Simulating the Impact of Transportation-Related Energy Policies on Travel Behavior and Transportation Demand

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Examination of the interface between transportation and energy consumption has been going on for several years, but most efforts have concentrated on estimated changes in energy consumption under varying transportation scenarios. At the same time, many energy conservation policies have been proposed that are aimed at reducing energy consumption by changing transportation patterns. The impacts of these policies on transportation demand, however, have not been systematically examined. A methodology for estimating incremental changes in travel demand resulting from the imposition of various policy options is presented. The methodology is tested through a case study of several communities in a transportation corridor in northern New Jersey and is found to produce reasonable results.

In 1973 and 1974, the United States experienced its first severe energy shortage other than those caused by war mobilization efforts. The impacts of the 1973-1974 energy shortage were expressed in terms of queues at gasoline stations, curtailments and cutbacks in heating-fuel supplies, and dramatic increases in the price of energy in virtually all forms. Although there has been some relaxing of the situation, the supply of energy continues to be constrained and the price continues to climb. Short-run shortages of various kinds of fuel have occurred periodically, the most severe of which was the gasoline shortage in the summer of 1979.

Many potential policy actions have been proposed for reducing the use of energy for transportation purposes, and most have included estimates of the amount of energy or fuel to be saved. Most of these proposed energy policies have not, however, been evaluated in terms of their impact on the existing transportation system and on the ability of that system to respond to the policy impacts.

The research reported here, which was funded by the Urban Mass Transportation Administration through the Tri-State Regional Planning Commission, is an attempt to remedy this oversight. It is often simply assumed that energy conservation policies will reduce the demand for transportation and there should thus be no problem for the transportation system. This is clearly not true. Federal programs that encourage the use of more fuel-efficient automobiles may actually increase automobile travel while at the same time reduce the amount of gasoline used for that travel. Policies that encourage the shift from automobiles to other modes of travel result in increased demand for those other modes. In these and other cases, it is desirable to anticipate the increases in demand so that appropriate capital investments can be made and the system is able to accommodate the changes.

RESEARCH OBJECTIVES

The purpose of this study was to develop a methodology by which the impacts of energy conservation policies on transportation demand can be projected into the future in order to facilitate transportation planning decisions. In addition, there was a parallel objective of demonstrating the approach's applicability. To achieve this second objective, the approach was applied to a case study of a northern New Jersey transportation corridor. The purposes of the case study were several:

1. It was important to demonstrate the data needs of the methodology.
2. It showed exactly how the components or submodels of the approach interface.
3. It allowed the careful formulation of several possible policy scenarios and the translation of these into appropriate inputs for simulation by the models.
4. It permitted, in prototype fashion, a look at the impacts of these policies on travel demand in that corridor.

RESEARCH APPROACH

It was recognized at the outset that most transportation planning agencies currently have the capability of producing travel demand estimates in the absence of energy policies. Rather than duplicate those capabilities, it was decided to concentrate on estimating the marginal or incremental changes in current estimates that would result from imposition of the policies. It was also desired that the incremental changes be estimated on the basis of data that are reasonably available.

The approach developed for the research included the following five steps:

