forecasting are discussed. Because a considerable amount of fundamental research is necessary to develop such a system, only parts of it are implemented in this project. The remaining components are addressed qualitatively and should be the subject of further research. Second, the method for analyzing work trip travel is discussed. Finally, the nonwork trip method is presented.

REQUIREMENTS FOR A FORECASTING SYSTEM

A forecasting system for energy policy planning must be capable of producing reasonable estimates of the key impacts of a range of planning actions. For example, the system should allow decision-makers to answer questions, such as: How will transit use increase with coupon rationing? Will gasoline price increases lead to auto ownership and residential location changes? Will behavior change more for work or nonwork travel under various policy options? At the same time, the system should be understandable to, and easily used by, decision-makers; should be efficient with respect to the time and monetary resources needed to use it; and should be reasonably sound theoretically.

These characteristics indicate the directions this and other research efforts must take in order to improve the analytical capabilities of public agencies. The purpose of this discussion is to outline the concepts and approaches that can be used in the design of a reasonably flexible energy policy forecasting system.

Basic Concepts

Ideally, a modeling system should be designed with the end use in mind. That is, if detailed estimates of the use of various components of a transportation system are needed, a modeling approach based on complex spatial and temporal definitions of travel patterns is appropriate. Such a system might be too detailed and cumbersome for other purposes, however. For example, it might be somewhat inefficient to generate metropolitan VMT from a modeling system based on individual travel patterns. Recognition of this possibility suggests the development of different tools and methods for different applications. That is, rather than having a single set of models for all policy applications, the modeling system may have different models for different applications. This concept will be important in the discussion that follows.

The goal of streamlined planning tools may appear to be inconsistent with the need for planning methods to have a sound theoretical base with respect to travel behavior. Inasmuch as researchers have considered travel and activity behavior other than mode choice, they have come to recognize the complexity of such behavior (e.g., the alternatives are not easy to define, the conventional definition of trip might be overly simplified, and travel might be only a small part of a daily activity pattern). These theoretical issues are important here because behavioral adjustments to changes in the energy situation appear to be much more complicated than simple modal shifts. The forecasting system developed in this research will attempt to deal realistically with travel behavior by imposing reasonable simplifying assumptions in describing behavioral patterns. This approach will be discussed in detail in subsequent sections of this appendix.

Elements of a Forecasting System

The discussion of the forecasting system will first consider a comprehensive decription of the relevant input variables, behavioral aspects, and impacts. As such, it will outline an ideal system that may emerge after long-term basic and applied research. The advantage of the initial comprehensive viewpoint is that it recognizes the complexity of the problem and it lessens the likelihood that important behavioral elements and/or impacts of policies are overlooked. Next, the simplifying assumptions necessary to design a tractable modeling system in a reasonable time frame will be identified.

The forecasting system is represented by the flowchart in Figure C-1. The key features of the flowchart are the sets of variables ranging from the input and policy variables, such as those presented in Appendix A and Chapter Two, to long-run impact variables resulting from long-run adjustments in travel, auto ownership, and location choices.

The discussion in this section will be organized into the following subsections: (1) overview of the system; (2) links between input and policy variables and the modeling system; (3) models of short-run activity and travel patterns; (4) short-run impacts; (5) models of long-run behavior; and (6) long-run impacts.

Overview of the System

A useful way of characterizing the system is first to discuss the nature of the variables in the modeling system and then sketch how policies lead to changes in these variables.

The dependent variables in the modeling system measure either short- or long-run behavior. The distinction between short- and long-run behavior is common in the literature (*C-1, C-2, C-3*); short-run behavior includes activities and travel patterns that can be changed quickly, while long-run behavior includes choices such as auto ownership decisions and residential location choices.

For both types of behavior, it is useful to categorize the independent variables into (1) benefits derived from the behavioral choices in question, (2) costs incurred from the behavior, and (3) exogenous variables such as demographic characteristics of individuals in households. In general, people try to acquire benefits while avoiding costs when deciding on particular behaviors. The exogenous variables allow for the fact that people with different characteristics might choose differently, and may have different opportunities. (The possibility of having different sets of available alternatives (choice set) can be thought of as an exogenous input.)

The basic principle in linking the input data with the modeling system is to translate particular policies into changes in the independent variables of the relevant model. For some policies this is straightforward. For example, a tax on gasoline can easily be translated into an auto cost variable in a mode choice model. On the other hand, the effects of carpool promotion policies appear to be more difficult to capture for two reasons: (1) possible changes in the alternatives commuters perceive to be available, and (2) the lack of an independent variable corresponding to perceptual changes resulting from the promotion program. More details in the link between the forecasting system and policy inputs are discussed in the next subsection.

Linking Policy Inputs into the Forecasting System

The key issue in determining the policy sensitivity of a forecasting system is the extent to which the changes in the transportation environment resulting from the policy can be translated into changes in the independent variables of the forecasting system. The capability of existing models of handling various energy policy actions definitely varies. This can be seen by considering both independent variables typically included in existing models and, also, reasons why other policy sensitive variables are not included.

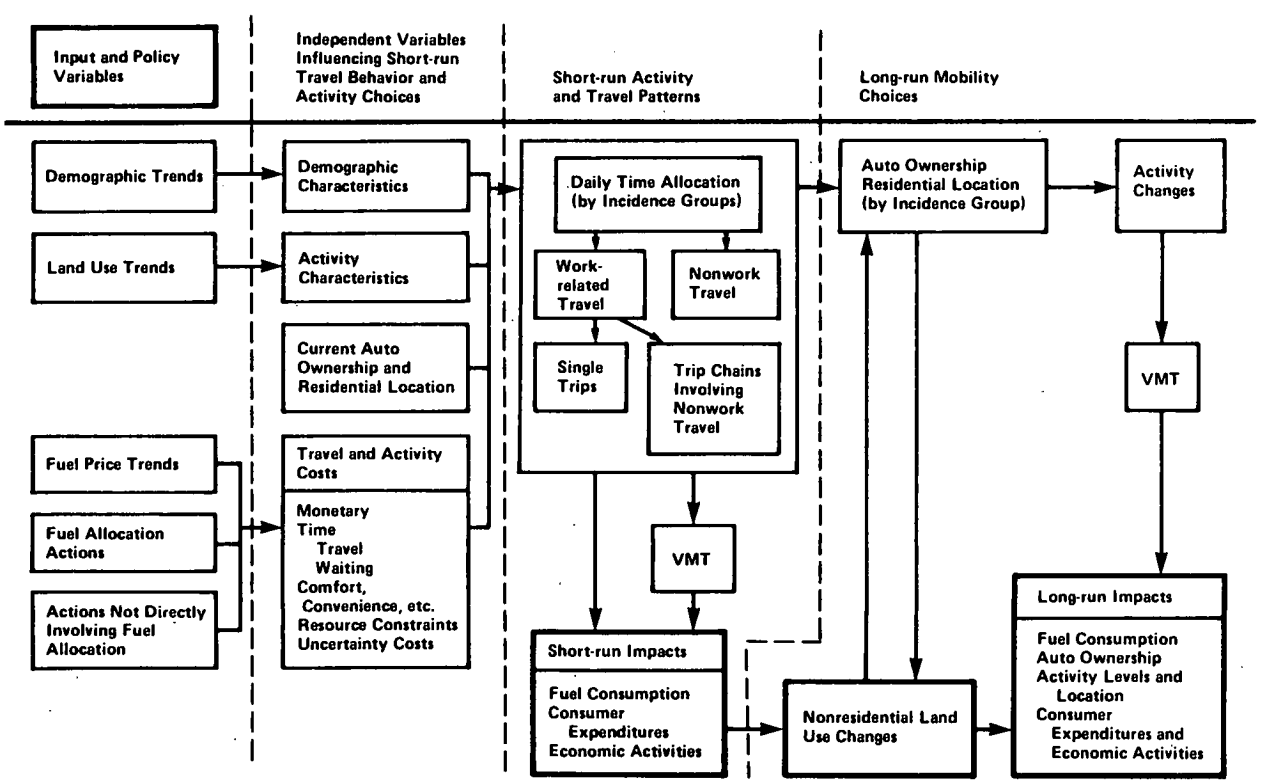

Figure C-1. Flowchart of idealized forecasting system.

Because existing models have been designed to analyze transportation policies, it is not surprising that physical level-of-service variables (e.g., travel times and monetary costs) have been prominent. The consequence is that policies that change the time and monetary costs of travel are the most conducive to analysis. Examples include policies that change auto costs (e.g., fuel taxes, parking charges, pricing), transit fare policies, and policies that change the travel times for modes (e.g., exclusive lanes for high-occupancy vehicles, etc.).

In considering possible policy actions for reducing fuel consumption, it is apparent that changes in times and monetary costs are not the only consequences. For example, a high-occupancy vehicle lane might change people's perceptions of the safety of travel, a carpool promotion and marketing program might introduce a new mode into travelers' choice sets, or a rationing policy might introduce a resource constraint not normally present. Consideration of why existing models might not be sensitive to these types of policies is useful in establishing the requirements of an improved forecasting system.

Some variables may be important, in theory, but difficult or impossible to measure in practice. The safety example is a case in point. Although attitudinal techniques can be used to measure such variables, there is no obvious way to translate policy actions into changes in perceived safety. Although attitudinal models might be used to indicate the direction of behavioral change resulting from changes in the transportation environment, quantification of such variables in physical units (or linking perceptions to physical variables) is a future research direction that may yield more policy-sensitive models.

Second, in normal situations there may not be enough variation in an important independent variable to allow measurement and inclusion of the variable in a travel model. For example, it was suggested in Appendix A that gasoline allocation through long lines may result in frustration costs due to waiting, costs from the perceptions of a resource constraint, and costs from uncertainty over whether gasoline is available. In normal times, the value of all these costs approaches zero; hence, there is little variation over time or people. Possible techniques for solving this problem include the collection of data on hypothetical responses through attitudinal surveys or laboratory simulations, or the collection of data on gasoline purchases and travel behavior during energy shortage periods (see App. E).

Third, there may be no theory that includes the variables affected by the policy. An example of this is the issue of choice set formation. Although the identification of available opportunities is a crucial step in the application of transportation choice models, the step has typically been performed in an ad hoc manner because of a lack of theory. Not surprisingly, understanding the mechanisms of choice set formation has been identified as an important topic in future fundamental research in travel behavior (*C-4*).

Models of Short-Run Activity and Travel Patterns

The most relevant component for purposes of this discussion is the definition of the dependent variables. The representation of the activity and travel behavior of interest is of great importance in developing models for analyzing the impacts of energy policies.

Travel-related behavior, both in normal periods and under energy constraints, appears to be very complex. In the most abstract and general case, individuals in households may be assumed to choose a location and a set of activities over a long period of time (*C-1*). Although this approach would yield a comprehensive description of both long- and short-run behavior, large conceptual and practical difficulties are present. In order to proceed from this level of abstraction to workable definitions of behavior, simplifying assumptions are necessary.

Probably the most basic simplifying assumption is the separation of long- and short-run behavior. As previously noted, this is common in existing models. Further, empirical evidence from the 1973–1974 and 1979 energy shortages suggests that adjustments were mainly short-term in nature (*C-5*) (this information is discussed in Chap. Three).

The typical modeling approach assumes that short-term behavior is conditioned by long-run choices (e.g., residential and employment locations and auto ownership). However, changes in short-term activity or travel patterns resulting from changes in the transportation environment could lead to changes in long-run choices (*C-6*). Hence, a complete description of the impacts of energy policies requires the consideration of long-run behavior.

A second simplifying assumption is the separation of travel into work and nonwork trip purposes. Previous research seems to indicate that work trips are easier to model than are nonwork trips. As a result, much more research has been devoted to the work trip, and the resulting models are more fully developed as planning tools.

The relative ease of dealing with work trips results from the fact that, in the shortrun, most features of such trips are fixed (i.e., the origin, destination, time of day, frequency, etc.), and the choice of mode is of prime importance. Because of the level of effort that was given to work trip models, the analysis of policies designed to induce modal shifts is fairly straightforward, and existing models are readily available. (For example, CRA has used such models to analyze pollution control strategies (*C-7*) and integrated transit plans (*C-8*).)

There are a couple of relevant research issues involving such trip models, however. First, it is not clear that existing models are capable of explaining the increased transit ridership during the recent gasoline shortage. (For example, ridership on the BART system reached record levels (*C-9*).) If as has been hypothesized earlier, there are costs of auto travel that are not present during normal periods, existing models may not be adequate. Exploration of this issue with travel behavior data from energy shortage periods and/or data from laboratory simulations is a useful area of further research.

Second, it appears that the trip definition used in most work trip models might be too simple, even in normal periods. Damm (*C-10*) has found that a fairly large proportion of work trips involve diversions for nonwork purposes (in a 1970 subsample of Minneapolis/St. Paul residents,

10.1 percent of the morning work trips and 16.3 percent of the evening work trips involved such diversions). It is possible that such diversions may be even more prominent during energy emergencies and/or with higher gasoline prices. Because of its detailed trip definitions, the Baltimore disaggregate data set may be an important source for examining trip chaining behavior involving work trips.

Nonwork travel has posed especially difficult problems for transportation researchers. (The complexities of nonwork travel are discussed in greater detail in the review of nonwork trip models in App. B and in the discussion of complex travel patterns in App. D.) The consequence of this is that there is a lack of useful policy models (*C-11*); there have been concerted efforts to understand the fundamentals of this complex behavior (*C-12, C-13*).

The complexity of nonwork travel arises from the complexity of daily activity patterns. Although it is fairly easy to isolate and define individual work trips, it has not been as easy to define nonwork travel. Difficulties arise from the fact that there is no natural way to define destination alternatives (*C-14*) and from the fact that a substantial proportion of nonwork travel does not conform to the typical trip definition adopted by travel data collection (*C-15*).

There appear to be two approaches to dealing with the complexity of nonwork travel. First, the complexity can be directly confronted by devising complex definitions of activity and travel patterns. This approach is illustrated by the use of spatial and temporal mapping of activity patterns (*C-12*). Certainly, this type of approach is important in improving fundamental understanding of travel behavior. Also, the detailed description of travel patterns inherent in this approach may be useful in predicting impacts for particular components of the transportation system (or for small subareas). However, the level of detail may be unnecessary if the major concerns are impacts at the regional level.

The alternative approach is to define variables that summarize some of the essential features of complex travel patterns without actually replicating the patterns. Notable examples include using time allocation to characterize activity patterns (*C-13*) and using frequencies and average distance to characterize nonwork travel (*C-11*).

The approach is attractive because of the economy afforded by the simplified summary variables. Standard statistical techniques and their variations are readily applicable. Also, the resulting models are typically sufficiently simple to be easily applied for policy analysis purposes. For these reasons, this approach is used in this study.

It should be noted that information on the travel behavior of various incidence groups might be important in analyzing alternative policies. For example, it has been noted that during the 1973–1974 energy shortages, changes in travel behavior were influenced by several demographic variables, especially income (*C-16*). Because existing or proposed models of travel behavior typically include demographic variables, estimates of travel behavior by incidence groups often can be derived by applying models to various strata of interest.

Short-Run Impacts

Short-run impacts of interest include fuel consumption, consumer expenditure patterns, and possible impacts on economic activities (e.g., employment and retail sales).

Fuel consumption is the most direct of these impacts. Also, it is the central focus of policies for alleviating temporary fuel shortages. Although it is often not a direct output of existing travel demand models, it can be derived through the use of reasonable assumptions.

In order to link travel behavior to fuel consumption, it is necessary first to derive vehicle-miles traveled (VMT) from a given travel pattern and then multiply this figure by an appropriate fuel efficiency figure. The latter step can be done either at a disaggregate level (if auto ownership information is available) or at an aggregate level by using average fuel efficiencies.

The derivation of VMT depends on the definition of travel behavior used in the model. For models that directly represent the spatial pattern of travel, VMT can be calculated directly by simply observing the distance involved in the given pattern. Similarly, models including VMT as a dependent variable yield direct information.

Models including dependent variables, such as the time allocated to travel or trip frequencies, would require auxiliary information on distance per unit time or distance per trip. If models of this sort are used in this study, distance information might be available from the detailed travel information contained in the Baltimore disaggregate data set.

Travel models emphasize travel patterns, per se, and not the activities at the end of the trips. Consequently, little direct quantitative information is available on the effects of travel patterns on consumer expenditures. However, models that explain shopping trip making or time allocation can yield qualitative information on the likely amount and location of consumer expenditures. Future research on the direct linkage between travel and consumer expenditures would be useful in this regard. Such research is beyond the scope of this project, however.

Changes in consumer expenditure patterns, as well as any changes in work travel and activity behavior resulting from energy constraints, will affect regional and national economies. Again, the link between existing travel demand models and impacts of this nature is primarily qualitative. Changes in economic activity are important in their own right. In addition, such changes might also lead to nonresidential land-use changes, which may be important in explaining long-run behavior such as auto ownership and residential location changes.

As noted in the previous subsection, the forecasting system should be capable of tracing the incidence of short-run impacts on particular groups. With appropriate input from decision-makers on the groups of primary interest, this capability would yield valuable information on the equity impacts of alternative policies.

Models of Long-Run Behavior

Two household decisions relevant to travel and energy conservation can be considered under this heading: (1) auto ownership, and (2) household location. In addition, the previously mentioned changes in nonresidential land-use patterns also have implications for long-term impacts.

Vehicle demand models, which were mentioned in Ap-

pendix B, are potentially useful for energy policy analyses. However, the complexity of available models and the fact that many models produce results for large aggregates (e.g., the nation) indicate that further research would be useful for developing the vehicle ownership components of a forecasting system intended for state and local analysis.

Household location decisions are not as well understood as vehicle ownership decisions. Existing models are prototypical in nature, and the problem of location choice modeling has been recognized as a key area of future research (*C-17*). Consequently, the ability to predict long-term location changes might be limited to qualitative statements about the likely direction and magnitude of such changes. Possible sources for insight into this problem are the spatial choice, location theory, and urban modeling literature.

A possible research strategy for modeling location behavior parallels the nonwork travel modeling approach which simplifies the definition of travel patterns. That is, rather than define choice of residence as involving a specific spatial location, the choice could be defined in terms of variables such as distance from the city center and distance from work. Data from the ongoing Panel Study of Income Dynamics (*C-18*), which contains demographic, transportation, and moving behavior data, could be used in estimating models of this type. Another approach would involve the use of laboratory simulations or consumer panels in a manner similar to that suggested for analyzing travel patterns.

Long-Run Impacts

Long-run impacts can be divided into two groups: (1) land-use changes, and (2) changes resulting from long-run adjustments in activity patterns. The first category would be an output of location models discussed in the previous subsection. Therefore, the ability of the forecasting system to deal with such impacts is directly related to the quality of the residential choice components.

In principle, the estimation of long-run impacts, such as activity location and level, consumer expenditures, and economic activities, is analogous to estimating the corresponding short-run impacts. The major difference is that in the short-run problem, auto ownership and residential location are taken as given input variables, while, in the long run, they must be forecasted. Again, the quality of the long-run modeling components becomes important here.

At a minimum, planners should have qualitative information on the direction and magnitude of long-run impacts and their incidence for particular groups of interest. In addition, the research requirements that would allow more precise forecasts should be specified.

WORK TRIP ANALYSIS

In this section, the development of the work trip methodology is described. As indicated in Chapter Two, the method combines the traveler classification aggregation method (*C-19*) with the incremental, or pivot point, form of the logit model. (In previous studies, the classification method has been called the market segmentation method (*C-11, C-02*).) The choice of this approach is discussed in the first two subsections. Following this, the use of elasticity analysis for evaluating work trip impatcs is discussed. Elasticity analysis is conceptually quite similar to incremental logit analysis. Therefore, the method may be considered as an optional work trip analysis technique.

Choice Set/Distance Trip Segmentation for Work Mode Choice Analysis

Background

In an earlier CRA study (*C-11*), a traveler classification procedure was developed for applying a logit work trip mode choice model. Because of the nonlinearity of the logit model, prediction biases arise if regionwide averages on the independent variables are used to predict regionwide modal shares. Classification is used to divide regional trip makers into groups that are fairly homogeneous with respect to transportation systems and demographic characteristics. Modal shares for each traveler class are estimated by using the class means on the independent variables. The regionwide modal shares are weighted averages of the class shares, where the weights are the ratio of trip makers in a class to the total number of trip makers in the region. Application of the model in this manner reduces prediction biases.

In the earlier study, respondents in the Nationwide Personal Transportation Study (NTPS) were divided into 12 classes based on trip distance, auto availability, and transit accessibility. The distribution of the sample across the classes as well as the modal split within each segment are given in Table C-1 (constructed from Table 2.2 of CRA (*C-11*)).

Koppelman (*C-19*) has suggested that traveler classification based on choice sets is a simple, but effective procedure. Following this suggestion, the classes are revised in the earlier study so that they are based on choice set and trip distance. This classification is attractive for energy policy analyses because trip distance can be used in VMT calculations and choice set availability can be affected by transportation policies.

Procedure

The following steps are performed in developing the traveler classes. First, the original classification is transformed into the new classification. Second, average values on the independent variables for each mode are estimated for each class. Third, modal shares for each class are estimated. These are used to estimate overall modal shares and automobile VMT. Finally, the results of the classification are compared to the original classification and to classifications based on distance and choice set alone.

Three alternative choice sets are used in the classification. The full choice set consists of auto drive alone, *A*, shared ride, *S*, and transit, *T*. Auto drive alone and shared ride constitute the second choice set and shared ride and transit form the third choice set.

The work trip mode choice model (in Chap. Two, the model is used in its incremental form and the cost coeffi-

TABLE C-1

MODE SPLITS AND TRIPS FOR ORIGINAL TRAVELER CLASSES

	Greater than .5 Autos per Worker						Less than .5 Autos per Worker					
	Short Trips			Long Trips			Short Trips			Long Trips		
	High Trans. Access	Middle Trans. Access	Low Trans. Access	High Trans. Access	Middle Trans. Access	Low Trans. Access	High Trans. Access	Middle Trans. Access	Low Trans. Access	High Trans. Access	Middle Trans. Access	Low Trans. Access
Mode												
Auto Drive Alone	190	73	277	87	54	237	1	2	0	1	1	2
Carpool	63	37	76	24	12	52	11	0	11	4	1	3
Transit	62	14	2	24	10	8	61	22	1	19	10	0
Total Trips	315	124	355	135	76	297	73	24	12	24	12	5

cient is updated to reflect 1979, rather than 1967, cost of living) has the following forms. For the full choice set,

$$MS_S = \exp(U_{AS})/[1 + \exp(U_{AS}) + \exp(U_{AT})] \quad \text{(C-1a)}$$

$$MS_T = \exp(U_{AT})/[1 + \exp(U_{AS}) + \exp(U_{AT})] \quad \text{(C-1b)}$$

$$MS_A = 1 - MS_S - MS_T \quad \text{(C-1c)}$$

For the drive alone, shared ride choice set,

$$MS_S = \exp(U_{AS})/[1 + \exp(U_{AS})] \quad \text{(C-2a)}$$

$$MS_A = 1 - MS_S \quad \text{(C-2b)}$$

For the shared ride, transit choice set,

$$MS_T = \exp(U_{ST})/[1 + \exp(U_{ST})] \quad \text{(C-3a)}$$

$$MS_S = 1 - MS_T \quad \text{(C-3b)}$$

The MS terms are the modal shares and the U terms are the differences in the nonrandom components of the utilities for the alternative modes. They are as follows:

$$U_{AS} = C_S + 2.24(\text{Cost}_A - \text{Cost}_S) + 0.0411(\text{Time}_A - \text{Time}_S) \quad \text{(C-4a)}$$

$$U_{AT} = 0.17 + 2.24(\text{Cost}_A - \text{Cost}_T) + 0.0411(\text{Time}_A - \text{Time}_T) - 0.114 \text{ Walk time} \quad \text{(C-4b)}$$

$$U_{ST} = (4.77 - C_S) + 2.24(\text{Cost}_S - \text{Cost}_T) + 0.0411(\text{Time}_S - \text{Time}_T) - 0.114 \text{ Walk time} \quad \text{(C-4c)}$$

Cost and time are the round-trip, out-of-pocket costs and trip times for each mode. Walk time applies only to transit. CS is a shared ride constant, which will be described later.

Definition of Distance/Choice Set Classes. The 6 distance/choice set classes are constructed from the 12 original classes in Table C-1 as follows. For each trip distance category, respondents with high automobile availability and high or medium transit accessibility are assumed to have the full choice set available. Respondents with high auto availability and low transit accessibility are assigned to the drive alone, shared ride segments. All respondents with low auto availability are assigned to the shared ride, transit segments. The distribution of respondents across the 6 classes is given in Table C-2.

Values on the Independent Variables. The round-trip times and costs for the auto drive alone and transit modes are the sample averages as reported in CRA (*C-11*). Transit walk times are estimated in the following way. The average one-way distances from home to bus stop for each of the transit accessibility categories used in the original classification are high (0.068 miles), medium (0.375 miles), and low (1.325 miles). The round-trip walk time for each of the categories is

$$\text{Walk time} = 2 \times \text{Distance} \times 19 \text{ Minutes/mile} \quad \text{(C-5)}$$

Average walking speed is assumed to be 19 min per mile. The transit walk times for the new classes are the weighted averages of the walk times of the original classes that constitute the new classes. For example, the walk time for the full choice set, short trip class is

$$\begin{aligned}\text{Walk time (Minutes)} &= \frac{1}{439}\, 2 \times 0.068 \text{ Miles} \times 19 \frac{\text{Minutes}}{\text{Mile}} \times 315 \\ &\quad + 2 \times 0.375 \times 19 \frac{\text{Minutes}}{\text{Mile}} \times 124 \\ &= 5.88 \text{ Minutes} \quad \text{(C-6)}\end{aligned}$$

Shared ride, level of service variables are estimated in the following way. To the travel time of auto drive alone, a component is added representing the circulation time necessary to pick up passengers. This is estimated as one-third the auto drive alone distance divided by the assumed shared ride circulation speed of 15.25 miles per hour. (Average round trip distance is 8.63 for short trips and 33.28 for long trips. Shared ride circulation speed is estimated from the sample of carpoolers.) Shared ride cost equals shared ride distance (4/3 auto drive alone distance) times ($0.035/mile) divided by an assumed carpool size of 2. For example, for short trips,

$$\text{Shared ride cost} = \left(\frac{4}{3} \times 8.63 \times 0.035\right)/2 = \$0.20137$$

$$\begin{aligned}\text{Shared ride time} &= 29.04 \text{ Minutes} + \frac{1}{3} \times 8.63 \text{ Miles} \\ &\quad \times \frac{1}{15.25} \frac{\text{Hours}}{\text{Mile}} \times \frac{60 \text{ Minutes}}{\text{Hour}} \\ &= 40.36 \text{ Minutes} \quad \text{(C-7)}\end{aligned}$$

Table C-3 gives the average values of the independent vari-

TABLE C-2

DISTRIBUTION OF TRIPS ACROSS THE SIX CHOICE SET/ DISTANCE TRAVELER CLASSES

Choice Set*	Distance Short	Distance Long
A/S/T (Full)	439	211
A/S	355	297
S/T	109	41

*A/S/T is the choice set with auto drive alone, shared ride, and transit; A/S is the choice set with auto drive alone and shared ride; S/T is the choice set with shared ride and transit.

SOURCE: Constructed from Table C-1.

TABLE C-3

AVERAGE VALUES ON THE INDEPENDENT VARIABLES FOR THE CHOICE SET/DISTANCE TRAVELER CLASSES

Choice Set	Mode*	Distance: Short (8.63 miles) Cost ($)	Short Time (minutes)	Short Walk Time (minutes)	Long (33.26 miles) Cost ($)	Long Time (minutes)	Long Walk Time (minutes)
A/S/T	A	.30205	29.04	0	1.1641	64.53	0
	S	.20137	40.36	0	.77607	108.15	0
	T	.4928	50.95	5.88	.4928	109.83	6.78
A/S	A	.30205	29.04	0	1.1641	64.53	0
	S	.20137	40.36	0	.77607	108.15	0
S/T	S	.20137	40.36	0	.77607	108.15	0
	T	.4928	50.95	10.42	.4928	109.83	11.82

*The modes are auto drive alone (A), shared ride (S), and transit (T).

ables (table constructed from data in Sec. 2.2 of CRA (*C-11*)).

The shared ride constant, C_S, is estimated from data from the four classes including shared ride and drive alone. For each trip length category, a constant that equates observed and estimated modal shares is calculated and these constants are averaged to yield C_S. For short trips, there are 176 carpoolers and 540 drive alone trips in the full choice set and drive alone, shared ride choice set. The constant that equates observed and predicted trips is

$$\begin{aligned} C_S' &= \log\left(\frac{176}{540}\right) - 2.24(\text{Cost}_A' - \text{Cost}_S') \\ &\quad -0.0411(\text{Time}_A' - \text{Time}_S') \\ &= \log\left(\frac{176}{540}\right) - 2.24(0.30205 - 0.20137) \\ &\quad - 0.0411(29.04 - 40.36) \\ &= -0.8814 \end{aligned} \tag{C-8}$$

The constant for long trips is calculated in the same manner and the average value is —0.7077.

The treatment of the shared ride mode differs in three ways from the previous CRA study. First, shared ride is defined as a single alternative, while the previous study defined 2-, 3-, and 4-passenger carpools as separate alternatives. The level-of-ervice variables are constructed for a carpool size of two, under the assumption that an actual carpool will have at least as high a utility to a commuter as a 2-passenger carpool. Because the observed characteristics of carpools with more than two occupants become quite unfavorable under the circuity assumptions used to construct level-of-service variables, the use of 2-person carpools to construct such variables probably approximates overall utility better than the use of the rather pessimistic values for larger carpools. Second, the former study added a 20 min per person schedule delay to auto shared ride travel time. This assumption leads to quite unfavorable shared ride times and was not used here. Third, a shared ride constant was used in the utility function in this study, but was not used previously.

Estimation of Modal Shares and VMT. The data in Table C-3 are used in Eqs. C-1, C-2, and C-3 to estimate the modal shares for each class. These shares are multiplied by the number of trip makers in each class and summed to obtain the modal shares for each trip length as well as for the entire sample.

VMT is estimated from the drive alone and shared ride modal shares. For the former,

$$VMT_A = 8.63 \times N_{AS} + 33.26 \times N_{AL} \quad \text{(C-9)}$$

where VMT_A are VMT from drive alone trips, N_{AS} and N_{AL} are the number of short and long drive alone trips, respectively. For shared ride trips

$$VMT_S = \frac{1+S}{L}(8.63 \times N_{SS} + 33.26 \times N_{SL}) \quad \text{(C-10)}$$

where VMT_S, N_{SS}, and N_{SL} are analogous to the corresponding terms for drive alone, L is the average carpool occupancy, and S is a circuity factor for picking up and dropping off passengers. A value of 2.5 is assumed for L and 0.5 for S. The circuity factor assumes that each additional passenger adds one-third of the drive alone distance to the trip length.

The modal shares and VMT estimates are given in Table C-4. The modal predictions match the actual values quite closely. It should be noted that the procedure used to estimate the shared ride constant is essentially a calibration exercise that should lead to a fairly close fit between actual and predicted results. This calibration is similar to the procedure of recalibrating the alternative specific constants of an existing model to match regionwide modal shares.

Comparison to Other Classifications. This section compares the choice set/distance trip classification results to three alternative classifications: (1) the original classification represented in Table C-1; (2) a classification based on trip distance alone; and (3) a classification based on choice set availability alone.

The results of the original classification, which are constructed from Tables 2.4 and 2.5 in CRA (*C-11*), are given in Table C-5. The difference in the treatment of the shared ride mode should be noted when interpreting these results.

In terms of overall modal shares and VMT, the results in Table C-5 are very close to those in Table C-4. Both traveler classification results match the observed values very closely. The choice set/distance classification appears to match the observed values for particular trip lengths somewhat better, however.

The analysis for the trip distance classification follows the same procedure as did the choice set/distance classification analysis. In constructing the average values of the independent variables for the two distance classes, the trip time and cost variables are the same as those in Table C-2 because they are a function of trip length only. The transit walk time variables are the weighted averages of the walk times for the three transit accessibility categories. Because a large number of low access trips are included in these averages, the walk times for the two segments are quite large: 23.91 min for short trips and 30.73 min for long trips. The effects of averaging the different levels of auto availability are addressed by adjusting the constant term in the expression for U_{AT} in Eq. C-4 to 0.64. Finally the shared ride constant term is somewhat different because all observed shared ride and drive alone trips are used in the estimation. (In the previous case, trips in the shared ride, transit segments were not used in the calculation.) The resulting value is —0.6133.

Application of Eq. C-1 (with the modified utility functions) yields the predicted modal shares and VMT estimates given in Table C-6. The results are quite unsatisfactory. The transit share is underpredicted by a large amount. Because of this, VMT is substantially overpredicted.

For the choice set only classification analysis, the average values of the independent variables are simply the weighted averages over the two distance categories of the values in Table C-3. The only other adjustment in the analysis is a slight adjustment of the shared ride constant to —0.7328. The calibration procedure used to obtain this estimate involves an averaging process similar to the one used earlier. In this case, the constant terms to be averaged are those that equate the observed and predicted shares for drive alone and shared ride for the full choice set and the drive alone/shared ride choice sets, respectively.

Table C-7 reports the results of the analysis. In calculating VMT, the weighted averages of the short and long trip lengths are used for each class. These are 16.63 miles for the full choice set class; 19.85 miles for the drive alone, shared ride class; and 15.36 miles for the shared ride, transit class. The predicted values are fairly close to the observed values. Drive alone trips are somewhat overpredicted at the expense of shared ride trips. This leads to an overestimate of VMT.

Conclusion

A traveler classification approach for applying a logit work trip mode choice model has been presented. The classification is based on two trip distance categories and three choice set categories resulting in six classes.

Predictions of overall modal shares and VMT using this classification compare very favorably to the predictions from the classification approach developed in the earlier CRA study. The new classification approach seems to have three practical advantages over the old approach. First, there are only half as many classes. Second, the new approach appears to perform somewhat better for the individual trip distance categories. Third, both classification bases are relevant for transportation energy conservation analyses. Trip distance is related to VMT and choice set availability can be affected by various policies.

The new approach was compared to even simpler classifications: distance alone and choice set alone. The distance classification substantially underpredicted transit trips. The choice set classification results were much better, but still were not as satisfactory as the distance/choice set classification analysis.

Comparison of Incremental Logit and Conventional Logit

Background

The use of incremental methods for forecasting travel demand is becoming increasingly popular among transportation planners. These incremental methods estimate changes in existing travel behavior in response to transportation improvements or exogenous changes in the travel environment. Because they require minimal data and computational resources, incremental methods are well suited to testing the travel impacts of small-scale TSM strategies, implemented singly or in multiple combinations.

TABLE C-4

MODAL SHARES AND VMT FOR CHOICE SET/ DISTANCE TRAVELER CLASSIFICATION *

Mode**	Trip Distance: Short (8.63 miles)	Long (33.26 miles)	Total
A	540 (543)	382 (382)	922 (925)
S	213 (198)	75 (96)	288 (294)
T	151 (162)	92 (71)	243 (233)

VMT 19,965 (19,794)

*Actual values are in parentheses next to the predicted values.

**Modes are defined in Table C-3.

TABLE C-5

MODAL SHARES AND VMT FOR ORIGINAL TRAVELER CLASSIFICATION *

Mode**	Short	Long	Total
A	532 (543)	389 (382)	921 (925)
S	231 (198)	68 (96)	299 (294)
T	138 (162)	93 (71)	231 (233)

VMT 19,475 (19,794)

*Actual values are in parentheses next to predicted values.

**Modes are defined in Table C-3.

TABLE C-6

MODAL SHARES AND VMT FOR DISTANCE TRAVELER CLASSIFICATION *

Mode**	Short	Long	Total
A	619 (543)	437 (382)	1056 (925)
S	264 (198)	94 (96)	358 (294)
T	20 (162)	18 (71)	38 (233)

VMT = 23,119 (19,794)

*Actual values are in parentheses next to predicted values.

**Modes are defined in Table C-3.

TABLE C-7

MODAL SHARES AND VMT FOR CHOICE SET TRAVELER CLASSIFICATION *

Mode**	Total
A	940 (925)
S	275 (294)
T	237 (233)

VMT 20,288 (19,794)

*Actual values are in parentheses next to predicted values.

**Modes are defined in Table C-3.

In addition, incremental methods may provide more accurate estimates of travel behavior responses than those forecasting methods that synthesize travel behavior as a function of service and socioeconomic inputs.

In this subsection, the demand for a new park-and-ride service for commuters traveling between Towson, Maryland, and the Baltimore CBD is forecasted. Specifically, the work trip modal split is estimated using two methods: incremental logit and a conventional logit mode choice model (i.e., future level-of-service variables are used in forecasting modal shares). This is in contrast to incremental logit in which present modal shares and changes in level of service are inputs for forecasting. Because ridership data are available for both before and after the service was implemented, an opportunity is provided to test the accuracy of these demand forecasting methods. In the following, the transportation improvement and necessary input data are described. Then, the new modal split is forecasted using the two methods and compared with the actual modal split observed after the new service was implemented.

New Baltimore Park-n-Ride Service

In December 1976, a free parking lot for bus commuters traveling from Towson to the Baltimore central business district was opened. The lot has a capacity of approximately 200 cars and is located adjacent to a major freeway, I-695, at the Providence Road interchange about 16.1 km north of the CBD. An express bus, No. 26, was initiated to service the lot, traveling to the downtown area via I-695 and a radial highway, the Jones Falls Expressway. (The impact of this transportation improvement was examined in the Phase II report for NCHRP Project 8-13 (*C-20*), which provides the input data used here.)

Prior to the construction of this parking lot, the area was served by express bus No. 18, which continued service after No. 26 was initiated. Bus No. 18 also originates at Providence Road, but circulates on local arteries before joining I-695. No. 26 has a shorter line-haul time because it does not circulate local streets. Average headway frequency for No. 26 is also greater than for No. 18, resulting in reduced passenger wait time.

Before the parking lot opened, 68 commuters boarded No. 18 in the vicinity of Providence Road. On average, 51 bus riders drove automobiles to the bus and 17 riders walked to the bus. From local data it was estimated that 781 travelers had a choice between auto and bus; hence, 713 commuters chose auto.

Counts of ridership for the new No. 26 bus and the No. 18 bus were made in February and March 1977. These counts revealed that about 200 commuters used the No. 26 bus per day and that all accessed the bus by automobile. About 24 riders boarded the No. 18 bus in the vicinity of Providence Road. Because the No. 26 bus is clearly superior to the No. 18 bus for travelers using auto

to access the bus, it is reasonable to assume that the commuters who previously accessed No. 18 by auto now use the No. 26 bus and parking lot and that all commuters boarding the No. 18 bus walk to the bus. The resulting difference in bus riders walking to the bus is most likely due to sampling variability (the number of riders walking to No. 18 before the lot opened varied from 5 to 29 daily). Because of this possibility and because the logit model does not predict an increased share for a mode that is not improved, it is assumed that 17 riders used bus, with walk access afterwards. Inasmuch as the park-n-ride and bus with walk access travel choices are assumed to represent distinct modes, ridership is forecasted for three modes: auto, bus with walk access, and bus with auto access (park-n-ride).

To forecast the new modal shares, the level-of-service variables for the travel alternatives before and after the transportation improvement must be examined. The logit model that will be used requires inputs on in-vehicle travel time (line haul plus wait time), walking time, and cost. Data for these variables are presented in Tables 6 and 12 of CRA (*C-20*) for the 12 segments used in the previous market segmentation aggregation procedures (2 income groups × 2 auto availability groups × 3 distance-from-transit groups). In addition to the level of service variables, the model also requires average auto availability (autos per driver) and income.

In-vehicle travel time and cost do not vary by market segments for any mode. Similarly, auto walk time is assumed to be zero and bus with auto access walk time is assumed to be 8.6 min for all segments. The remaining three variables, bus with walk access walk time, auto availability, and income, are weighted averages of the values of these variables for the market segments.

Tables 6 and 12 of CRA (*C-20*) indicate that 5.8 percent of work trip makers are within 3 blocks of transit, 4.1 percent are between 3 and 6 blocks, and 90.1 percent are more than 6 blocks from a transit stop. The average round-trip walk times are 13.4 min, 27.9 min, and 60.8 min, respectively. The weighted average walk time is 56.36 min.

For the income groups, 49.9 percent are in the low income group, which averages $14.7 thousand, and 50.1 percent are in the high group, which averages $47.6 thousand. The weighted average is $28.68 thousand.

Average auto availability is different for each of the 12 segments. However, it is about 0.5 for the low segment, which is about 40 percent of the trip makers, and about 1.05 for the high segment. The weighted average is 0.8427 (which is close to the 0.83 derived from using the approximations just presented). Table C-8 (constructed from Tables 5, 6, 12, and 13 of CRA (*C-20*)) gives the relevant variables.

TABLE C-8

AVERAGE VALUES FOR VARIABLES OF WORK TRIP MODES *

Mode	Variable: In-Vehicle Time	Variable: Walk Time	Cost	Trips (Before)	Trips (After)
Automobile	58.0 minutes	0	$3.22	713	564
Bus No. 18 with walk access	88.4 minutes	56.36 minutes	$1.50	17	17
Bus No. 18 with auto access	88.4 minutes	8.6 minutes	$1.80	51	-
Bus No. 26 with auto access	75.0 minutes	8.6 minutes	$1.80	-	200

Average Income: $28.68 thousand.

Average Auto Availability: .8427 autos per driver.

*All values refer to round trip.

Forecasting Demand for Work Trip Modes

Two demand forecasting methods are tested: incremental logit and a conventional logit model. These methods are described below and the resulting forecasts are compared to the actual change in mode choice observed.

Incremental Logit. The incremental form of the logit model predicts the new mode choice probabilities as a function of existing travel behavior and changes in the level of service. In this regard, it is like elasticity analysis. Incremental logit is also similar to the elasticity method in that model coefficients estimated on one population are typically transferred to some other population facing the transportation change. The guidelines for transferring model coefficients and elasticities are, not surprisingly, the same. To the extent that transferability is limited by variations in travel behavior across populations, the factors that determine travel behavior should be similar for the two populations.

Incremental logit can be distinguished from the elasticity method in several ways. First, the analyst is limited to using disaggregate logit mode choice models. These models reveal the choice probabilities for individuals. To obtain an unbiased estimate of the aggregate mode choice, aggregation procedures (e.g., market segmentation, complete enumeration) must be employed. These procedures may require time and computational resources beyond those required by the elasticity method. (For a concise discussion of aggregation procedures, see Koppelman (*C-21* and CRA (*C-22*).) With incremental logit the analyst is also restricted by the fact that the model coefficients are estimated on cross-section data. Hence, the travel response predicted will lie somewhere between the true short-run and the true long-run response. Elasticities, on the other hand, may reveal short-run or long-run behavior depending on the source of the elasticity estimate. Moreover, because the logit model is a mode choice model, changes in trip generation and other travel choices cannot be identified; elasticities of modal demand (ridership) measure the total change in travel behavior. Incremental logit, however, provides a key advantage relative to the elasticity method. The logit model assumes that elasticities vary along the demand curve. The elasticity method, in contrast, typically involves application of a single elasticity estimate over the range of values under consideration. This feature of the logit model may be particularly important when a policy involves large changes in modal attributes.

The incremental logit formula is as follows (*C-23*):

$$P'(i|A) = \frac{P(i|A)e^{\Delta V_i}}{\sum_{m \epsilon A} P(m|A)e^{\Delta V_m}} \qquad \text{(C-11)}$$

where:

m, i = travel alternatives;
A = set of available alternatives;
$P(i/A)$ = probability of choosing alternative i;
$P'(i/A)$ = predicted probability of choosing alternative i after the change; and
ΔV_i = change in the utility for alternative i (see Eq. 3).

The existing mode shares in Baltimore prior to the new parking lot and express bus are as follows: P (auto) = 0.913; P (bus with walk access) = 0.022; and P (park-n-ride) = 0.065.

To predict the change in mode choice as a result of the new park-n-ride service in Baltimore, the coefficients for CRA's work trip mode choice logit model estimated for Pittsburgh are used. (For a description of this model, see the next subsection on conventional logit analysis.) Observations included commuters with a choice between auto drive alone and bus with walk access. The model included five variables and a mode-specific constant. The independent variable affected by the new service is IVT, a combined measure of round-trip line-haul and wait time. The coefficient for IVT was estimated to be −0.06426 (*C-20*).

Parameters are expressed in terms of average values for the population with a choice between auto and bus. Because the population faces the same modal choices, traveler classification by choice set is implicitly applied in this case. Hence, the use of average values in this example should produce relatively unbiased results.

Prior to the change, IVT for bus with auto access was 88.4 minutes. After the change, IVT is reduced to 75 min. Using the formula for incremental logit, the revised mode shares are as follows: P (auto) = 0.0838; P (bus with walk access) = 0.020; and P (park-n-ride) = 0.142.

The following choices are predicted: 655 auto trips, 16 trips by bus with walk access, and 111 trips by bus with auto access.

Comparison of these values with the actual modal shares indicates that park-n-ride is substantially underpredicted. This suggests that the assumptions used in CRA (*C-20*) may not have adequately represented the improvements offered by the park-n-ride lot. In particular, it is possible that the parking lot reduced walk time relative to the other two modes. To explore this possibility, the bus with auto access time is reduced by 2 min to 6.6 min. The coefficient of this variable is −0.2834. Using the incremental logit formula, the new mode shares are: auto = 0.757 (591 trips); bus with walk access = 0.018 (14 trips); and park-n-ride = 0.225 (176 trips). These values are much closer to the actual values. (Although the assumption of a 2-min improvement in round-trip walk time is quite reasonable, it should be noted that actual modal shares were known before the analysis was performed. In actual forecasting, this outcome would not be known.)

Conventional Logit Analysis. This method involves the application of a previously estimated mode choice logit model to the travel alternatives being evaluated. The travel choices are simulated in terms of the variables included in the model. CRA's Pittsburgh model (*C-1*) is used, updated for Baltimore. CRA's model is based on the 1967 Pittsburgh data set, adjusted to include only those observations that were judged to have a choice between bus and auto. (This is a different version of the model used in Chap. Two. This version was developed for the specific park-n-ride case study.)

The updating procedures are described in detail in CRA (*C-20*). They involved adjusting the coefficient of cost to reflect the fact that average income in Towson is higher than in Pittsburgh and the estimation of mode-specific constant terms that equated predicted and observed modal shares for the period before the park-n-ride lot was implemented. The adjusted utility functions for the three modes are as follows:

$$\begin{aligned} V\text{ (auto)} &= -13.20 - 0.06426\,IVT - 0.2834\,WT \\ &\quad - 1.480\,Cost + 5.664\,A/D \\ &\quad + 0.3470\,INC; \\ V\,(bus) &= -0.06426\,IVT - 0.2834\,WT \\ &\quad - 1.480\,Cost;\text{ and} \\ V\text{ (park-n-ride)} &= -13.64 - 0.06426\,IVT \\ &\quad - 0.2834\,WT - 1.480\,Cost \\ &\quad + 5.664\,A/D + 0.3470\,INC \end{aligned} \tag{C-12}$$

where:

IVT = a combined measure of in-vehicle and wait times in minutes;
WT = walk times in minutes, with walk time for auto assumed to be zero;
$Cost$ = cost of making a trip, measured in 1967 dollars;
A/D = number of automobiles per licensed driver in the household; and
INC = family income in thousands of dollars.

The values for the independent variables are given in Table C-8. Because the population for both Towson and Pittsburgh has been restricted so that all members face the same choice set, aggregation by traveler classification is implicitly applied. Hence, the estimated modal split is relatively unbiased.

Modal shares are calculated based on the values for parameters existing after the new service. Hence, the park-n-ride mode takes on the values for bus No. 26 with auto access. Mode shares are calculated using the following formula:

$$P(i|A) = \frac{e^{V_i}}{\sum_{m \epsilon A} e^{V_m}} \tag{C-13}$$

The mode shares estimated with the updated model are as follows: auto = 0.866; bus = 0.000; and park-n-ride = 0.134. Hence, it is predicted that there will be 676.5 auto trips, 0 trips by bus with walk access, and 104.5 trips by bus with auto access. (The results derived from using the market class aggregation procedure are 662, 17, and 102 (CRA (*C-20*). Since there is insufficient information to perform incremental logit with the traveler classification aggregation procedures, the modal shares presented are the relevant basis for comparing the two methods.)

Again, it is useful to examine the alternative assumption that the park-n-ride lot improves walking time for bus with

auto access by two minutes. The results are auto = 0.786 (613.9 trips); bus with walk access = 0.000 (0 trips); and park-n-ride = 0.214 (167.1 trips). (When the traveler classification aggregation procedure is used, the corresponding results are 602.5, 14.5, and 164 trips, respectively. These are much better than the results in CRA (*C-20*) and suggest that the conclusions presented there on transferring the logit model may have been unduly pessimistic.)

Conclusion

The results of the comparisons of the alternative forecasting methods are summarized in Table C-9. (Note: column "Actual Trips" from unpublished data supplied by Maryland Mass Transit Administration and Baltimore Regional Planning Administration, reported in CRA (*C-20*).) The superior performance of the incremental logit method for forecasting travel demand relative to application of a previously estimated logit model has been demonstrated for the park-n-ride case study.

The incremental logit results are even superior to the corresponding conventional analysis results based on the more complex market segmentation aggregation procedure. It is likely that if incremental logit were combined with market segmentation aggregation, as in Chapter Two, the results would be even better.

The test carried out here suggests that incremental methods, which estimated revised behavior as a function of existing demand and changes in level of service, may be superior to methods that attempt to synthesize travel behavior. The advantage of incremental methods is not surprising; travel decisions are complex and cannot easily be simulated by models that inevitably impose simplifying assumptions on behavioral processes. This finding is particularly hopeful in light of the practical advantages of incremental methods. These manual methods provide answers quickly at little cost, and they can be used with data readily available to transportation planners.

Demand Forecasting with Elasticities: Impacts of Policies on Work Trip Modal Choice

Background

The use of elasticities as a tool for demand forecasting has often been suggested and appears to be increasing in popularity as the demand for simple and inexpensive methods grows. Because the data requirements are relatively small and easily met by transportation planners and the forecasts can be provided quickly, elasticities appear to be an attractive energy contingency planning method. (In addition to local and regional data typically collected by planning agencies, there are a variety of nationally published sources of urban transportation data including Refs. (*C-25* through *C-32*). This section describes how elasticities can be applied to energy contingency planning.

In the following subsection, the procedure for demand forecasting with elasticities is described. Next, a prototypical urban area is described and forecasts of the impacts on work trip modal choice for five typical energy contingency actions are presented. In the last subsection, estimates of average daily vehicle-miles traveled are provided for each policy scenario, including the base case.

TABLE C-9

TOWSON WORK TRIP PREDICTIONS

Mode	Actual Trips	Incremental Logit First* Assumption	Incremental Logit Second** Assumption	Conventional Logit First* Assumption	Conventional Logit Second** Assumption
Auto	564	655	591	676.5	613.9
Bus with Walk Access	17	16	14	0	0
Park-n-Ride	200	111	176	104.5	167.1

*Park and ride assumed to change only in-vehicle time for bus with auto access.

**Park and ride assumed to change both in-vehicle time and walk time for bus with auto access.

Formula for Demand Forecasting

Demand elasticities summarize the relationship between demand for some good and an independent variable at a given point along the demand curve. Therefore, the functional form employed in applying elasticities is directly related to the functional form of the demand curve. This relationship can be shown by comparing demand forecasts resulting from different assumptions about the true functional form.

On the basis of the definition of point elasticities, the exact formula for demand estimation is

$$C_1 = C_0 + \int_{X_0}^{X_1} \eta_X \frac{C(X)}{X}\, dX_1 \qquad \text{(C-14)}$$

where $C(X)$ is the demand and η_X is the elasticity at X. Two approximations of this formula have been used in the literature:

$$C_1 = C_0 \left(1 + \eta_{X_0} \left(\frac{X_1 \times X_0}{X_0}\right)\right) \qquad \text{(C-15)}$$

$$C_1 = C_0 \left(\frac{X_1}{X_0}\right)^{\eta_{X_0}} \qquad \text{(C-16)}$$

The additive formula is exact when the demand function is linear, and the multiplicative formula is exact when the demand function is multiplicative (log-linear or Cobb-Douglas). As one would expect, the demand forecasts derived from these formulas become more dissimilar as the change in the independent variable increases. (The reason for this is that over small changes, a linear approximation of an arc is reasonable.)

To demonstrate the difference between demand forecasts resulting from alternative functional forms, a simple example of a transit fare change is used. Let C_0, transit trips made daily, equal 1,000 and X_0, the transit fare, equal \$0.25. Assuming that the transit demand elasticity is —0.33, one can forecast the new transit demand for a 100 percent increase in fare. Using the additive formula, the new demand is predicted as follows:

$$C_1 = 1{,}000 \left(1 + (-0.33) \left(\frac{0.50 - 0.25}{0.25}\right)\right.$$

$$C_1 = 670$$

Using the multiplicative formula, new demand is calculated as follows:

$$C_1 = 1{,}000\left(\frac{0.50}{0.25}\right)^{-0.33}$$

$$C_1 = 796$$

It is clear, then, that the demand forecast is sensitive to the functional form of forecast equation.

The case for change in a single independent variable is easily generalized to multiple system changes. For the additive formula, the demand forecast equation becomes

$$C_1 = C_0\left(1 + \eta_1\left(\frac{X_{11} - X_{10}}{X_{10}}\right) + \ldots + \eta_k \left(\frac{X_{k1} - X_{k0}}{X_{k0}}\right)\right) \qquad \text{(C-17)}$$

The multiplicative formula is

$$C_1 = C_0\left(\frac{X_{11}}{X_{10}}\right)^{\eta_1}\left(\frac{X_{21}}{X_{20}}\right)^{\eta_2} \ldots \left(\frac{X_{k1}}{X_{k0}}\right)^{\eta_k} \qquad \text{(C-18)}$$

Using an extension of the simple example shown, consider the impact of a reduction in transit line-haul travel time in addition to the fare change. Let X_t, the line-haul time, be equal to 40 min in the base case and 30 min after the improvement. The elasticity for line-haul time is assumed to be −0.5. Using the additive formula, the demand after both system changes is calculated as follows:

$$C_1 = 1{,}000\left(1 + \left(-0.33\right)\left(\frac{0.50 - 0.25}{0.25}\right) + (-0.5)\left(\frac{30 - 40}{40}\right)\right)$$

$$C_1 = 795$$

Using the multiplicative formula, demand is forecast as follows:

$$C_1 = 1{,}000\left(\frac{0.50}{0.25}\right)^{-0.33}\left(\frac{30}{40}\right)^{-0.5}$$

$$C_1 = 919$$

As in the single system change case, the multiplicative and additive formulas yield substantially different demand forecasts.

Because the formula employed reflects a certain demand function, the additive formula should be used if there is *a priori* evidence that the demand is linear and the multiplicative formula should be used if the demand is believed to be multiplicative. In the event that the shape of the demand curve is unknown, use of both formulas yields a range of estimates serving as a sensitivity test for the functional form of the demand equation.

Policy Evaluation

This section evaluates the impact of five policies on work trip mode choice for a prototypical urban area. The policies examined are gasoline tax, automobile fuel economy improvement, surcharge on CBD parking, increased transit availability, and bus priority treatment. Three work trip modes are considered: automobile (drive alone), carpool (driver and passenger), and bus. Elasticities are used to forecast the new modal split in response to a policy. Forecasting with elasticities involves representing a policy as changes in independent variables (for which elasticities are available) and selecting the appropriate functional form for the forecast equation. As noted earlier, the appropriate forecast formula is determined by the form of the demand equation.

The logit model has been extensively applied to modal choice analysis. The direct disaggregate elasticity formula for the logit model is

$$\eta_{xi} = b_i x_i\,[1 - P(x_i)] \qquad \text{(C-19)}$$

This elasticity bears some resemblance to the elasticity for a linear demand function in that it varies directly with x_i and its coefficient. Moreover, the logit curve is approximately linear when the probabilities are not extreme. Therefore, in forecasting the impact of policies on the modal split, the additive formula is used.

Base values of parameters for the urban area, necessary for the policy analyses, are given in Table C-10. These values are intended to be illustrative rather than precise for any single urban area. Ranges of values for the relevant direct and cross-elasticities are given in Table C-5. Because of the uncertainty inherent in applying elasticities estimated from one data set to another area, ranges rather than point estimates are provided. The use of ranges allows one to evaluate the sensitivity of demand forecasts to the elasticity values.

The elasticity values used here were estimated from cross-section data. To the extent that cross-section data reflect both short-run and long-run relationships, these elas-

TABLE C-10

PROTOTYPICAL URBAN AREA—BASE CONDITIONS

Work Trip Modal Split: 70 Percent Auto (Drive Alone)
20 Percent Carpool
10 Percent Bus

(Twenty percent of trips by the auto and carpool modes are destined for the Central Business District.)

Modal Parameters	Mean Value -- One-Way Trip
Auto trip distance (door-to-door)	7 miles
Auto line-haul travel time	18 minutes
Auto out-of-vehicle time	7 minutes
Auto line-haul operating cost (gasoline, oil, maintenance, replacement tires)	80 cents
Auto out-of-pocket cost (parking charge and tolls)	40 cents
Parking charge	30 cents
Carpool trip distance (door-to-door)	9 miles
Carpool line-haul travel time	20 minutes
Carpool out-of-vehicle time	10 minutes
Carpool line-haul operating cost (per person)*	41 cents
Carpool out-of-pocket cost (per person)*	24 cents
Parking charge (per person)*	18 cents
Bus trip distance (station-to-station)	6.5 miles
Bus line-haul travel time	23 minutes
Bus out-of-vehicle time	18 minutes
Bus line-haul cost	40 cents

*Carpool per person costs are based on average occupancy of 2.5 persons.

ticities probably lie somewhere between the short-run and long-run values. Finally, because the direct- and cross-elasticities used here often come from different models, the mode split forecasts are always normalized so that the shares sum to one.

Gasoline Tax. The impact of 100 percent gasoline tax on the before-tax price raises the pump price by 70 percent. Assuming gasoline represents 40 percent of operating costs for the auto mode, the increase in operating cost for this mode is 28 percent. The increase in total auto cost is 18.7 percent (because gasoline represents 26.7 percent of the total cost). For the carpool mode, both operating costs and out-of-pocket costs are lumped together. Gasoline costs represent about 25 percent of total trip cost. For the carpool mode this policy represents a 17.5 percent increase in carpool costs.

Lower Bound

New auto share $= 0.7(1 + (-0.1)(0.28)) = 0.680$
New carpool share $= 0.2(1 + (-0.06)(0.175)) = 0.198$
New bus share $= 0.1\,[1 + (0.4)(0.187) + (0.03)(0.175)] = 0.108$

Normalized New Modal Shares

Auto = 0.690
Carpool = 0.201
Bus = 0.110

Upper Bound

New auto share $= 0.7(1 + (-0.3)(0.28)) = 0.641$
New carpool share $= 0.2(1 + (-0.1)(0.179)) = 0.197$
New bus share $= 0.1\,[1 + (0.6)(0.187) + (0.04)(0.175)] = 0.112$

Normalized New Modal Shares

Auto = 0.675
Carpool = 0.207
Bus = 0.118

Fuel Economy Improvement. A 50 percent improvement in automobile fuel economy is represented as a 50 percent decrease in gasoline costs. The same assumptions described in the gasoline tax policy evaluation are used. It is assumed that gasoline represents 40 percent of auto operating costs; the decrease in total auto trip costs is 13.4 percent. The decrease in trip costs for the carpool mode is 12.5 percent.

Lower Bound

New auto share $= 0.7(1 + (-0.1)(-0.20)) = 0.714$
New carpool share $= 0.2(1 + (-0.06)(-0.125)) = 0.202$
New bus share $= 0.1\,[1 + (0.4)(-0.134) + (0.03)(-0.125)] = 0.094$

Normalized New Modal Shares

Auto = 0.707
Carpool = 0.200
Bus = 0.093

Upper Bound

New auto share $= 0.7(1 + (-0.3)(-0.20)) = 0.742$
New carpool share $= 0.2(1 + (-0.1)(-0.125)) = 0.203$
New bus share $= 0.1\,[1 + (0.6)(-0.134) + 0.04)(-0.125)] = 0.091$

Normalized New Modal Shares

Auto = 0.716
Carpool = 0.196
Bus = .088

CBD Parking Surcharge. A \$1.00 surcharge on CBD parking spaces is examined. Given that 20 percent of automobiles are destined for the CBD, the maximum number of vehicles affected by this policy is 20 percent of the total. A \$1.00 surcharge represents a \$0.50 increase in the parking cost for a one-way trip. The increase in average parking costs for the auto mode can be approximated as follows: 0.8(\$0.30) + 0.2(\$0.30 + \$0.50) = \$0.40. (By applying a single elasticity to the average cost increase, it is implicitly assumed that travelers destined for the CBD and travelers with different destinations constitute a homogeneous population segment.) The average out-of-pocket cost for the auto mode, then, is increased 25 percent, from \$0.40 to \$0.50, reflecting the \$0.10 increase in average parking costs. The increase in total trip costs for the auto mode is only 8.3 percent, from \$1.20 to \$1.30. For carpoolers parking in the CBD, the surcharge only increases the average parking cost per person by \$0.20 (assuming average carpool occupancy is 2.5 persons). It is assumed that 20 percent of all carpools are also destined for the CBD. Hence, the average increase in parking charges is approximately equal to 0.8(\$0.18) + 0.2(\$0.18 + \$0.20) = \$0.22. Leaving all other charges unchanged, the average total cost for the carpool mode is increased 6.2 percent, from \$0.65 to \$0.69.

Lower Bound

New auto share $= 0.7(1 + (-0.3)(0.25)) = 0.648$
New carpool share $= 0.2(1 + (-0.06)(0.062)) = 0.199$
New bus share $= 0.1(1 + (0.4)(0.083) + (0.03)(0.062)) = 0.104$

Normalized New Modal Share

Auto = 0.681
Carpool = 0.209
Bus = 0.109

Upper Bound

New auto share $= 0.7(1 + (-0.5)(0.25) = 0.613$
New carpool share $= 0.2(1 + (-0.1)(0.062)) = 0.199$
New bus share $= 0.1(1 + (0.6)(0.083) + (0.04)(0.062) = 0.105$

Normalized New Modal Share

Auto = 0.668
Carpool = 0.217
Bus = 0.115

Increased Transit Availability. This policy involves an expansion of bus service so that for all trips transit is within ½ mile of the place of residence. For the sake of simplicity, it is assumed that the access mode for all bus trips is walk and that the median distance from residence to bus stop is 0.5 miles. Suppose the average improvement for those trips not presently accessible to transit will be a reduction in access time of 7 min at the origin (no improvement occurs at the destination). Given that this improvement affects only 50 percent of total trips, the average improvement over all trips will be 3.5 min or a 20.6 percent reduction in bus out-of-vehicle time.

Lower Bound

New auto share = 0.7(1 + (0.3)(−0.206)) = 0.657
New carpool share = 0.2(1 + (0.09)(−0.206)) = 0.196
New bus share = 0.1(1 + (−0.6)(−0.206)) = 0.112

Normalized New Modal Shares

Auto = 0.681
Carpool = 0.203
Bus = 0.116

Upper Bound

New auto share = 0.7(1 + (0.4)(−0.206)) = 0.642
New carpool share = 0.2(1 + (0.1)(−0.206))
= 0.196
New bus share = 0.1(1 + (−0.8)(−0.206)) = 0.116

Normalized New Modal Shares

Auto = 0.673
Carpool = 0.205
Bus = 0.122

Bus Priority Treatment. Bus priority treatment at traffic signals and reduced headways are assumed to reduce bus line-haul time by 10 percent and reduce passenger wait time 10 percent. Given the base line-haul time of 23 min, the line-haul time after the improvement is 20.7 min. Before the improvement, average total out-of-vehicle time is 12 min, with average wait time of 6 min. A 10 percent reduction in wait time leads to a new average wait time of 5.4 min. Hence, bus out-of-vehicle time is reduced 3.3 percent from 18 min to 17.4 min.

Lower Bound

New auto share = 0.7 [1 + (0.1)(−0.1)
+ (0.3)(−0.033)] = 0.686
New carpool share = 0.2 [1 + (0.02)(−0.1)
+ (0.09)(−0.033)] = 0.199
New bus share = 0.1 [1 + (−0.3)(−0.1)
+ (−0.6)(−0.033)] = 0.105

Normalized New Modal Shares

Auto = 0.693
Carpool = 0.201
Bus = 0.106

Upper Bound

New auto share = 0.7 [1 + (0.3)(−0.1)
+ (0.4)(−0.033)] = 0.670
New carpool share = 0.2 [1 + (0.04)(−0.1)
+ (0.1)(−0.033)] = 0.199
New bus share = 0.1 [1 + (−0.5)(−0.1)
+ (−0.8)(−0.033)] = 0.108

Normalized Modal Shares

Auto = 0.686
Carpool = 0.204
Bus = 0.111

VMT Estimation

To determine the relative energy savings of each of the five policies examined, it is useful to compare the policies with respect to vehicle-miles traveled (VMT). It is assumed that 200,000 work trips are made daily, in the base case. To calculate total daily VMT, both average trip distance and vehicle occupancy for each mode must be considered. As noted in Table C-1, average occupancy for the carpool mode is assumed to be 2.5 persons. The average occupancy for the bus mode is assumed to be 60. (It may be more realistic to assume that average bus occupancy changes under different policy scenarios. If bus load factors increase as the transit modal share increases (due to a fixed supply of transit vehicles), the VMT results would differ from those presented here.) Daily VMT is calculated with the following equation:

$$\text{VMT} = (\text{auto share})(200{,}000)(7) + (\text{carpool share})(200{,}000)(9)(1/2.5) + (\text{bus share})(200{,}000)(6.5)(1/60) \qquad \text{(C-20)}$$

This calculation, of course, provides only rough estimates of actual VMT in response to policies. The policies discussed here most likely affect different market segments differently. For example, current auto users facing longer trips may shift mode at a different rate than auto users with shorter trips. Hence, the use of average trip length provides biased estimates of VMT changes. The calculations presented here, however, are intended to illustrate a methodology rather than provide precise estimates. Use of average values, then, is adequate for this purpose. Moreover, to minimize the number of calculations, VMT estimates are only presented for the results of the lower bound elasticity estimates. These results are given in Table C-11.

The relative efficacy of these policies as energy conservation strategies, as indicated by the VMT estimates, generally affirms the conventional wisdom in this area. As expected, disincentives to automobile travel, in the absence of explicit incentives to shift to more efficient modes, are not

TABLE C-11

DAILY VEHICLE MILES TRAVELED

Policy Scenario	Vehicle Miles Traveled*
Base Case	1,126,167
Gasoline Tax	1,113,103
Fuel Economy Improvement	1,135,815
CBD Parking Surcharge	1,106,242
Transit Availability	1,102,073
Bus Priority Treatment	1,117,780

*Vehicle Miles Traveled estimates are rounded off to the nearest integer.

particularly effective with respect to the journey to work. It is also reasonable that a parking surcharge is more effective in reducing VMT than a gasoline tax of the same magnitude, reflecting the inelasticity of demand with respect to gas price and gasoline's relatively small share of trip costs. The increase in VMT resulting from fuel economy improvements, relative to the base case, suggests the need for a broad-based approach to energy conservation. Policies that appear to conserve energy must be examined closely as the results may be counterproductive.

The effectiveness of transit improvements is a function of the energy efficiency of transit relative to private vehicles. However, the difference in energy savings of the transit actions relative to the auto disincentives is smaller than reflected in VMT estimates, since the fuel requirements of an urban bus are between three and four times as great as for a passenger car.

NONWORK TRIP ANALYSIS

This section describes how models developed in a previous CRA study (*C-11*) can be used in quick response analyses of energy policies. Unlike probability choice models, which require policy actions to be translated into changes in independent variables for small geographic areas and/or particular individuals, the models described here require information on changes in regional averages only because the models are linear.

Application of Simultaneous Equation Models

Before presenting the actual models, it is useful to discuss the essentials of applying simultaneous linear equation models. Three application approaches are possible: (1) direct application of the models to produce absolute forecasts, (2) use of the elasticities derived from the models, and (3) incremental forecasts that are based on information on the dependent variables for a base period.

Direct Application

In this case, forecasts for a particular period are produced independently from forecasts from other periods and/or base period values on the dependent variables. That is, forecasts are a function of only the independent variables for the forecast period. (This assumes that there are no lagged dependent or independent variables, which is the case for the models presented here.) The essentials of forecasting are illustrated by considering a 2-equation system

$$Y_1 = aY_2 + \Sigma b_i X_i \qquad \text{(C-21a)}$$

$$Y_2 = cY_1 + \Sigma d_i X_i \qquad \text{(C-21b)}$$

where Y_1 and Y_2 are the dependent variables, and X_i includes all independent variables appearing in the two equations. (Some of the b_i and d_i will be zero.)

To apply the models, the two equations must be transformed into reduced form. This yields

$$Y_1 = \frac{1}{1-ac} \sum_i (b_i + ad_i)\, X_i \qquad \text{(C-22a)}$$

$$Y_2 = \frac{1}{1-ac} \sum_i (d_i + cb_i)\, X_i \qquad \text{(C-22b)}$$

Forecasts are then obtained by inserting values for the X_i in the two equations. Information on the independent variables can be obtained from the following sources. First, some independent variables may not change over time (e.g., a region may be experiencing a steady state population). Second, external forecasts such as regional income projections may be available. Third, changes in some independent variables are consequences of the particular policies under consideration.

A key assumption in applying the models in this manner is that the effects of unobserved variables vary randomly over time for particular regions (e.g., a region that is below average on the dependent variables relative to similar regions may be above average in the next period). The extent to which there is persistence in unobserved effects makes this approach more or less reasonable.

Application of Elasticities

This type of analysis is a special case of elasticity analysis, which is described earlier in this appendix. Previous CRA policy analyses with the nonwork trip models have used this approach (*C-11*).

Incremental Forecasting

With linear models, it is straightforward to derive expressions for changes in the dependent variables. The resulting equations are

$$\Delta Y_1 = a\Delta Y_2 + \sum_i b_i \Delta X_i \qquad \text{(C-23a)}$$

$$\Delta Y_2 = c\Delta Y_1 + \sum_i d_i \Delta X_i \qquad \text{(C-23b)}$$

where Δ denotes the difference in a variable between two time periods. The corresponding reduced form equations, which are used in forecasting, are

$$\Delta Y_1 = \frac{1}{1-ac} \sum_i (b_i + ad_i)\Delta X_i \qquad \text{(C-24a)}$$

$$\Delta Y_2 = \frac{1}{1-ac} \sum_i (d_i + cb_i)\Delta X_i \qquad \text{(C-24b)}$$

The changes in dependent variables, ΔY_1, are then added to the base values.

This approach assumes that the effect of unobserved variables persists over time periods for a given region (i.e., a below-average region in the base period will be below average in the forecast period (relative to similar regions)). In many cases, this appears to be a reasonable assumption. Further, comparison of this forecasting approach with the previous approach would yield a range for the forecasted dependent variables.

One advantage of this approach is that independent variables that do not change are not relevant in the forecasting applications. When the number of independent variables is fairly large and the calculations are done by hand, this property is advantageous.

The incremental approach can be shown to be formally equivalent to elasticity analysis. The advantage of this approach is that regions with different characteristics have different implied elasticities. With elasticity analysis there is the temptation to use a single set of elasticities over a range of locations, without recognizing variations in elasticities.

The Nonwork Trip Model

In this section, one version of the disaggregate simultaneous equation nonwork trip model is presented, and the results of a previous application are reproduced. Both a 2-equation model, which is described below, and a 3-equation model were developed in the previous study (*C-11*). The 3-equation model included an average auto trip frequency equation, an average auto distance per trip equation, and a transit trip equation. The 2-equation model is described here and applied in Chapter Two because it produces direct estimates of VMT, which is an output variable of prime interest.

The Model

The model is a 2-equation system. The first equation explains nonwork automobile VMT for a 4-day period as a function of: (1) transit trips, (2) auto level of service variables, (3) socioeconomic characteristics, and (4) urban structure variables. The second equation explains transit trips as a function of transit level of service and socioeconomic characteristics. The model, which was estimated with two-stage least squares, is reported in Tables B-1(a) and B-1(d). The definitions of the variables in the model are given in Table B-1(e). This version and other versions of the model are discussed in more detail in Appendix B and in the original report (*C-11*).

The data necessary to apply the model for particular regions should be available from various sources. Base period levels on the dependent variables as well as the level-of-service variables would be derived from transportation survey data. The economic and demographic variables, such as household income, gasoline prices, household size variables, and urban form characteristics, would be available in various published sources such as census data.

Previous Applications

Elasticities derived from the model have been used to evaluate several policies involving changes in level-of-service variables and urban form variables. The direct- and cross-elasticities derived from the models are given in Table C-12, and the results of policy analyses are given in Table C-13. Details of these policy evaluations are contained in CRA (*C-11*).

Summary

This section has described how simultaneous linear models can be used in regional and national energy policy analyses. Models of this type can be used to analyze policies that affect only one or a small number of independent variables, such as price increases, as well as policies that change several variables, such as large changes in transit systems. Similarly, several policy actions contained in a contingency plan could be analyzed, provided that the effects of the actions are translated into changes in the independent variables of the model in question.

Simultaneous linear models appear to be a promising approach to quick response policy analysis. The particular

TABLE C-12

LEVEL OF SERVICE ELASTICITIES

Own Elasticity of VMTs	
With respect to:	
Auto travel time per mile	-.4944
Gasoline cost per mile	-.2102
Free parking availability	-.1006
Own Elasticity of Transit Trips	
With respect to:	
Transit trip time	-.0989
Transit availability	.4628
Cross Elasticity of VMT's*	
With respect to:	
Transit trip time	.0068
Transit availability	-.0317

*Percentage change in VMTs divided by percentage change in transit trips = -.0685.

TABLE C-13

SUMMARY OF POLICY SCENARIO PREDICTIONS USING WORK AND NONWORK TRAVEL MODEL ELASTICITIES

Policy Scenario	Percentage Change in VMTs
100 percent gasoline tax	-15
50 percent decline in free parking	5
50 percent increase in auto fuel economy	10
10 percent increase in transit speed	0
Transit available for all trips	-10
Higher density urban form	0

model used in this section and in Chapter Two should be viewed as an example of this approach. Further research to update the models with more recent data and to include more policy sensitive variables and recently emerging concepts in travel behavior may be desirable.

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APPENDIX D

EMERGING APPROACHES IN TRAVEL BEHAVIOR RESEARCH FOR ENERGY POLICY ANALYSIS

Several emerging concepts in travel behavior research may be useful in yielding a better understanding of travel responses to energy shortfall situations. As noted in Chapter Three, existing quantitative methodologies are incapable of producing the full amount of information necessary for analyzing the impacts of fuel shortages and governmental actions to deal with shortages. In addition, it is possible that behavior during energy shortage periods is fundamentally different from behavior typical of nonshortage periods.

Three research issues are addressed in this appendix. First, research focusing on the definition and analysis of complex travel patterns is described. Better understanding of these travel patterns may be especially important during energy shortfalls, since available survey data (described in Chap. Three and in Peskin (D-1)) indicate that combining trips is a prominent means of conserving energy during shortfalls. Second, research on nonmotorized modes is discussed. Finally, the issue of the effects of constraints (e.g., time, money, and fuel) on travel behavior is described. Some researchers believe that constraints are a very important factor affecting travel behavior, in general, and the effects of constraints may be even more important during energy shortfall periods.

COMPLEX TRAVEL PATTERNS

Because most quantitative models of travel behavior are based on simple trip definitions (single links or home-destination-home round-trip definitions), the question arises of the extent to which they adequately represent travel behavior, which can be more complex than simple trip definitions would indicate. This question has motivated research to define and model travel behavior in a more realistic manner.

Analysis of complex travel patterns (trip chaining behavior) can emphasize different trip purposes. Horowitz (*D-2, D-3, D-4*) has examined complex nonwork travel patterns. Adler and Ben-Akiva (*D-5*) and Burnett and Hanson (*D-6*) defined and analyzed travel patterns that included both work and nonwork destinations. Another approach is to examine nonwork trips that are made as parts of chains involving work trips. Damm's (*D-7*) analysis of time allocation to nonwork activities by time of day indirectly addresses this type of trip chaining.

There are also alternative approaches to dealing with the complexity of travel patterns. Burnett and Hanson (*D-6*) deal directly with the spatial and temporal complexity of travel by defining categories of trip patterns. Alternatively, simple variables that characterize the essential features of travel patterns, such as VMT (*D-8*), travel distance (*D-9*), or time allocation (*D-7, D-10*), can be used. Although the latter approach may not contribute as much to understanding the complexities of travel behavior, it does result in more tractable models.

The issue of how important complex travel patterns are in overall travel behavior is relevant in assessing the usefulness of models based on simple trip definitions. During nonshortage periods, it appears that most travel behavior is fairly simple. For example, the models developed by Horowitz (*D-3*) can be used to derive a ratio of destinations to tours of about 1.25 for his subsample of nonwork trips from the 1968 Washington survey. This ratio suggests that over 70 percent of the tours are simple trips. (A ratio of 1 implies that all tours are simple trips.) Preliminary analysis of the 1977 Baltimore disaggregate data set suggests a similar ratio. Finally, over 80 percent of all tours in a recent Hague, Rotterdam, Netherlands travel study are simple trips. (G. Weisbrod of Cambridge Systematics reported this information at the Passenger Travel Demand Forecasting Committee meeting at the 1980 Transportation Research Board annual meeting.)

Trip chaining may be a much more important phenomenon during periods of gasoline shortages. Surveys conducted during the 1973–1974 gasoline shortage and the 1979 shortage indicate that trip chaining is a common conservation action. Since research on complex travel patterns has not yet resulted in quantitative models that are easy to understand and apply, insight from surveys conducted during shortage periods can be used in qualitative analysis of trip chaining and its impacts on fuel consumption. Findings from studies of this type are described in Chapter Three.

The remainder of this section first discusses research that deals directly with complex travel patterns. Second, sim-

plified quantitative models are discussed. Following is a discussion of how simplified variables such as VMT, distance, or time allocations might be linked directly to complex travel patterns.

Research on Complex Travel Patterns

The essentials of this approach are being developed by Burnett and Hanson (*D-6*) in an ongoing major research project. The research, which is heavily based on previous work in the geographic and regional science literature, emphasizes the inherent spatial and temporal complexity of travel behavior. At the same time, it is conjectured that decision processes resulting in choices among complex travel patterns may be much simpler than those implied by typical destination choice models based on utility maximization assumptions.

The approach is articulated by establishing counter hypotheses to three major assumptions implicit in typical choice models: (1) behavior is relatively simple and can be defined in terms of a trip; (2) behavior involves choices among alternatives; and (3) decision processes are complex, involving trade-offs among a large set of characteristics of alternatives. The counter hypotheses are as follows: (1) travel behavior is complex; (2) constraints, rather than choice, may be more important in explaining behavior; and (3) decision processes are simple and involve consideration of only a small number of characteristics.

Empirical work to date has emphasized the measurement and classification of complex travel patterns. The first step involves observing daily travel patterns with the aid of graphs representing the spatial and temporal coordinates of travel patterns. By observing and comparing the travel patterns generated for a sample of individuals over time, the authors concluded that there may be similarities among travel patterns that allow classification into a reasonably small number of groups.

The preceding qualitative analysis is followed by the use of quantitative classification techniques. For example, Burnett and Hanson (*D-6*) characterize the individual stops in a travel pattern by seven variables: (1) mode of travel, (2) time of day, (3) land use, (4) activity, (5) north-south location, (6) east-west location, and (7) distance from previous stop. Multidimensional scaling techniques are then used to reduce the number of characteristics. The hypothesis is that the essential features of stops can be characterized by a small number of dimensions.

Linkages among stops are also examined. Focusing on the activity characteristic, Burnett and Hanson (*D-6*) construct flow matrices that represent how likely a particular activity is to precede or follow any other activity. Principal components analysis of the flow matrices results in a classification of activities in terms of their links to other activities.

Another approach to classification is presented by Pas (*D-11*). First, daily travel patterns are classified by mode, activity, and time of day. Second, a measure of the similarity of the travel patterns of different individuals is defined in terms of a stop-by-stop comparison of patterns. Next, the similarity measures are input into a hierarchical cluster analysis program, which results in a reasonably small number of groups of travel patterns. Finally, a version of the multinomial logit model is used to examine the effects of age and sex on type of travel pattern.

Classification of complex travel patterns is an important step in the development of practical travel behavior models. An alternative approach is to treat each possible daily travel pattern as an alternative in a choice modeling framework (*D-5*). Although this approach can be useful in explaining the important determinants of travel patterns, practical application of such models is inhibited by the large size of choice sets and by the inherent difficulty in defining potential travel patterns.

Simplified Nonwork Travel Models

This approach can be viewed as being based on an extremely simple classification of daily travel patterns (i.e., by nonspatial variables such as VMT or time allocation). The use of VMT as the dependent variable in these types of models is especially useful for energy and transportation policy analysis because the model outputs are of direct interest. Models of this type, developed by CRA (*D-8*), are used for the quantitative analyses of this study. The development and application of the models are described elsewhere in the report and in Appendix C.

Zahavi (*D-9*) has used a similar approach in his development of the United Mechanism of Travel (UMOT) model. The key hypothesis is that the utility of daily travel patterns can be represented by total travel distance (by all modes). Households are assumed to maximize this distance subject to travel time budget and monetary budget constraints.

Zahavi's (*D-9*) approach is potentially useful for transportation energy analysis. The focus on distance yields results that are of direct interest. Further, constraints may be especially important factors during periods of fuel supply limitations.

The analysis of the amounts of time allocated to daily activities (including travel) is another approach using simplified measures of activity behavior. Steinberg et al. (*D-10*) have estimated a system of simultaneous equations that explain amounts of time allocated to 12 purposes. The current version of the system includes household and individual characteristics as explanatory variables. Therefore, no direct analyses of the impacts of changes in the transportation system are possible. However, information on the variance–covariance structure of the residual terms of the system of equations can be used to examine the impacts of changes in time allocated to particular activities on other activities (*D-12*). For example, this approach has been used to explore the effects of increased time spent in gasoline lines on daily time allocation to other activities.

Damm (*D-7*) has developed models that explain whether and how long people participate in nonwork activities during five daily periods: (1) before work, (2) on the way to work, (3) during work hours, (4) on the way home from work, and (5) after work. Time allocation is explained by socioeconomic characteristics, transportation system characteristics, and time constraints (e.g., work schedule). The models for periods 2, 3, and 4 may be useful for analyzing trip chaining behavior associated with the work trip. How-

ever, because the models explain total activity time, but not travel time, travel impacts must be dealt with indirectly.

Although these time allocation studies have made important initial contributions to improved understanding of travel behavior, they may not be directly useful for quantitative energy policy analyses. The dependent variables, time allocations, do not correspond to impacts of direct policy interest. Further, there are features of the existing models that inhibit practical application. The CRA models do not contain policy-sensitive independent variables. Although Damm's (*D-7*) model does, it is quite complex in its functional form and in the definition and number of independent variables. These features inhibit quick response policy analyses.

Both modeling systems provide useful insights for qualitative analyses. The trade-off structure among alternative activities used in the CRA system is one example. Another example would be the use of Damm's (*D-7*) models to explore qualitatively the impacts of changes in work schedule on activity scheduling and, indirectly, on trip chaining.

Integrating Simplified Models and Complex Travel Patterns

While the outputs of simplified models, especially VMT or travel distance models, are of primary interest in transportation and energy policy analyses, the outputs of models based on complex travel patterns would require an additional step for deriving measures such as VMT. On the other hand, the simplicity of the former type of model may hide features of travel behavior that are especially relevant during periods of energy shortages. For example, the relationships in a VMT model may reflect the fact that travel patterns are fairly simple during normal periods. If energy shortages result in more complex travel patterns, the relationships in the VMT model may be suspect.

The modeling system developed by Horowitz (*D-3*) provides a useful framework for relating VMT to travel patterns. The system contains a multinomial logit destination choice model, a model of sojourn frequency (total number of daily nonhome, nonwork destinations), a model of daily tour frequency, and a model for estimating daily VMT.

The VMT model is of primary interest to this discussion. The model has the following form:

$$\mathrm{VMT} = 2DN_t + r(N_s - N_t) \qquad \text{(D-1)}$$

where VMT is vehicle-miles traveled; D is the weighted average distance (in Horowitz's model, the weights are the probabilities of destination choice estimated from the destination choice model) from home to destinations in a tour; N_t is the number of tours; r is the average distance between destinations within a tour; and N_s is the number of sojourns (destinations).

The motivation for the model is represented in Figure D-1. D can be thought of as the distance between home and the centroid of the tour and r as a measure of the dispersion of individual destinations within the tour.

Horowitz's (*D-3*) model of tour frequency can be used to simplify the analysis further. This model suggests that the number of tours are independent of demographic and transportation systems variables. Therefore, the number of

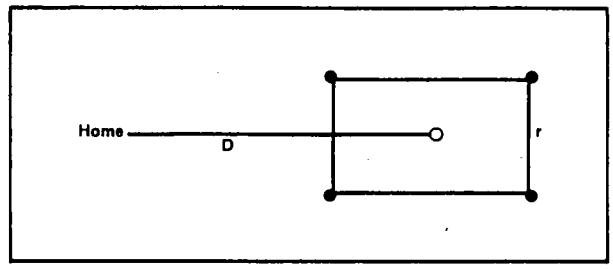

Figure D-1. Representation of VMT model.

tours can be modeled as a fixed function of the number of sojourns:

$$N_t = kN_s \qquad \text{(D-2)}$$

Substitution of Eq. D-2 for Eq. D-1 yields:

$$\mathrm{VMT} = 2DkN_s + r(1-k)N_s \qquad \text{(D-3)}$$

The sojourn frequency, N_s, is analogous to nonwork trip generation. The other three variables, D, k, and r, describe various facets of trip chaining behavior. As mentioned earlier, D and r describe the spatial characteristics of the tour, and k is a measure of the propensity to combine sojourns into complex tours. In order to develop behaviorally sound and policy-sensitive models of the form of Eq. D-3, D, r, and k would function as demographic and transportation systems variables. This type of analytical model development is beyond the scope of the project.

Equation D-3 can be used for qualitative analyses of the impacts of changes in tour structure on VMT. By taking the partial derivatives of VMT with respect to each of the four right side variables, it is possible to examine the consequences of behavioral changes:

$$\frac{\partial \mathrm{VMT}}{\partial N_s} = 2Dk + r(1-k) \qquad \text{(D-4a)}$$

$$\frac{\partial \mathrm{VMT}}{\partial D} = 2kN_s \qquad \text{(D-4b)}$$

$$\frac{\partial \mathrm{VMT}}{\partial k} = 2DN_s - rN_s \qquad \text{(D-4c)}$$

$$\frac{\partial \mathrm{VMT}}{\partial r} = (1-k)N_s \qquad \text{(D-4d)}$$

(In Eqs. D-4a through D-4b, it is assumed that each of the four independent variables is independent of the remaining three.)

Equations D-4a through D-4d have straightforward interpretations. The first equation states that a reduction in sojourn frequency leads to a proportionate reduction in VMT. The factor, $2Dk + r(1-k)$, is the average total distance per sojourn.

The second equation represents the effects of reducing the average distance between home and the centroid of a tour. An example of such a change would be the selection of a closer shopping area (which includes multiple destinations) in place of a farther area with, perhaps, higher quality stores. The amount of reduction of VMT to a one-unit reduction in distance, D, is simply twice the number of tours, $2kNs$.

The third equation represents the effects of increasing the propensity to combine trips. Trip chaining increases as k decreases. A decrease in k leads to a decrease in the number of tours but an increase in the number of links per tour. The first effect decreases distance (the first term on the right side), while the second effect increases distance. The net change in distance per sojourn, $2D - r$, is likely to be positive, indicating that increases in trip chaining are likely to decrease VMT.

Equation D-4d represents the effect of reducing the average distance between destinations within a tour. This type of behavioral change might arise from better trip planning. That is, travelers may rearrange the sequence of stops within a tour to reduce travel distance. The reduction of VMT is simply the reduction in r times the number of sojourns in excess of simple trips $[N_s(1 - k)]$. (Note: if all tours were simple trips, $k = 1$, the number of sojourns in excess of simple trips is zero.)

Elasticities of VMT with respect to the variables N_s, D, k, and r indicate the relative magnitudes of VMT reductions resulting from changes in each of the four components of tour structure. Table D-1 presents the formulas for these elasticities and specific values based on values of the tour structure variables close to the sample averages used by Horowitz. (Horowitz supplied the sample averages in a personal communication; they have been slightly modified to round numbers.)

The elasticity of 1 for sojourn frequency follows from the fact that VMT is directly proportional to the number of sojourns. Because of the small magnitude of trip chaining in the sample, most of the average distance per sojourn can be attributed to the home to centroid movement, D. Consequently, the elasticity with respect to intratour distance, r, is low and the elasticity with respect to D is high. This outcome suggests that encouraging destinations closer to home might be a more effective VMT-reduction approach than reducing intratour distance through encouraging trip planning or other means.

TABLE D-1

ELASTICITIES OF VMT WITH RESPECT TO CHARACTERISTICS OF TOURS

Elasticity	Formula	Value*
Sojourn frequency (N_s)	1	1
Home to centroid distance (D)	$\frac{2kD}{[2kD + r(1-k)]}$	.91
Chaining propensity (k)	$\frac{2D - rk}{[2kD + r(1-k)]}$	.54
Intra tour distance (r)	$\frac{(1-k)r}{2kD + r(1-k)}$	.09

*The values of k = .8, r = 3.75, D = 4.65, and N_s = 1.15 were used in calculating the elasticities.

The chaining propensity elasticity of 0.54 indicates that a 10 percent decrease in k leads to roughly a 5 percent reduction in VMT. The practical significance of this result can be illustrated with a hypothetical example. The average value of N_s in Table D-1 indicates that about 115 sojourns will occur in a 100-day period. If all tours contain either 1 or 2 sojourns, 69 one-sojourn tours and 23 two-sojourn tours result in 115 sojourns and a tour-to-sojourn ratio, k, of 0.8. If travel behavior changes so that 49 tours contain single sojourns and 33 contain two sojourns, the total number of sojourns remains at 115, but the tour-to-sojourn ratio is reduced to 0.71 (a greater than 10 percent reduction). The elasticity value indicates that VMT would be reduced by over 5 percent. That is, by combining fewer than one-fourth of single sojourn tours into two-sojourn tours, a greater than 5 percent reduction in VMT is realized. (This result assumes that the distance variables, D and r, remain constant.)

The approach outlined here is similar to that used by Erlbaum et al. (*D-13*) in their analysis of the energy savings potential of trip chaining and other behavioral changes. Rather than defining travel in terms of tours, however, they used the conventional trip definition (a one-way movement between two destinations). The relationship between the conventional definition and Horowitz's concepts is that the total number of conventional trips equals the number of sojourns plus the number of tours (Trips $= Ns + Nt$).

In the conventional trip definition framework, trip chaining can lead to reduction in VMT in a number of ways. For example, increasing the number of sojourns per tour (1) may decrease the average trip distance if $D > r$, and (2) decreases the number of trips because the number of trips from destinations other than home-to-home is reduced. VMT reduction can be estimated by assuming magnitudes for each such effect. For example, Erlbaum et al. (*D-13*) assumed that increased trip chaining results in a 25 percent reduction in average trip length.

NONMOTORIZED MODES

Most of the work in nonmotorized modes has focused on the bicycle. Demand for bicycles has been investigated using several techniques: mode choice modeling (*D-14*); exploratory analysis of mode choice survey data (*D-15, D-16*); and analysis of trips that could be taken by bicycle, based on actual and/or hypothetical data (*D-17, D-18, D-19*). Each of these methods focuses on the variables affecting the decision to use a bicycle.

In the following, major findings from previous studies are described. Next, approaches for analyzing nonmotorized modes in this and future studies are suggested.

Previous Research

The findings from previous studies are organized in terms of the variables that have been found to be important factors affecting bicycle travel.

Trip Distance

There is clearly an upper limit for trip lengths that will be made by bicycle. Estimates of this trip length, however, vary considerably. Ohrn (*D-19*) assumes that the maximum distance for a bike trip is 2 miles (10 min at average speed of 12 mph) based on data from England and the Netherlands. Hanson and Hanson (*D-15*) found that in Uppsala 96 percent of all bicycle movements were under 1.86 miles. Using survey data from Davis, Lott et al. (*D-14*) found that while commuters choosing bicycle as their most frequent mode had a mean trip distance of 1.32 miles, the frequency of bicycling was related to trip length; individuals who commuted by bike only one day per week had an average trip distance of 1.67 miles. Both Everett (*D-17*) and Hirst (*D-18*) assumed that the bicycle could be used for trips up to 5 miles in length.

Trip Purpose

The potential use of bicycles for different trip purposes is unclear. Using data from St. Paul–Minneapolis, Ohrn (*D-19*) found that 48.6 percent of shopping trips (8.9 percent of total trips), 40.5 percent of personal business trips (8.7 percent of total trips), and 18.9 percent of work trips (5.1 percent of total trips) were less than 2 miles. These trip purposes were each dominated by the automobile driver mode (more than 50 percent). The flexibility in scheduling of discretionary trips also encourages the (potential) switch to bicycles for these trips. On the other hand, the need for storage space for packages discourages the potential for shopping trips made by bicycle.

Hanson and Hanson's (*D-15*) analysis of trip purpose, using Uppsala data, found that only 4.3 percent of daily discretionary travel is done by bicycle, whereas 26.7 percent of daily work journeys are made by bicycle. However, at least 10 percent of shopping and personal business trips were made by bicycle. They also found that bicycle use for the work trip is less sensitive to temperature and more sensitive to cloud coverage than its use for discretionary trips. Hence, flexibility in scheduling for discretionary trips (allowing delays based on weather conditions) appears to enhance the attractiveness of bicycle use for these trips (since precipitation varies on a daily basis to a greater extent than does temperature).

Level of Service

Both the availability of the automobile and accessibility to transit may affect the potential for bicycle use. Ohrn (*D-19*) found that 31.3 percent of home-based vehicular trips made in Minneapolis–St. Paul were automobile passenger trips. These trip-makers are the best candidates for bicycle use because as many as 10 percent of total auto trips are made just to accommodate the passenger. Although there is some evidence that use of bicycles is not the result of unavailability of the automobile (*D-16*), when bicycles were not used for the journey to work because of inclement weather in Uppsala, the use of bus, walking, and automobile passenger modes increased rather than the use of the automobile driver mode. Moreover, in Davis, where bicycle use is prevalent for the work trip, it is also true that the number of two-car households is very low (*D-14*). Hence, the demand for bicycle use may be related to competition for the automobile in a household. In addition, a high level of auto congestion or parking difficulty may encourage bicycle use.

Bicycle use may also be affected by the availability of transit. Availability of transit in terms of distance to transit can affect the use of bicycles as an access mode. Ohrn (*D-19*) suggests that while the maximum distance for access by walking is likely to be 0.5 miles, access by bicycle can be expected for distances of up to 2 miles. In fact, the the Uppsala survey revealed a high incidence of bicycle use as access to transit. Low transit frequencies may also stimulate bicycle use for short trips where the transit wait times is particularly onerous.

The level of service of the bicycle mode also influences bicycle travel. It is typically assumed that bicycle use would increase if appropriate facilities were provided. The high use of bicycles in Davis is certainly consistent with attractive bicycle facilities. The direction of causation, however, is not clear; good bicycle facilities in Davis may be the result of what was an already high level of bicycle use. There is some evidence that high bicycle use is possible without special facilities; this appears to be the case in Uppsala. On the other hand, bicycle facilities are a low-capital investment and are likely to stimulate bicycle use, especially for the inexperienced rider who is unwilling to ride in automobile traffic. An examination of before-and-after data at sites where bikeways were introduced (e.g., Ravenna Boulevard in Seattle (*D-20*)) may shed more light on this issue.

Socioeconomic Characteristics

Lott et al. (*D-14*) found that age and occupation had significant effects on the choice between motorized and nonmotorized modes. Age was negatively related to bicycle use for the work trip. In Uppsala, however, bicycle use appears to remain fairly stable throughout the stages of the life cycle until retirement. Both managers and blue-collar workers were more likely to choose the automobile mode

than were professionals; sales and clerical workers were less likely to use an automobile than were professionals. All other factors equal, managers are least likely to use nonmotorized modes. Everett (*D-17*) suggests that white-collar workers may be less likely to bicycle to work if they must change clothes at the office, and that this additional time should be considered.

Suggestions for Analysis of Nonmotorized Modes

There are several approaches for analyzing nonmotorized modes. The hypothetical techniques employed by Everett (*D-17*), Hirst (*D-18*), and Ohrn (*D-19*) can be used. The potential number of bicycle trips in a region or corridor can be estimated based on multivariate distributions of trip length and age and occupation of the trip-maker. Employing assumptions about the impact of other variables, the potential shift to bicycle use can be estimated. This technique can also demonstrate a methodology for planners considering construction of a bikeway.

Next, a previously estimated logit model can be used, with the bicycle treated as a new mode. The bicycle constant can be fitted based on data for the existing modal split (e.g., from the Baltimore (the Baltimore data set is one of the few urban travel surveys that contains observations of travel by nonmotorized modes) or other available data. The constant term would include effects of variables that are difficult to specify, such as safety and the quality of facilities. Therefore, a possible strategy for examining the effects of large-scale improvements in bicycle facilities could be to use information from an area with excellent facilities, such as Davis, to select the bicycle constant.

Third, a new mode choice model of the type similar to Lott et al. (*D-14*) can be estimated using the Baltimore data set (assuming there are a sufficient number of observations). Both bicycle and walk modes, both access and line-haul modes, and both work trips and other trip purposes can be treated. It also would be possible to test the stability of the coefficients of Lott's model in an area with no special bicycle facilities. The Baltimore data set could also be used to determine the effect of level of service of alternate modes, including transit, and to test the effect of competition for automobiles in the household.

TRAVEL BEHAVIOR UNDER RESOURCE CONSTRAINTS

Most existing travel demand models are consistent with the assumption that travel is not directly subject to resource constraints. In some studies, this assumption is only implicit, while in other studies it is a consequence of the assumption that travel makes relatively small demands on resources. In discrete choice models, although constraints are present in choice set construction, explicit time or money constraints are not stated.

Recently, it has been recognized that constraints may be important phenomena in explaining travel behavior (*D-6, D-21*). Consideration of constraints is important theoretically and may also be of practical importance during periods such as energy shortages. That is, models that do not explicitly consider constraints may not be appropriate for analyzing situations in which constraints occur.

Previous Work Using Constraints

McLynn and Spielberg (*D-22*) use mainly algebraic and graphical analyses in their discussion of the effects of monetary and time budgets on travel. Zahavi (*D-9*) has implemented this approach in his United Mechanism of Travel (UMOT) model. The approach can be represented by the following problem:

$$\text{Max } U(X_T, X_A) \tag{D-5}$$

subject to

$$T = t_T X_T + t_A X_A \tag{D-6}$$

$$M = C_T X_T + C_A X_A \tag{D-7}$$

where the utility function contains transit miles, X_T, and auto miles, X_A, as its arguments. The first constraint is the time-budget constraint, where T is the time budget and t_T and t_A are the time costs per mile by transit and auto, respectively. The second constraint is the monetary budget constraint with M, C_T, and C_A analogous to the corresponding symbols in the time-budget constraint.

There are some problems with this approach and the author's interpretation of it. First, in many cases, only one constraint will be binding. This results in the shadow price of the nonbinding resource being zero and exclusion of the variable from the resulting demand functions. For example, if the time budget is nonbinding, the value of time is zero and the demand models contain only cost terms. This may not be completely realistic in some situations. Second, the authors claim that if the feasible region involves both constraints, the amount of travel by mode can be determined from the intersection of the constraint lines. This is represented in Figure D-2.

The authors claim that P is the solution. However, this claim is incorrect. The solution can occur along either constraint line as well as at the intersection. If it is along the time constraint, the following holds:

$$\frac{\partial U/\partial X_T}{\partial U/\partial X_A} \geqq \frac{t_T}{t_A} \tag{D-8}$$

Similarly, if the solution is on the monetary constraint, then

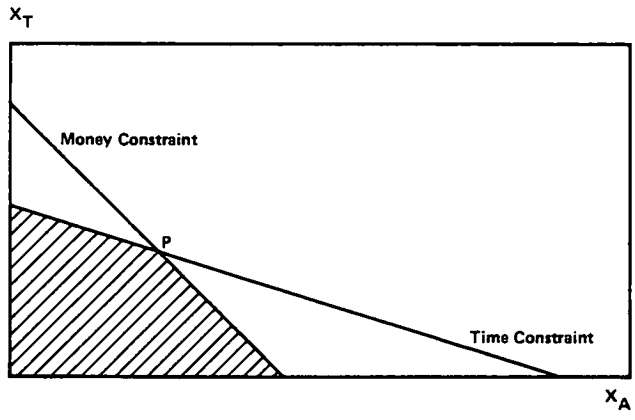

Figure D-2. Representation of constrained travel behavior.

$$\frac{\partial U/\partial X_T}{\frac{\partial U}{\partial X_A}} \leq \frac{C_T}{C_A} \qquad \text{(D-9)}$$

The intersection is the solution when

$$\frac{C_T}{C_A} < \frac{\partial U/\partial X_T}{\partial U/\partial X_A} < \frac{t_T}{t_A} \qquad \text{(D-10)}$$

It should be noted that in this example it is assumed that $t_T \geq t_A$ and $C_T \leq C_A$. These assumptions are reasonable in most cases. The point of the argument, which this example illustrates, is that, contrary to the claim of McLynn and Spielberg (*D-22*), knowledge of the utility function is necessary, regardless of whether both constraints are potentially binding.

Golob et al. (*D-23*) analyzes travel behavior, subject to a constraint on total travel cost. Cost is interpreted to include both time and monetary costs. A simplified version of the problem consists of a single travel variable (e.g., auto VMT).

$$\text{Max } U(X) \qquad \text{(D-11)}$$

subject to

$$Y = bX \qquad \text{(D-12)}$$

where X is the travel variable; Y is the available resource; and b is the per mile resource expenditure.

Using Lagrange multipliers, the problem can be formulated as:

$$\text{Max } V(X,\lambda) = U(X) + \lambda(Y - bX) \qquad \text{(D-13)}$$

One of the equations of the solution is

$$\partial U/\partial X = \lambda b \qquad \text{(D-14)}$$

Golob et al. (*D-23*) then apply an inverse function to Eq. D-14 to obtain

$$X = \Psi(\lambda b) \qquad \text{(D-15)}$$

Dunbar used this approach in the development of simultaneous travel demand equations. However, he interpreted the constraint equations as supply side relations rather than resource constraints (*D-24*).

The demand function here implicitly accounts for the constraint through λ. It should be noted that λ varies with Y. Therefore, in estimating a demand model of this nature, the effect of the price variable, b, would vary with the resource variable, Y.

The constraint variable, Y, can be directly included in the demand function by adding

$$\partial V/\partial \lambda = Y - bX = 0 \qquad \text{(D-16)}$$

to Eq. D-14 and solving this system of equations for X and λ. This latter approach is appealing when the constraint variable is of direct interest and will be developed further later.

Effects of Resource Constraints on Travel Behavior

In this section, simple models are used to illustrate how resource constraints lead to changes in travel patterns. Similar to Zahavi (*D-9*) and Golob et al. (*D-23*), it is assumed that utility is a function of the amount of travel (distance and number of trips) for particular purposes (e.g., work, recreation, etc.). During normal periods the definition of the resource constraint follows that of Golob et al. in that a single, generalized cost constraint is used.

Formally, the problem can be stated as

$$\text{Max } U(X_1, X_2, \ldots, X_n) \qquad \text{(D-17)}$$

subject to

$$C + vT = \Sigma a_i X_i + v\Sigma b_i X_i \qquad \text{(D-18)}$$

where U is the utility function; X_i is the amount of travel for the ith activity; C is the money budget constraint; v is the value of time; T is the time budget constraint; a_i is the amount of money expenditure per unit travel for activity i; and b_i is the corresponding time expenditure.

Using standard economic analysis (see, for example, Varian (*D-25*)), the constrained optimization problem can be solved for X_i to yield demand functions of the form

$$X_i = f_i(C + vT, a_1 + b_1 v, a_2 + b_2 v, \ldots, a_n + b_n v) \qquad \text{(D-19)}$$

$C + vT$ corresponds to income and $a_i + b_i v$ corresponds to price in ordinary demand functions.

Particular functional forms for the demand functions are used in empirical studies. For example, the multiplicative demand function, which has the convenient property of the elasticities being the exponents, is often used. This function is represented in Eq. D-20):

$$X_i = a_i(C + vT)^{\beta_i}(a_i + b_i v)^{\gamma_i} \qquad \text{(D-20)}$$

β_i corresponds to the income elasticity and γ_i corresponds to the price elasticity.

Several comments about this approach are appropriate. First, several of the terms of Eq. D-20 are likely to vary with variations in demographic characteristics. For example, the value of time, v, and the parameters of the utility function (α, β, γ), probably vary with demographic characteristics. Separate sets of demand models might be necessary for different demographic groups.

Second, the effects of time and monetary constraints are different from the effects of price increases. For example, a gasoline rationing policy without white markets can be interpreted as lowering the monetary constraint, C. A gasoline price increase, on the other hand, would result in an increase in a_i, the monetary expenditure of travel.

A somewhat more satisfactory manner of handling constraints like rationing would be to disaggregate the resource constraint into two components: (1) a component consisting of the total time expenditures and the monetary expenditures associated with the activity itself, and (2) a component consisting of monetary expenditures on travel. This approach is consistent with the fact that, under rationing, monetary travel resources cannot be traded off with other resources.

The reformulated problem would be

$$\text{Max } U(X_1, \ldots, X_n) \qquad \text{(D-21)}$$

subject to

$$C = \Sigma a_i X_i \qquad \text{(D-22)}$$

and

$$vT = v\Sigma b_i X_i \qquad \text{(D-23)}$$

where C is the monetary constraint, and vT is the time constraint on travel.

Under rationing, it is likely that only the first constraint is binding. In this case, the problem involves optimization subject to this constraint only. This problem is formally equivalent to the standard demand analysis problem in economics. The resulting demand equation would be

$$X_i = a_i(C)^{\beta_i}\,(a_i)^{\gamma_i} \qquad \text{(D-24)}$$

The demand equation is of the same general form as the previous equations. The key feature is that demand is a function of the constrained resource and constrained resource expenditure coefficients. Therefore, it appears that the former models can be used to analyze the latter situation if the appropriate factors are used (i.e., C is substituted for $C + vT$ and a_i is substituted for $a_i + b_i v$).

Numerical Example

If Eq. D-20 gives the appropriate demand functions, the key variables are $C + vT$, $a_i + b_i v$, a_i, β_i and γ_i. Consider the allocation of travel to two activities. Activity 1 has a fairly low per-mile money expenditure, a_1, but a high time expenditure coefficient, b_1. Activity 2 has a higher money expenditure coefficient, a_2, but a lower time coefficient, b_2. The b_i can incorporate the effects of different values of time for different activities as well as different time expenditures. With this interpretation, the first activity might be interpreted as work travel (fairly low money expenditures, high value of time), while the second may be leisure travel (higher money expenditures because of nontransport expenses such as meals, but lower value of time). Specific values for the key variables might be as follows:

Activity	a	b	$a + bv$	a	β	γ
1	\$0.15/mi	0.05 hr/mi	\$0.25/mi	0.5	1	−1
2	\$0.25/mi	0.0083 hr/mi	\$0.267/mi	0.5	1	−1

$v = \$2.00/\text{hr}$, $T = 1.1$ hr/day, $C = \$5/\text{day}$

Because of the combined form of the resource constraint, the individual time and monetary budgets are not binding individually. For example, an individual may spend somewhat more than 1.1 hours (perhaps borrowing from in-home activities). However, the combined constraint is binding as in the case

$$C + vT = \$5.00 + \$2.00/\text{hour} \times 1.1 \text{ hours} = \$7.20 \qquad \text{(D-25)}$$

Equation D-20 predicts the following travel distances:

$$X_1 = \frac{0.5 \times 7.2}{0.25} = 14.4 \text{ miles} \qquad \text{(D-26)}$$

$$X_2 = \frac{0.5 \times 7.2}{0.267} = 13.5 \text{ miles} \qquad \text{(D-27)}$$

This results in the following expenditures (assuming Travel Time = 30 mph average speed):

Activity	Travel Distance	Travel Time	Monetary Travel Cost
1	14.4 mi	0.48 hr	\$2.16
2	13.5 mi	0.45 hr	\$3.38
Total	27.9 mi	0.93 hr	\$5.54

Suppose now that gasoline rationing reduces the monetary travel budget, C, to \$4.00/day. Using the already available information in Eq. D-24 yields:

$$X_1 = \frac{0.5 \times 4}{0.15} = 13.3 \text{ miles} \qquad \text{(D-28)}$$

$$X_2 = \frac{0.5 \times 4}{0.75} = 8 \text{ miles} \qquad \text{(D-29)}$$

This results in the following expenditures (assuming Travel Time = 30 mph average speed):

Activity	Travel Distance	Travel Time	Monetary Travel Cost
1	13.3 mi	0.44 hr	\$2.00
2	8.0 mi	0.27 hr	\$2.00
Total	21.3 mi	0.71 hr	\$4.00

The constraint imposed by rationing is clearly binding and results in both absolute and relative reallocations of time. In particular, travel for the activity for which monetary expenses are relatively high (the nonwork activity) is reduced to a greater extent.

Discussion

The examination of the role of resource constraints appears to have produced qualitatively plausible results. In particular, this approach seems to explain the greater reductions in discretionary travel during periods of resource constraints (fuel shortages). The use of constraints to explain this observed pattern of travel reductions contrasts with Lee's (*D-26*) explanation. He conjectured that the total gasoline price (pump price plus waiting time) was greater for discretionary travel. Insofar as this explanation may not be consistent with observed patterns of gasoline lines (*D-27*), the resource constraint approach may be more plausible.

The analysis described here is clearly highly simplified and preliminary. Empirical estimation of models of this type would be a useful area of further research. Data from periods of energy shortfalls, in which monetary travel budgets can be viewed as being constrained, would be especially useful for such research.

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APPENDIX E

GUIDELINES FOR DATA COLLECTION

This appendix addresses the data collection needs associated with two broad purposes for data collection related to energy shortfalls: monitoring and planning activities, and behavioral research. Both the application of existing data and the need for new data under each function are discussed. Specifically, the variables, data sources, and data collection techniques are considered.

MONITORING AND PLANNING

Monitoring and planning activities can be classified into

three groups: integrating fuel use indicators into continuous, on-going planning activities; identifying triggers denoting energy shortfalls or escalations of shortages; and monitoring the impact of contingency actions, traveler response to fuel shortages, and transportation system needs. Many of these activities can rely on data already collected or data collected by state and local agencies as part of the general transportation planning process. The data needs for each type of activity are discussed in the following.

Use of Fuel Indicators in Planning

Integrating fuel use indicators into continuous, ongoing planning activities would provide planners real-time knowledge of the availability of fuel supplies and would offer prior warning of fuel shortages. Such indicators include weekly gasoline sales and price data and monthly fuel supply inventories. Gasoline sales and price data provide information on local seasonal variations in gasoline use. These data are typically available from state and/or local energy and taxation offices. Given data on demand (and expected demand), the planner can determine the adequacy of available fuel supplies.

Monthly transit ridership data by route, collected regularly by most transit properties, also provide information on the level and distribution of demand for transit relative to capacity. Given this information, the planner can determine likely bottlenecks in the transit system in the event of a fuel shortfall.

Related to the incorporation of fuel use indicators into the planning process is the analysis of proposed energy contingency actions. Clearly, it is desirable to have some estimate of the impact of proposed actions on travel behavior. In many agencies policy analyses are based on models calibrated with out-of-date household interview survey (HIS) data. The use of old data can impose a large degree of bias on estimates since it is likely that travel patterns have changed significantly. There are two general options for updating old HIS data: (1) the use of recent data available from published sources (such as Levinson (*E-1*)) or recent local data collected for a special purpose (e.g., data collected for a study under UMTA's Service and Methods Demonstration Program); and (2) the collection of new household survey data. Several state and regional planning agencies have successfully conducted small-scale home interview surveys that are relatively inexpensive. For example, the Southwestern Pennsylvania Regional Planning Commission undertook a small ongoing home interview survey including 1,600 householdes in the first year and 800 households in each of the two subsequent years. The cost was $22.30 per interview in the first year, 1978, and annual total survey costs averaged about $66,000 per year (*E-2*). New York State DOT has administered a number of surveys including a 1970 statewide household travel survey conducted by telephone (*E-3*) and a home interview survey taken in Buffalo in the fall of 1973 (*E-4*).

Trigger Mechanisms

The use of triggers denoting energy shortfalls or escalations in shortfalls involves the identification of short-term indicators (short term triggers, which indicate the need for immediate response, are distinguished from fuel use indicators, which would offer some lead time). The most obvious indicator is gasoline station lines. The advantage of gasoline lines is that shortages at any geographic level can be observed because they represent an observable imbalance between fuel supply and demand at the source; hence, spot shortages can be identified even though the aggregate supply and demand are equal. Other short-term indicators are transit load factors, traffic counts, and gasoline prices. Because travel behavior may exhibit a delayed response to stimuli (in this case a fuel shortage)—due to persistence of habit, schedule constraints, and lack of awareness of alternatives—transit load factors and traffic counts are often not timely indicators of fuel shortfalls. Similarly, gasoline prices often display a lagged response to market forces due to imperfect information and institutional constraints, etc.

Monitoring Transportation System Performance

During an energy shortfall, planners should monitor both traveler response to fuel supply limitations and contingency actions implemented, and transportation system needs. To serve these monitoring activities, the data should be collected at several points in time. Tye (*E-5*) suggests the following list of data to monitor traveler response:

1. *Gasoline purchase decisions*—average gallons/purchase, tank inventories and capacity, queueing time/visit and queueing time/gallon, time of day and week of purchase, value of time for different market segments, and socioeconomic data on motorists.
2. *Driving and travel decisions*—trip purposes, origin and destination, trip lengths, local and intercity travel VMT, mode shifts and carpooling, trip generation, and demand elasticity by type of travel.
3. *Gasoline availability*—supplies for area and location of station, station opening and purchase policy, waiting time for stations with different locations and gasoline prices, and station pricing policies.
4. *Public policy and station policies*—minimum/maximum purchase, "regular customers" only, even/odd or other rationing, incentives for carpooling, improved transit service or other alternative service, and forced station closing, e.g., on weekends.

These data also provide information required to identify bottlenecks and excess capacity in the transportation system. Much of these data are available to planning agencies and can be collected by agency personnel using minimal resources. Special surveys might be necessary for some of the travel behavior and gasoline purchase data.

BEHAVIORAL RESEARCH

The objectives of behavioral research go beyond those of monitoring and planning activities. Behavioral research is designed to explain complex behavioral choices; monitoring seeks to describe observed choices; and planning activities typically rely on previously developed models of behavior. Accordingly, the data requirements of behavioral research are greater.

In this section, two methods of data collection are addressed that serve the requirements of behavioral research. The first is interactive methods and the second is attitudinal surveys. It should also be noted that the time-series data suggested in the previous section can be used to calibrate models of travel behavior and gasoline demand.

Interactive Data Collection Methods

Although household interview survey data remain the basic data base for travel behavior research, many analysts are finding that the data collected in the past are too limited to fully explain the complexities of travel choices. In many ways the traditional travel behavior models have been defined by the variables available in existing data sets. (Variables included in these models have been identified in the discussion of travel estimation methods in App. B.) It has been suggested elsewhere in this report that travel behavior during energy shortages is likely to be more complex than during nonshortage periods and that traditional models are often unable to explain the full range of responses.

New interactive data collection methods have been developed that are responsive to the needs of researchers investigating complex travel behavior; to date, they have been applied in transportation research on an experimental basis. These methods employ a range of measurement tools including observation, written questionnaires, personal interviews, and interactive games (*E-6*). These games allow respondents to play out their responses to policy changes and constraints imposed by the analyst. The results of the game represent only one of several steps used to investigate behavior and motivations for behavior.

Interactive methods have been used to analyze different aspects of transportation behavior. Jones (*E-7*) used the HATS game to analyze responses to transit service improvements, Burnett (*E-8*) used a game to investigate destination and mode choice, and NYSDOT applied the REACT game to analysis of responses to energy constraints (*E-9*). As expected, application of these games varies with the focus of the analysis; however, the theoretical basis for interactive methods and the data collection procedures are similar. The following discussion describes the theoretical basis, the data collection procedure used by Burnett, and how the REACT game was used to analyze energy constraints.

Theoretical Basis

The interactive method was developed in response to the inadequacy of traditional travel demand models. Specifically, these models impose restrictive assumptions on the structure of responses. Heggie and Jones (*E-10*) describe responses in terms of the following four domains:

1. Independence—each travel decision is made independently of other travel decisions and other people.
2. Spatio-temporal linkages—an individual's travel decisions are interdependent in time and space, but independent of other people.
3. Interpersonal linkages—travel decisions are interdependent with other peoples' travel decisions but independent of space and time.
4. Full interdependence—travel decisions are interdependent in time and space and across people.

Interactive methods greatly reduce the potential for bias in measuring travel responses and motivating factors. By allowing all household members to describe their travel behavior and responses to changes, the games permit the full set of interactions to take place. Therefore, no artificial restrictions are imposed on the structure of response.

A common source of bias is the use of improper tools to measure certain types of information. For example, surveys often ask respondents to indicate reasons for behavior. Often, their reasons are too complex to allow the respondent to realistically choose one of the simple answers provided in the survey. Other times respondents do not remember or know why certain actions were taken, and will select the answer that seems most reasonable at the time of the survey. As a result, the responses recorded are biased measures of the true motivations for action. The interactive games provide an opportunity for the analyst to observe the decision-making process and to clarify motivations for actions as they are being decided.

One of the reasons that behavioral intentions data are often of questionable accuracy is that respondents do not consider the full range of implications of policy changes or of the intended action. The interactive game allows respondents to see how a given policy or possible response can affect the range of activities and the activities of other members of his household. Moreover, logical constraints on certain planned responses are made clear by the game board or can be indicated by the analyst. In a survey such constraints may not be revealed because each question is answered individually and because only one member of the household is administered the survey.

Interactive Data Collection Procedure

As noted previously, the game results represent only one of several steps in the interactive measurement process. The data collection procedure outlined by Burnett (*E-8*) is representative of interactive techniques. Burnett's procedure involves several parts. The first part involves a written questionnaire administered to each member of the household. It is designed to collect data on the characteristics that affect the respondents' ability and needs for travel around the city and the activities undertaken at each destination. Socioeconomic and demographic questions are also included.

The second part involves the use of a game board. Respondents indicate their typical daily activity pattern and certain nondaily activities. Respondents discuss aloud why the places indicated are used and how these places compare with other possible destinations. These reasons are recorded on tape. Respondents assess the importance of a standard set of attributes in determining destination choice. The interviewer also obtains satisfaction ratings for each place chosen for each attribute considered important by the respondent. Each respondent is also asked to indicate any transit routes and other special transportation services known, and to record all service characteristics known about each. As part of this task the respondent also fills

out the daily trip log including all at-home and out-of-home activities.

The third part, which is an in-depth examination of part of the activity pattern described in the second part, involves a personal interview designed to obtain data on the factors influencing the travel decisions indicated on the game board. The interview focuses on the shopping and personal business stops made during the day that are perceived to be most important by the respondent. Specific destination and modal attributes are considered here. Responses are recorded on tape and in writing by the interviewer.

Some versions of Burnett's game contain a fourth part. This part is designed to explore changes in activity patterns that result from changes in the transportation system. Thus, it is quite similar to HATS (*E-7*) in its focus.

The amount of data generated by this technique is large and can be analyzed using any number of methods. The most obvious danger of this technique is that the data will be analyzed using models which impose the same restrictive assumptions that interactive measurement was designed to overcome. For the most part, data collected by this type of procedure have been described and the findings assessed in a more qualitative than quantitative fashion. The low level of experience with analyzing the data collected with this method reflects the fact that the procedure is still in the experimental state.

Policy Analysis Application

The REACT game was specifically designed to examine responses to transportation policy changes, particularly constraints. Therefore, although less data are collected in the REACT applications relative to Burnett's method, the ability of the game to measure fully interdependent responses may be more obvious.

REACT consists of a main board on which any individual playing board can be pinned. The playing board has three slots, each slot indicating the hours of the day. The three slots can be used to represent three different days, one base day and reactions to two policy changes, or in-home, out-of-home, and travel activities separately. There are five sizes of playing pieces to indicate intervals from 5 min to 2 hours (where 1 in. represents 1 hour). These pieces are color-coded to correspond to 13 types of activity and travel. Pins are used to indicate the locations traveled to, and rubber bands are hooked around the pins to symbolize the trip route followed. Interviewers measure the trip lengths and note the mode of travel used for each trip. Each respondent indicates his or her base travel and activity pattern.

The REACT game was administered to a small sample of households to evaluate four different policies: ban on driving an auto 1 day during the week (Monday through Thursday); ban on driving an auto 1 day during the weekend; reduce weekday travel by 20 percent; and reduce weekend travel by 20 percent. Each respondent uses the playing board to adjust his base travel and activity pattern in response to the policies previously described. The household members are asked to discuss out loud their decisions in response to the policy. Interviewers probe in order to clarify any reasoning not mentioned. Interviewers may also point out any logical constraints on decisions such as two household members using a car at once. The maps are photographed and the discussions are recorded.

The results of this game provide an initial evaluation of the impacts of a policy. The differential impacts on different households can be revealed, and the process by which households trade off activities is demonstrated. Hence, the full range of impacts of a given policy can be explored in contrast to traditional travel demand models that impose restrictive assumptions on the range of impacts.

Attitude Survey Data Collection

Several issues must be addressed in the collection and analysis of attitudinal data. In addition to attitudinal and behavioral variables, opportunities for or constraints to behavior are important factors (*E-11*). Constraints include expectations placed upon an individual through social norms associated with his/her role. Subjective constraints also include the respondent's level of awareness about the alternatives available. Objective constraints may be long- and short-term. Intervening events that are transient and unusual relative to the respondents' day-to-day environment may also alter the relationship between behavioral intentions and behavior in the short run (*E-12, E-13*). The researcher must distinguish between temporary reasons why an individual chooses certain travel alternatives and reasons that are an enduring aspect of his decision-making environment.

Ideally, a survey research approach for developing reliable attitudinal models would involve data collection over a relatively long period of time so that attitudinal and behavioral changes could be observed. One survey research method available to planners is the tracking technique (a panel approach). Surveying the sample over a period of time can be used to monitor attitudinal stability and possible intervening events (*E-13, E-14*). There are two major problems with this technique. First, if tracking is carried out during the energy crisis, considerable time will pass before the researcher has data for enough points in time to be able to predict behavior. Second, the survey instrument and/or the fact that these individuals are being surveyed may cause their attitudes and behavior to differ from that of the general population. The probability of bias due to testing is greater the closer together the questionnaires are administered (*E-14, E-15*). Hence, there is a tension between avoiding biases and determining the stability of attitudes and the need to collect data quickly.

In addition to these problems, such a procedure is probably beyond the resources available to state and local planners for energy contingency planning. By using some findings from past research on the attitude-behavior relationship, a simple but crude means of analyzing travel responses can be devised. This methodology, which can be used to monitor the impacts of an energy crisis and of contingency policies, is described below.

There is evidence that individuals from the same socioeconomic group have similar attitudes (*E-12*). One would also expect individuals choosing the same travel alternative to have similar attitudes with respect to travel modes. These two assumptions can be used to design a survey method that avoids the problems of the tracking technique. The

population can be stratified by socioeconomic characteristics and by mode choice (the mode used most regularly) for a given trip purpose. By distinguishing between trip purpose, the researcher will be able to predict peak period and offpeak period travel responses. Two subsamples should be selected from each stratum. The first set of subsamples would be surveyed, and the second set would be administered the same questionnaire at some later date. The timing of the second survey would depend on the objectives of the survey and the timing of other relevant events, such as the implementation of contingency plans.

Each administration will undoubtedly take at least 1 week or 2 weeks. The interviews should be timed so that there will be individuals in each stratum that are interviewed at least 1 week apart. If the correlation among scores on some item for individuals in the same stratum, interviewed on the same day, is higher than that between forms administered 1 week apart, the attitude measured tends to fluctuate over short periods of time (*E-15*). This design will allow the researcher to determine which attitudes tend to fluctuate in the short run and which remain relatively stable over at least 1 week. If the correlation among scores is low for tests administered on the same day, the questionnaire is not reliable and should be redesigned. The reliability of the questionnaire, however, should be examined during the pretest (*E-15*).

With the second survey, the researcher will have measures of attitudes over a relatively longer period of time, such as 2 months or more. If the correlation among scores months apart is lower than for scores a week apart within the same stratum, there has been some systematic change in attitudes (*E-15*). It is possible, of course, that some event could affect the whole population before the second survey that actually causes only a short-range fluctuation in attitudes and might be misinterpreted as a systematic change. A presidential address on the need to conserve energy might have this effect. It is important that the researcher be aware of such occurrences that threaten the validity of his findings and require modification of the research design, such as delaying the second survey.

Comparison of the strata would be the primary data analysis technique. Controlling for the respondents' ability to act on their attitudes, the researcher can judge which relatively stable attitudes (those correlating highly 1 week apart) characterize given travel choices. If these attitudes for the group choosing one mode shift converge with the attitudes of the group choosing a different mode, it is reasonable to assume that this change in attitudes will result in a change in behavior for at least some of the individuals. The proportion of individuals who change their travel behavior will most likely increase with the strength of the relationship between these attitudes and a given travel choice. The proportion changing their behavior is also likely to increase with the degree of convergence in attitudes observed.

There are several practical issues that must be considered in employing this design. First, it is preferable to identify all the population elements in each stratum and then randomly sample the strata. This is not likely to be feasible. One alternative is to take a simple random sample of the population and screen respondents to determine which stratum they belong to, and then randomly assign units to the first or second survey group. This is a statistically sound procedure because a random subsample of a random sample is itself a random sample (*E-16*). If this sampling design is beyond the researcher's budget, a less expensive alternative may be employed. Within these areas, quota sampling could be used. Half of the eligibles in each stratum could be interviewed immediately and the other half reserved for the second survey. Of course, this design precludes a mail survey, at least for the first survey sample.

A second potential limitation facing this research design is that the real differences among attitudes for groups making different travel choices may be too subtle to be measured by the survey questions. Again, this should be determined during the pretest. Finally, if the direction of causality is behavior affecting attitude, there might be a future change in behavior without an observable change in attitudes during the duration of this research. This design, however, can be adapted to a continuous survey design by taking larger samples and dividing each stratum into more than two groups. Moreover, after the 6 months have elapsed since being surveyed, the same sample could be administered a survey with virtually no danger of contamination of responses (*E-15*).

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APPENDIX F

ADDITIONAL DETAILS FOR APPLICATIONS OF THE QUANTITATIVE FORECASTING SYSTEM

The input variables used for the base case and the scenarios described in Chapter Two are presented in this appendix. Sample calculations are given to illustrate the use of the forecasting system. The results of the sensitivity tests on the coefficients of the work trip model are described.

WORK TRIP ANALYSES

This subsection describes the input data, the computational procedures, and the results of the sensitivity analyses.

Input Variables

The input variables include the level-of-service variables for each mode included in the logit modal choice models used in the analysis. The variables are as follows:

Cost = round-trip, line-haul operating cost and out-of-pocket charges for each mode (in 1979 dollars);

IVTT = round-trip, in-vehicle travel time for each mode including line-haul and wait time (in minutes); and

WT = round-trip walk time for each mode (in minutes).

Each of these variables is defined for each traveler class (see Table 8 for definitions of the traveler classes and App. A for calculation of private vehicle operating cost). Other input variables include trip length (miles) for each mode in each class, average on-road fuel economy (miles per gallon) for each mode, average occupancy (persons per vehicle) for each mode, and the number of (round) trips in each traveler class. Values for trip length and vehicle occupancy remain constant for all scenarios.

Operating cost per mile for the automobile mode is estimated using the following formula:

$$\text{Operating cost} = \frac{P_{\text{gas}}}{\text{mpg}} + \text{Other costs} \qquad \text{(F-1)}$$

where P_{gas} is the price of gasoline; mpg is the on-road average fuel economy in 1985 or 1990 (presented in App. A); and other costs are operating costs excluding gasoline (presented in App. A).

Auto trip costs are calculated by multiplying costs per mile by average trip length and adding parking and toll charges. Carpool trip costs are equal to one-half of auto trip costs. As explained in Appendix C, the level-of-service variables for shared ride (carpool) are represented by the values for a two-person carpool. This is a simplification over the procedure used in a previous CRA study (*F-1*), in which each carpool size was a separate mode, and over the approach used by CSI (*F-2*), which requires an auxiliary carpool size model. This simplification is based on plausible assumptions about the utility of carpools and appears to yield reasonable results.

The Base Case

Incremental logit involves the use of a base or pivot. This base includes both the base utility functions for each alternative and the base (observed) travel behavior. Each scenario can then be described in terms of changes relative to the base values; hence, data for only those variables that change are required. Base levels of service for each mode and base modal shares are defined for each traveler class. Values for a prototypical urban area in 1980 are assumed in the base case. The base case assumes no energy shortage and low (controlled) gasoline price levels (see App. A).

The input data for the base case (1980) are given in Table F-1.

The total number of work trips is assumed to grow at the projected national growth rate for government and private nonagricultural employment. The 5-year rates are 10.2 percent for the 1980 to 1985 period and 6.5 percent for the 1985 to 1990 period (*F-3*). Therefore, the total number of work trips increases to 160,150 for the 1985 scenarios and to 170,600 for the 1990 scenarios. The relative distribution of work trips among the six segments is assumed to be the same as the base case distribution for the 1985 market price/TSM and the 1990 rationing/TSM scenarios. The other two scenarios involve changes in the relative distributions of work trips that are described below.

TABLE F-1

INPUT DATA—BASE CASE

Level of Service	Traveler Class 1	2	3	4	5	6
Automobile						
COST (dollars)	0.94	3.99	1.00	4.23	--*	--
IVTT (minutes)	16.50	60.00	62.00	62.00	--	--
WT (minutes)	5.50	10.00	6.00	10.00	--	--
Mode Share	0.70	0.70	0.80	0.70	--	--
Trip Length (miles)**	5.50	30.00	6.00	32.00	--	--
Fuel Economy (mpg)*** = 15.0						
Occupancy (persons per vehicle) = 1.0						
Carpool						
COST (dollars)	0.53	2.23	0.56	2.29	0.56	2.29
IVTT (minutes)	29.50	74.00	31.00	75.00	31.00	75.00
WT (minutes)	6.50	10.00	7.00	10.00	7.00	10.00
Mode Share	0.15	0.20	0.20	0.30	0.20	0.25
Trip Length (miles)**	6.50	34.00	7.00	35.00	7.00	35.00
Fuel Economy (mpg)*** = 15.0						
Occupancy (persons per vehicle) = 2.5						
Transit						
COST (dollars)	0.33	1.80	--	--	0.36	1.92
IVTT (minutes)	27.50	126.00	--	--	28.00	128.00
WT (minutes)	10.00	20.00	--	--	11.00	18.00
Mode Share	0.15	0.10	--	--	0.80	0.75
Trip Length (miles)**	5.50	30.00	--	--	6.00	32.00
Fuel Economy (mpg)*** = 4.1						
Occupancy (persons per vehicle) = 75.0						
Trips (thousands)	43.90	21.10	35.50	29.70	10.90	4.10

*Mode not defined for this class.

**1 mile = 1.61 kilometers.

***1 mpg = 0.425 kilometers per liter.

1985 Sticker Plan

As described in Chapter Two, the effects of the sticker plan are represented by (1) adjusting the gasoline price to reflect the monetary equivalent of waiting in gasoline lines and (2) shifting one-seventh of the trips in the four classes with driving alone as an available mode to the remaining two classes, which have only shared ride and transit as available modes. The former adjustment produces a gasoline price between the nonshortage price for 1985 and the market clearing price under a 15 percent shortfall. The trips that are shifted out of the traveler classes with driving alone as an available mode are assigned to the shared ride/transit class with the same trip length classification.

The gasoline price is based on the assumption that the sticker plan lowers demand by 6.25 percent under what it would have been at the nonshortfall price. However, because the shortfall is 15 percent, a gap of 8.75 percent still remains. The assumptions used to produce this result are described in Chapter Two. The gasoline price level of $1.735 per gallon is derived from Eq. A-16, using the 1985 nonshortfall price, a shortfall level of 8.75 percent and a price elasticity of —0.2.

Table F-2 gives the input variables for the scenario. Note that the in-vehicle and walk time variables are identical to the base case. As noted in Chapter Two, the 1985 scenario results are compared to (1) the 1985 nonshortfall conditions, and (2) the results that assume the market clearing gasoline price, but no governmental actions affecting other level-of-service variables and/or modal availability. The trip costs for the drive alone and shared ride modes for these comparisons are given in Table F-3.

1985 Market Price/TSM

This scenario involves adjustment of auto and carpool trip costs to reflect the market clearing gasoline price ($2.11 per gallon) and adjustment of carpool and transit level-of-service variables to reflect preferential treatment. The 1985 market clearing price under a 15 percent shortfall is derived in Appendix A. As described in Chapter Two, the toll reduction is $0.04 for short trips and $0.08 for long trips. Reduction in in-vehicle time (IVTT) for bus is 6.91 to 7.5 percent for short trips and 18.4 percent for long trips relative to the base case. Input data are given in Table F-4. The nonshortfall and market (high) price comparisons are the same as for the 1985 sticker plan scenario. Therefore, the relevant drive alone and carpool cost variables are in Table F-3.

1990 Rationing/TSM

The white market rationing scheme is assumed to lead to a total gasoline price (pump price plus coupon price) of $3.02 per gallon under a 25 percent shortfall (see App. A). This price, estimated fuel economies, and nongasoline operating costs are used to derive per mile costs using Eq. F-1. Because no long-term conservation adjustments are assumed, the lower 1990 fuel economy of 17.7 mpg is used.

The TSM actions to encourage high-occupancy vehicles and discourage low-occupancy vehicles result in an average cost increase of $0.03 for the drive alone mode and $0.02 for the carpool mode. (Since the carpool toll policy of the previous scenario is still in effect, there is still a net cost incentive favoring carpools). As described in Chapter Two, the parking policy also increases drive alone and carpool

TABLE F-2

INPUT DATA—1985 STICKER PLAN SCENARIO

Level of Service	Traveler Class 1	2	3	4	5	6
Automobile						
COST (dollars)	1.20	5.43	1.29	5.76	--*	--
IVTT (minutes)	16.50	60.00	18.00	62.00	--	--
WT (minutes)	5.50	10.00	6.00	10.00	--	--
Fuel Economy (mpg)** = 16.9						
Occupancy (persons per vehicle) = 1.0						
Carpool						
COST (dollars)	0.68	3.05	0.73	3.13	0.73	3.13
IVTT (minutes)	29.50	74.00	31.00	75.00	31.00	75.00
WT (minutes)	6.50	10.00	7.00	10.00	7.00	10.00
Fuel Economy (mpg)** = 16.9						
Occupancy (persons per vehicle) = 2.5						
Transit						
COST (dollars)	0.33	1.80	--	--	0.36	1.92
IVTT (minutes)	27.50	126.00	--	--	28.00	128.00
WT (minutes)	10.00	20.00	--	--	11.00	18.00
Fuel Economy (mpg)** = 4.1						
Occupancy (persons per vehicle) = 75.0						
Trips (thousands)	41.50	19.95	33.57	28.08	24.35	12.52

*Mode not defined for this class.

**1 mpg = 0.425 kilometers per liter.

TABLE F-3

1985 AUTO DRIVE ALONE AND CARPOOL COSTS UNDER NONSHORTFALL (LOW) AND SHORTFALL (HIGH) GASOLINE PRICES *

COST (Dollars)	Traveler Class 1	2	3	4	5	6
Automobile						
Costs under Low Gasoline Price	1.03	4.49	1.10	4.77	--**	--
Costs under High Gasoline Price	1.32	6.09	1.42	6.47	--	--
Carpool						
Costs under Low Gasoline Price	0.58	2.52	0.62	2.59	0.62	2.59
Costs under High Gasoline Price	0.75	3.43	0.80	3.52	0.80	3.52
Trips (thousands)	48.42	23.27	39.16	32.76	12.02	4.52

*Values for IVTT and WT for automobile and carpool and for COST, IVTT, and WT for transit appear in Table F-1.

**Mode not defined for this class.

walk times by 6.05 percent relative to the values used in the previous scenario. Input data for this scenario are given in Table F-5. The drive alone and carpool costs resulting from the 1990 nonshortfall (low) gasoline price and the shortfall (high) gasoline price alone are given in Table F-6.

TABLE F-4

INPUT DATA—1985 MARKET PRICE/ TSM SCENARIO

Level of Service	Traveler Class 1	2	3	4	5	6
Automobile						
COST (dollars)	1.32	6.09	1.42	6.47	--*	--
IVTT (minutes)	16.50	60.00	18.00	62.00	--	--
WT (minutes)	5.50	10.00	6.00	10.00	--	--
Fuel Economy (mpg)** = 16.9						
Occupancy (persons per vehicle) = 1.0						
Carpool						
COST (dollars)	0.72	3.35	0.76	3.44	0.76	3.44
IVTT (minutes)	29.50	74.00	31.00	75.00	31.00	75.00
WT (minutes)	6.50	10.00	7.00	10.00	7.00	10.00
Fuel Economy (mpg)** = 16.9						
Occupancy (persons per vehicle) = 2.5						
Transit						
COST (dollars)	0.33	1.80	--	--	0.36	1.92
IVTT (minutes)	25.60	102.80	--	--	25.90	104.40
WT (minutes)	10.00	20.00	--	--	11.00	18.00
Fuel Economy (mpg)** = 4.1						
Occupancy (persons per vehicle) = 75.0						
Trips (thousands)	48.42	23.27	39.16	32.76	12.02	4.52

*Mode not defined for this class.

**1 mpg = 0.425 kilometers per liter.

1990 Rationing/TSM with Long-Term Conservation Adjustments

The main differences between this scenario and the previous one are that (1) a higher average fuel economy of 20.2 is used; and (2) the number of short trips in each short trip class has increased by 10 percent, with offsetting reductions in the long trip classes. Both differences reflect long-term energy conservation adjustments. Table F-7 gives the input data for this scenario. Table F-8 gives the drive alone and carpool costs for the nonshortfall (low) gasoline price and the shortfall (high) gasoline price alone. These costs also reflect the long-term adjustments in vehicle fuel economy and household residential and employment location decisions.

Scenario Test Calculations

This section provides a step-by-step description of the calculations carried out for each scenario test. The results of these calculations are then presented in the next section.

Given the range of values obtained for logit modal choice model coefficients, sensitivity analysis provides an opportunity to evaluate the uncertainty associated with the use of any one set of coefficients. In this analysis, scenario tests were carried out with the three alternative sets of coefficients for the three level-of-service variables. These coefficients are given in Table 5.

As noted previously, each model is used in an incremental fashion such that the revised modal share estimates for

TABLE F-5

INPUT DATA—1990 RATIONING/TSM SCENARIO

Level of Service	Traveler Class 1	2	3	4	5	6
Automobile						
COST (dollars)	1.68	7.89	1.80	8.39	--*	--
IVTT (minutes)	16.50	60.00	18.00	62.00	--	--
WT (minutes)	5.80	10.60	6.40	10.60	--	--
Fuel Economy (mpg)** = 17.7						
Occupancy (persons per vehicle) = 1.0						
Carpool						
COST (dollars)	0.93	4.37	0.99	4.49	0.99	4.49
IVTT (minutes)	29.50	74.00	31.00	75.00	31.00	75.00
WT (minutes)	6.90	10.60	7.40	10.60	7.40	10.60
Fuel Economy (mpg)** = 17.7						
Occupancy (persons per vehicle) = 2.5						
Transit						
COST (dollars)	0.33	1.80	--	--	0.36	1.92
IVTT (minutes)	25.60	102.80	--	--	25.90	104.40
WT (minutes)	10.00	20.00	--	--	11.00	18.00
Fuel Economy (mpg)** = 4.1						
Occupancy (persons per vehicle) = 75.0						
Trips (thousands)	51.57	24.79	41.70	34.89	12.80	4.82

*Mode not defined for this class.

**1 mpg = 0.425 kilometers per liter.

each segment is a function of the base modal shares and the change in the base levels of service. Using the 1985 sticker plan scenario and model 1 (first set) coefficients as an example, refer to the base input data (Table F-1) and the 1985 sticker plan scenario input data (Table F-2) for the first traveler class. By using Eqs. 2 and 3, the 1985 sticker plan scenario modal shares for the first class are calculated as follows:

$$MS^N_{11}\text{ (automobile)} = \frac{(0.7)\exp(-1.04*0.26)}{(0.15)\exp(-1.04*0.15)+(0.15)\exp(0)+(0.7)\exp(-1.04*0.26)} = 0.657 \qquad \text{(F-2)}$$

$$MS^N_{21}\text{ (carpool)} = \frac{(0.15)\exp(-1.04*0.15)}{(0.15)\exp(-1.04*0.15)+(0.15)\exp(0)+(0.7)\exp(-1.04*0.26)} = 0.158 \qquad \text{(F-3)}$$

$$MS^N_{31}\text{ (transit)} = \frac{(0.15\exp(0)}{(0.15)\exp(-1.04*0.15)+(0.15)\exp(0)+(0.7)\exp(-1.04*0.26)} = 0.185 \qquad \text{(F-4)}$$

TABLE F-6

1990 AUTO DRIVE ALONE AND CARPOOL COSTS UNDER NONSHORTFALL (LOW) AND SHORTFALL (HIGH) GASOLINE PRICES *

COST (Dollars)	Traveler Class 1	2	3	4	5	6
Automobile						
Costs under Low Gasoline Price	1.13	5.02	1.20	5.32	--**	--
Costs under High Gasoline Price	1.65	7.86	1.77	8.36	--	--
Carpool						
Costs under Low Gasoline Price	0.64	2.82	0.68	2.89	0.68	2.89
Costs under High Gasoline Price	0.95	4.43	1.01	4.55	1.01	4.55
Trips (thousands)	51.57	24.79	41.70	34.89	12.80	4.82

*Values for IVTT and WT for automobile and carpool and for COST, IVTT, and WT for transit appear in Table F-1.

**Mode not defined for this class.

TABLE F-7

INPUT DATA—1990 RATIONING/TSM WITH LONG-RUN CONSERVATION ADJUSTMENTS SCENARIO

Level of Service	Traveler Class 1	2	3	4	5	6
Automobile						
COST (dollars)	1.56	7.26	1.68	7.72	--*	--
IVTT (minutes)	16.50	60.00	18.00	62.00	--	--
WT (minutes)	5.80	10.60	6.40	10.60	--	--
Fuel Economy (mpg)** = 20.2						
Occupancy (persons per vehicle) = 1.0						
Carpool						
COST (dollars)	0.86	4.01	0.92	4.12	0.92	4.12
IVTT (minutes)	29.50	74.00	31.00	75.00	31.00	75.00
WT (minutes)	6.90	10.60	7.40	10.60	7.40	10.60
Fuel Economy (mpg)** = 20.2						
Occupancy (persons per vehicle) = 2.5						
Transit						
COST (dollars)	0.33	1.80	--	--	0.36	1.92
IVTT (minutes)	25.60	102.80	--	--	25.90	104.40
WT (minutes)	10.00	20.00	--	--	11.00	18.00
Fuel Economy (mpg)** = 4.1						
Occupancy (persons per vehicle) = 75.0						
Trips (thousands)	56.73	19.63	45.87	30.72	14.08	3.54

*Mode not defined for this class.

**1 mpg = 0.425 kilometers per liter.

TABLE F-8

1990 AUTO DRIVE ALONE AND CARPOOL COSTS UNDER NONSHORTFALL (LOW) AND SHORTFALL (HIGH) GASOLINE PRICES AND WITH LONG-RUN CONSERVATION ADJUSTMENTS *

COST (Dollars)	Traveler Class 1	2	3	4	5	6
Automobile						
Costs under Low Gasoline Prices	1.07	4.74	1.15	5.03	--**	--
Costs under High Gasoline Prices	1.53	7.23	1.65	7.68	--	--
Carpool						
Costs under Low Gasoline Prices	0.61	2.68	0.65	2.73	0.65	2.73
Costs under High Gasoline Prices	0.88	4.07	0.94	4.18	0.94	4.18
Trips (thousands)	56.73	19.63	45.87	30.72	14.08	3.54

*Values for IVTT and WT for automobile and carpool and for COST, IVTT, and WT for transit appear in Table F-1.

**Mode not defined for this class.

where MS^N_{i1} are the new modal shares for the first class under the 1985 sticker plan scenario. The base modal shares are 0.7, 0.15, and 0.15 for automobile, carpool, and transit, respectively. The change in level of service for the automobile mode was a $0.26 increase in trip cost. The change in the carpool utility function was a $0.15 increase in trip cost. There was no change in the transit utility function.

New modal shares are estimated for each class. The areawide modal shares are calculated by taking the weighted average of the class modal shares as follows:

$$MS_{\text{agg}}(i) = \sum_{s=1}^{6} W_s M^N_{is} \qquad \text{(F-5)}$$

where $MS_{\text{agg}}(i)$ is the aggregate modal share for alternative i; W_s is the class weight equal to the proportion of trips in that class; and MS^N_{is} is the modal share for alternative i in class s. The resulting areawide modal shares are 0.484, 0.236, and 0.279 for drive alone, shared ride, and transit, respectively.

Given the modal shares in each class and average trip length and occupancy for each mode in that class, total VMT (by automobiles and carpools) can be calculated with Eq. 4. The resulting VMT is 1.382 thousand. Similarly bus miles traveled is calculated with Eq. 6. The result is 9.19 thousand BMT.

The final calculations are for areawide fuel consumption. For private vehicles Eq. 5 produces a value of 81.8 thousand gallons. (Private vehicle fuel economy is 16.9 mpg for 1985.) Equation 7 produces a value of 2.24 thousand gallons. (Transit fuel economy is 4.1 mpg for all scenarios.)

Sensitivity Analysis

The scenario test calculations previously described (using alternative sets of coefficients) provide a range of estimates for the following variables under each scenario: modal shares, VMT, BMT, fuel consumption by private vehicles, and transit fuel consumption. The sensitivity analysis results for each scenario are given in Tables F-9 through F-12. In addition, the nonshortfall and high price comparisons are identical for the 1985 scenarios because they differ only in the contingency actions implemented.

The use of three alternative sets of coefficients was designed to evaluate the uncertainty underlying any single set of estimates. The reasonableness of each of the coefficients can be checked, however, by comparing the estimated energy savings with the assumed energy shortfall for each scenario. To carry out this test, fuel consumption by private vehicles is compared under the nonshortage and the high gasoline price alone conditions. The estimated fuel savings obtained from each set of coefficients are given in Table F-13.

Relative fuel savings associated with the journey to work are expected to be smaller than the areawide energy shortfall because proportionally more savings are expected from nonwork travel. Given this hypothesis, the model 1 coefficients appear to overestimate the reduction in fuel consumption, supporting earlier observation that these coefficients appear to be high. The model 2 coefficients result in lower energy savings for work trips relative to the total energy shortfall, as is expected. The model 3 coefficients appear to significantly underestimate the energy savings. Moreover, estimates using this set of coefficients are fairly insensitive to the assumed level of shortfall resulting in a greater degree of error for the high shortfall levels than for the low shortfall levels. Therefore, this test suggests that model 2 coefficients provide the best energy savings estimates. These are used in the analyses of Chapter Two.

NONWORK TRIP ANALYSIS

The input variables for the base case and the shortfall scenarios are described in this section. Following this, sample calculations are also presented.

Input Variables

As in the case of the work trip analyses, input variables are defined for the base case and each of the four scenarios. In addition, analyses are produced of the travel impacts resulting under low (nonshortfall) price levels and high (shortfall) price levels, without changes in other level-of-service variables.

Base Case

The base case consists of recently available information on the values of the dependent and independent variables. These values are needed to apply the incremental approach, but are not necessarily of direct interest in the analysis.

The values of the input variables for the base case are assumed to be from 1980 data for the same hypothetical urban area used for the work trip analyses. The size of the area is defined in terms of the number of households and the average household size. The former variable is the ratio of the number of U.S. households to the number of govern-

TABLE F-9

SENSITIVITY ANALYSIS—1985 STICKER PLAN SCENARIO

	Model 1*			Model 2**			Model 3***		
Modal Share	Non-Short-fall	High (Short-fall) Price Only	Sticker Plan	Non-Short-fall	High (Short-fall) Price Only	Sticker Plan	Non-Short-fall	High (Short-fall) Price Only	Sticker Plan
Automobile	0.62	0.52	0.49	0.64	0.59	0.52	0.65	0.63	0.55
Carpool	0.22	0.27	0.24	0.21	0.24	0.22	0.20	0.19	0.19
Transit	0.15	0.21	0.28	0.15	0.17	0.25	0.15	0.18	0.26
Trips (thousands)+	160.15	160.15	159.97	160.15	160.15	159.97	160.15	160.15	159.97
VMT (thousands)++	1,776.30	1,439.50	1,382.40	1,820.30	1,669.20	1,516.17	1,846.10	1,799.00	1,586.20
BMT (thousands)+++	4.31	7.23	9.19	3.98	5.16	7.91	3.96	4.76	7.79
Fuel (thousands of gallons)#	105.10	85.20	81.80	107.70	98.80	88.70	109.20	106.40	93.90
Transit Fuel (thousands of gallons)##	1.05	1.76	2.24	0.97	1.26	1.93	0.97	1.16	1.90

*Coefficients are COST = -1.04; IVTT = -0.0411; WT = 0.114.

**Coefficients are COST = -0.52; IVTT = -0.0205; WT = -0.066.

***Coefficients are lnCOST = -1.34; lnIVTT = -2.03; WT = -0.11.

+Difference in number of trips is due to rounding.

++VMT includes vehicle miles traveled by automobiles and carpools. 1 VMT = 1.61 vehicle kilometers traveled.

+++BMT includes vehicle miles traveled by transit.

#Fuel includes consumption by automobiles anc carpools, assuming all vehicles use gasoline. 1 gallon = 3.79 liters.

##Transit fuel includes consumption by transit, assuming all vehicles use gasoline.

mental and nonagricultural workers (*F-3*) times the number of work trips in the base case (i.e., the ratio of households to workers is assumed to be equal to the national ratio). The average household size is from CRA's (*F-4*) national forecast for 1980.

The product of the number of households and the average household size is the population, which defines the three urban structure variables (URBAN, SM.SZE, and PLCSZE). The 1980 population of about 327,000 corresponds to a place size in category 13 in Table 7. It is further assumed that the urban area category is 3 (250,000–999,999) and the SMSA category is 4 (500,000–999,999). Further, it is assumed that the area remains in these categories throughout the forecast period.

The remaining three household characteristics are assumed to be similar to national averages. The average number of household members 5 years of age and older was derived from 1980 estimates of population by age groups and the number of households (*F-4*). The average number of licensed drivers per household is based on the number of persons 15 years of age and older and an assumed ratio of licensed drivers to potential drivers. A value of 0.85, which is similar to the 1978 ratio (*F-5*), was used. Household income (in 1979 dollars) is based on 1976 national average household income and the real growth rate between 1967 and 1976 (about 1 percent per year (*F-6*)).

Base levels of the dependent variables and the level-of-service variables were chosen to fall within a reasonable range for such variables. The average values used in the sample to estimate the nonwork trip model (*F-1*) were used as reference points. As described earlier, travel time times wage (D.V.HH.TM/MI) and average per mile gasoline cost divided by wage (D.CO/MI.V.HH) are constructed from the averages of component variables. The former equals average travel time per mile (D.TM/MI) times household income in cents per minute. The latter is gasoline price divided by average fuel economy divided by household income (in cents per minute).

Gasoline prices and private vehicle and bus fuel economies are the same as in the work trip analyses. The factor that converts bus trips to bus miles is assumed to be 0.25 for all analyses.

Scenarios

The level-of-service variables are the key distinguishing characteristics among the scenarios. For a particular forecast year (1985) or 1990) the other variables do not vary across scenarios and are developed in a manner similar to that for the base case.

The number of households is assumed to grow at the national rate forecast by CRA (*F-4*) (about 11 percent

TABLE F-10

SENSITIVITY ANALYSIS—1985 MARKET PRICE/TSM SCENARIO

	Model 1*			Model 2**			Model 3***		
Modal Share	Non-Short-fall	High (Short-fall) Price Only	High Price and TSM	Non-Short-Fall	High (Short-fall) Price Only	High Price and TSM	Non-Short-fall	High (Short-fall) Price Only	High Price and TSM
Automobile	0.62	0.52	0.49	0.64	0.59	0.58	0.65	0.63	0.61
Carpool	0.22	0.27	0.26	0.21	0.24	0.24	0.20	0.19	0.19
Transit	0.15	0.21	0.25	0.15	0.17	0.19	0.15	0.18	0.20
Trips (thousands)	160.15	160.15	160.15	160.15	160.15	160.15	160.15	160.15	160.15
VMT (thousands)+	1,776.30	1,439.50	1,296.70	1,820.30	1,669.30	1,603.20	1,846.10	1,799.00	1,743.20
BMT (thousands)++	4.31	7.23	9.46	3.98	5.16	6.12	3.96	4.76	5.53
Fuel (thousands of gallons)+++	105.10	85.20	76.70	107.70	98.80	94.90	109.90	106.40	103.20
Transit Fuel (thousands of gallons)#	1.05	1.76	2.31	0.97	1.26	1.49	0.97	1.16	1.35

*Coefficients are COST = -1.04; IVTT = -0.0411; WT = -0.114.

**Coefficients are COST = -0.52; IVTT = -0.0205; WT = -0.055.

***Coefficients are lnCOST = -1.34; lnIVTT = -2.03; WT = -0.11.

+VMT includes vehicle miles traveled by automobiles and carpools. 1 VMT = 1.61 vehicle kilometers traveled.

++BMT includes vehicle miles traveled by transit.

+++Fuel includes consumption by automobiles and carpools, assuming all vehicles use gasoline. 1 gallon = 3.79 liters.

#Transit fuel includes consumption by transit, assuming all vehicles use gasoline.

between 1980 and 1985 and about 9.4 percent between 1985 and 1990). Similarly, the household structure variables (household size, number of household members 5 years and older, and licensed drivers) are assumed to reflect the changes evident in the national forecasts. Household income is assumed to grow about 1 percent per year, which is the historic rate of real growth between 1967 and 1976.

The level-of-service variables for the first scenario (1985, 15 percent shortfall with sticker plan) are generally the same as the base case values, with the exception of the two variables defined in terms of income, gasoline, price, and fuel economy—(D.V.HH.TM/MI) and (D.CO/MI.V.HH). The effect of banning household automobiles 1 day per week is represented by reducing the average number of licensed drivers per household by ¼. This reduction is based on the assumption that, because of opportunities to reschedule travel, only one-half of the maximum potential loss in vehicle availability is actually lost.

The 1985 market price/TSM scenario is defined in terms of the higher gasoline pump price resulting from the 15 percent shortfall and the policy actions encouraging increased transit ridership. In particular, it is assumed that preferential treatment for transit reduces average trip time by 5 to 25 min and that transit is now available for 45 percent rather than 40 percent of all nonwork trips.

The 1990 scenarios (rationing/TSM and rationing/TSM with long-run conservation adjustments) differ from each other in the private vehicle average fuel economies. This difference is reflected in different average per mile gasoline costs. The main feature of these scenarios is that they include private vehicle disincentives as well as the transit incentives of scenario B. Free parking is reduced so that it applies to 75 percent rather than 85 percent of trips. This reduction in parking availability is also assumed to increase average per mile trip time to 3.5 min per mile.

To assess the impacts of these scenarios, the appropriate bases for comparison are the corresponding conditions with the low (nonshortage) price levels and no additional level-of-service changes from the base case. Similarly, the effects of high (shortfall) prices alone are examined with the high price comparisons. They differ from the corresponding nonshortfall conditions only in the gasoline price per mile variable.

Table F-14(a) gives the input variable for the base case and the 1985 scenarios, and Table F-14(b) represents the corresponding information for the 1990 scenarios.

Sample Calculations

The values of the independent variables in Tables F-14(a) and F-14(b) are used in Eqs. 9a and 9b to produce house-

TABLE F-11

SENSITIVITY ANALYSIS—1990 RATIONING/TSM SCENARIO

	Model 1*			Model 2**			Model 3***		
Modal Share	Non-Short-fall	High (Short-fall) Price Only	High Price and TSM	Non-Short-fall	High (Short-fall) Price Only	High Price and TSM	Non-Short-fall	High (Short-fall) Price Only	High Price and TSM
Automobile	0.59	0.42	0.40	0.62	0.53	0.51	0.64	0.61	0.58
Carpool	0.24	0.30	0.29	0.22	0.26	0.26	0.20	0.18	0.18
Transit	0.17	0.28	0.31	0.16	0.21	0.23	0.16	0.21	0.23
Trips (thousands)	170.57	170.57	170.57	170.57	170.57	170.57	170.57	170.57	170.57
VMT (thousands)+	1,783.70	1,175.30	1,085.00	1,889.70	1,572.00	1,484.10	1,949.50	1,864.40	1,784.80
BMT (thousands)++	5.45	11.32	12.85	4.60	7.33	8.68	4.51	5.92	7.08
Fuel (thousands of gallons)+++	100.80	66.40	61.30	106.80	88.80	83.90	110.10	105.30	100.80
Transit Fuel (thousands of gallons)#	1.33	2.76	3.13	1.12	1.79	2.12	1.10	1.44	1.73

*Coefficients are COST = -1.04; IVTT = -0.0411; WT = -0.114

**Coefficients are COST = -0.52; IVTT = -0.0205; WT = -0.055.

***Coefficients are lnCOST = -1.34; lnIVTT = -2.03; WT = -0.11.

+VMT includes vehicle miles traveled by automobiles and carpools.
1 VMT = 1.61 vehicle kilometers traveled.

++BMT includes vehicle miles traveled by transit.

+++Fuel includes consumption by automobiles and carpools, assuming all vehicles use gasoline.
1 gallon = 3.79 liters.

#Transit fuel includes consumption by transit, assuming all vehicles use gasoline.

hold average 4-day forecasts. These forecasts and the number of households, fuel economies, and transit ridership/bus mile factor are then used to generate areawide mileage and fuel consumption forecasts.

The procedure can be illustrated by deriving the travel forecasts for the low (nonshortfall) price 1985 case. Six of the 13 independent variables do not change and therefore do not affect the incremental forecasting procedure.

The changes in 4-day average travel are:

$$\Delta\text{VMT} = -0.2422\ (\Delta\text{D.V.HH. TM/MI}) - 51.01\ (\Delta\text{D.Co/MI.V.HH}) - 14.128\ (\Delta\#\text{PPL.} > 4) + 15.14\ (\Delta\#\text{LIC.D}) + 0.0007728\ (\Delta\text{H.H.\$}) + 9.022\ (\Delta\text{H.H.SZE})$$

$$\Delta\text{Transit Trips}\ (\#\text{T.TRP}) = -0.00003188\ (\Delta\text{H.H.\$}) - 0.3722\ (\Delta\text{H.H.SZE}) + 0.7877\ (\Delta\#\text{PPL} > 4) \quad \text{(F-6)}$$

Substitution of the values of the variables from Table F-14(a) yields:

$$\Delta\text{VMT} = -0.2422(54.73 - 52.05) - 51.01\ (0.4229 - 0.4111) - 14.128(2.42 - 2.59) + 15.14(1.74 - 1.84) + 0.0007728\ (20{,}314 - 19{,}319) + 9.022(2.63 - 2.79) = -1.04$$

$$\Delta\#\text{T.TRP} = -0.00003188(20{,}314 - 19{,}319) - 0.3722(2.63 - 2.79) + 0.7877\ (2.42 - 2.54) = -0.106 \quad \text{(F-7)}$$

These changes are added to the base values of 80 and 0.6 to produce forecasts of 78.96 and 0.494 for average 4-day VMT and transit trips, respectively.

Areawide daily VMT is obtained by multiplying the household forecast by (the number of households divided by 4). Fuel consumption is obtained by dividing areawide VMT by average private vehicle fuel economy. For the example,

$$\text{Areawide VMT} = 78.96\,\frac{130.1}{4}\ \text{thousand} = 2568\ \text{thousand miles/day} \quad \text{(F-8)}$$

$$\text{Fuel consumption} = 2568/16.9\ \text{thousand} = 152\ \text{thousand gallons/day} \quad \text{(F-9)}$$

Areawide transit ridership is estimated in a similar way. The passenger/bus mile factor is used to derive areawide bus miles which, in turn, are translated into bus fuel consumption.

$$\text{Areawide ridership} = 0.494\left(\frac{130.1}{4}\right) = 16.05\ \text{Thousand trips/day} \quad \text{(F-10)}$$

TABLE F-12

SENSITIVITY ANALYSIS—1990 RATIONING/TSM WITH LONG-RUN CONSERVATION ADJUSTMENTS SCENARIO

	Model 1*			Model 2**			Model 3***		
Modal Share	Non-Short-fall	High (Short-fall) Price Only	High Price and TSM	Non-Short-fall	High (Short-fall) Price Only	High Price and TSM	Non-Short-fall	High (Short-fall) Price Only	High Price and TSM
Automobile	0.62	0.48	0.45	0.64	0.57	0.55	0.65	0.62	0.60
Carpool	0.22	0.28	0.27	0.21	0.25	0.24	0.20	0.18	0.18
Transit	0.16	0.24	0.28	0.15	0.19	0.21	0.16	0.26	0.22
Trips (thousands)	170.57	170.57	170.57	170.57	170.57	170.57	170.57	170.57	170.57
VMT (thousands)+	1,673.00	1,205.30	1,106.10	1,734.20	1,508.90	1,438.20	1,768.60	1,702.00	1,637.10
BMT (thousands)++	4.29	8.51	101.15	3.83	5.63	66.78	3.82	4.93	58.59
Fuel (thousands of gallons)+++	82.80	59.70	54.80	85.90	74.70	71.20	87.60	84.30	81.10
Transit Fuel (thousands of gallons)#	1.05	2.08	2.47	0.93	1.37	1.63	0.93	1.20	1.43

*Coefficients are COST = -1.04; IVTT = -0.0411; WT = -0.114.

**Coefficients are COST = -0.52; IVTT = -0.0205; WT = -0.055.

***Coefficients are lnCOST = -1.34; lnIVTT = -2.03; WT = -0.11.

+VMT includes vehicle miles traveled by automobiles and carpools. 1 VMT = 1.61 vehicle kilometers traveled.

++BMT includes vehicle miles traveled by transit.

+++Fuel includes consumption by automobiles and carpools, assuming all vehicles use gasoline. 1 gallon = 3.79 liters.

#Transit fuel includes consumption by transit, assuming all vehicles use gasoline.

TABLE F-13

FUEL SAVINGS *

Scenario	Assumed Shortfall	Model 1	Model 2	Model 3
1985	0.150	0.189	0.083	0.026
1990	0.250	0.341	0.169	0.044
1990 with Long-Run Conservation Adjustments	0.250	0.279	0.130	0.038

*Savings equal to one minus the ratio of fuel consumption by private vehicles under high gasoline price only conditions to fuel consumption by private vehicles under nonshortage conditions.

$$\text{Bus miles} = 16.06 \text{ Thousand trips/day} \times 0.25 \frac{\text{Miles}}{\text{Trip}} = 4.02 \text{ Thousand bus miles/day} \quad \text{(F-11)}$$

$$\text{Bus Fuel consumption} = 4.02 \text{ Thousand bus miles}/4.1 = 0.98 \text{ Thousand gallons/day} \quad \text{(F-12)}$$

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TABLE F-14(a)

INPUT VARIABLES FOR 1985 SCENARIOS

Dependent Variables*	Base (1980)	1985 Nonshortfall	1985 High (Shortfall) Price Only	1985 Sticker Plan	1985 Market Price/TSM
VMT	80.00				
NUMBER T.TRP	0.60				
Independent Variables					
D.TM/MI	3.23	3.23	3.23	3.23	3.23
D.V.HH.TM/MI	52.05	54.73	54.73	54.73	54.73
D.CO/MI.V.HH	0.4111	0.4229	0.7375	0.6065	0.7375
#PPL>4	2.59	2.42	2.42	2.42	2.42
URBAN	3.00	3.00	3.00	3.00	3.00
SM.SZE	4.00	4.00	4.00	4.00	4.00
PLCSZE	13.00	13.00	13.00	13.00	13.00
#LIC.D	1.84	1.74	1.74	1.62	1.74
D.PKAV	0.85	0.85	0.85	0.85	0.85
T.TIME	30.00	30.00	30.00	30.00	25.00
TAVL.D.T.T.TRIP	0.40	0.40	0.40	0.40	0.45
H.H.$	19,319.00	20,314.00	20,314.00	20,314.00	20,314.00
H.H.SZE	2.79	2.63	2.63	2.63	2.63
Number of Households (Thousands)	117.15	130.10	130.10	130.10	130.10
Gas Price (Cents)	99.27	121.00	211.00	173.50	211.00
Fuel Economy (MPG)					
Auto	15.00	16.90	16.90	16.90	16.90
Transit	4.10	4.10	4.10	4.10	4.10
Transit Mile to Trip Factor	0.25	0.25	0.25	0.25	0.25

*Dependent and independent variables are defined in Table 7

TABLE F-14(b)

INPUT VARIABLES FOR 1990 SCENARIOS

Dependent Variables	Base 1980	No Long-Run Conservation Adjustments			Long-Run Conservation Adjustments Assumed		
		1990 Non-Shortfall	1990 High (Shortfall) Price Only	1990 Rationing/TSM	1990 Non-Shortfall	1990 High (Shortfall) Price Only	1990 Rationing/TSM
VMT	80.00						
NUMBER T.TRP	0.60						
Independent Variables							
D.TM/MI	3.23	3.23	3.23	3.50	3.23	3.23	3.50
D.V.HH.TM/MI	52.05	57.55	57.55	62.30	57.55	57.55	62.30
D.CO/MI.V.HH	0.41	0.43	0.96	0.96	0.37	0.84	0.84
#PPL>4	2.59	2.32	2.32	2.32	2.32	2.32	2.32
URBAN	3.00	3.00	3.00	3.00	3.00	3.00	3.00
SM.SZE	4.00	4.00	4.00	4 00	4.00	4.00	4.00
PLCSZE	13.00	13.00	13.00	13.00	13.00	13.00	13.00
#LIC.D	1.84	1.66	1.66	1.66	1.66	1.66	1.66
D.PKAV	0.85	0.85	0.85	0.75	0.85	0.85	0.75
T.TIME	30.00	30.00	30.00	25.00	30.00	30.00	25.00
TAVL.D.T.T.TRIP	0.40	0.40	0.40	0.45	0.40	0.40	0.45
H.H.$	19,319.00	21,360.00	21,360.00	21,360.00	21,360.00	21,360.00	21,360.00
H.H.SZE	2.79	2.52	2.52	2.52	2.52	2.52	2.52

TABLE F-14(b) (Continued)

	Base 1980	No Long-Run Conservation Adjustments			Long-Run Conservation Adjustments Assumed		
		1990 Non-Shortfall	1990 High (Shortfall) Price Only	1990 Rationing/TSM	1990 Non-Shortfall	1990 High (Shortfall) Price Only	1990 Rationing/TSM
Other Input Variables							
Number of Households (Thousands)	117.15	142.30	142.30	142.30	142.30	142.30	142.30
Gas Price (Cents)	99.27	134.00	302.00	302.00	134.00	302.00	302.00
Fuel Economy (MPG)							
Auto	15.00	17.70	17.70	17.70	20.20	20.20	20.20
Transit	4.10	4.10	4.10	4.10	4.10	4.10	4.10
Transit Mile to Trip Factor	0.25	0.25	0.25	0.25	0.25	0.25	0.25

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