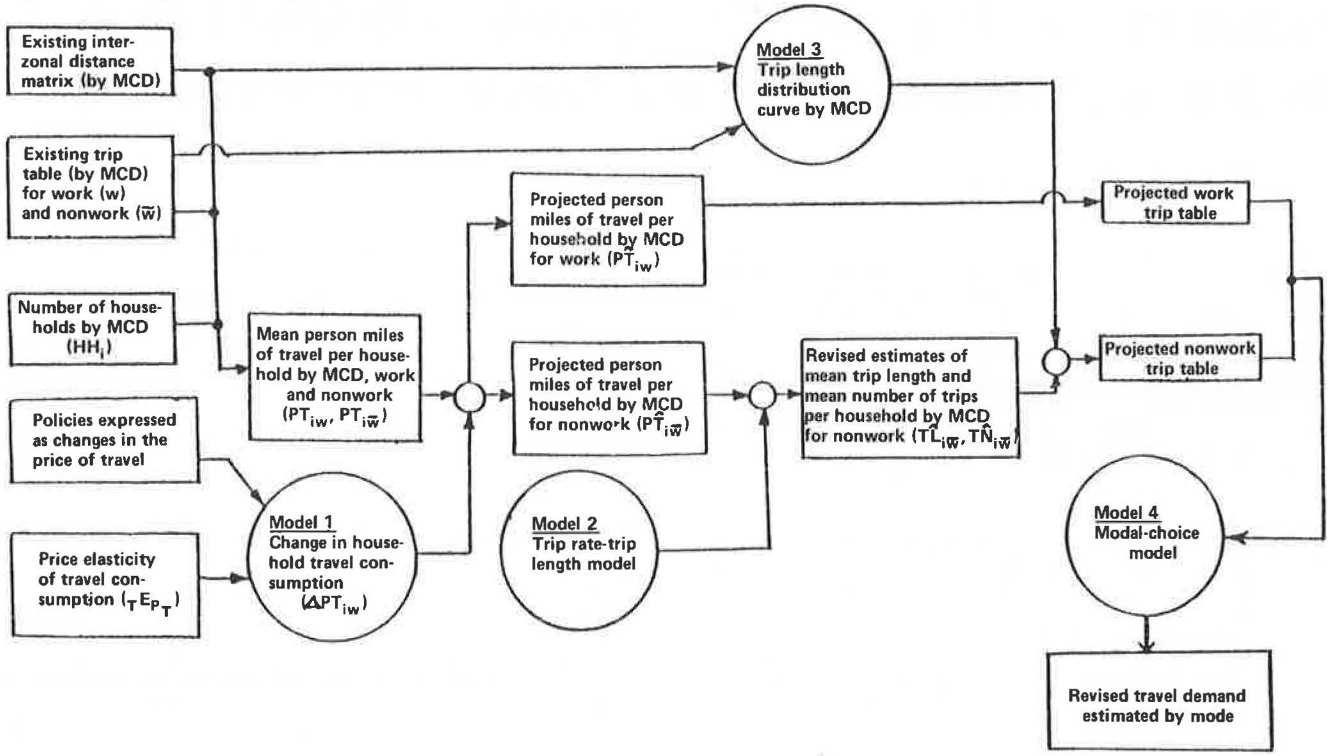
1. Potential energy policies were reviewed, and the likely consumer responses to them were outlined.
2. The likely responses were analyzed in terms of where in the transportation demand forecasting structure they would have an impact (1,2). The conclusion was that energy policies would affect travel demand in two basic ways: in the total amount of travel consumed and in the modes used for that travel.
3. Models were located or developed that would incorporate the two identified impacts on travel demand.
4. To complete the development of the methodology, models were developed that linked the two points of impact into a complete modeling structure. Altogether, a series of four models was developed that begins by estimating changes in total travel demand and concludes by producing revised modal distributions.
5. The final step in the approach was to undertake the necessary calibration and field testing of the modeling structure in order to demonstrate its applicability.

SIMULATION MODELS

Overview

As shown in the flow diagram in Figure 1, the modeling structure developed is sequential, includes four models, begins with an existing future trip table, and produces revised modal travel demand, which reflects the impact of the various energy policies. The boxes on the left-hand side of Figure 1 represent inputs needed for the analysis, most of which are generally available at transportation planning offices. Energy shortages or conservation policies must be expressed in terms of their impact on the price of travel, and acceptable estimates of the

Figure 1. Flow diagram of the analysis.



price elasticity of travel consumption must be available.

The analysis begins by computing the average number of person miles of travel per household (PT_i) in each origin zone at the horizon time point of the study in the absence of energy conservation policies. In this study, the zones were specified as minor civil divisions (MCDs) (designated i), and the horizon time was 1990. Two sets of figures are needed, one for work travel ($PT_{i,w}$) and one for nonwork travel ($PT_{i,\bar{w}}$), which can ideally be taken directly from the input data. Model 1, the total travel model, is applied to the household travel figures for each zone to produce a set of revised estimates of mean person miles of travel per household for work and nonwork purposes ($PT_{i,w}$,$PR_{i,\bar{w}}$). As indicated below, the short-run price elasticity of work travel (${}_{T_w}E_{P_{T_w}}$), is sufficiently small to be assumed equal to zero. Thus, household work travel remains the same (travel mode may shift), and the revised work-trip table will be identical to the input work-trip table. Nonwork travel, which is more discretionary than work travel, is much more sensitive to price changes, and has a nonzero price elasticity (${}_{T_{\bar{w}}}E_{P_{T_{\bar{w}}}} \neq 0$). Thus, model 1 will produce a revised set of mean household nonwork travel rates ($PTi_{i,\bar{w}}$).

Once revised estimates of total nonwork travel per household are prepared, the next step is to show how these changes are reflected in changes in the average household trip rate and the average trip length. Model 2 makes this conversion and produces revised estimates of nonwork trip lengths ($TL_{i,\bar{w}}$) and trip rates ($TR_{i,\bar{w}}$) for each zone i. These figures are used as input to model 3, the trip length distribution model, to create for each zone a nonwork trip length distribution appropriate to the estimated average nonwork trip length. For each origin zone, the trip length distribution and the total number of nonwork trips ($TN_{i,\bar{w}} \cdot HH_i$) are used to create trip destination distribution arrayed by distance. When this is completed for all zones, the individual destination distributions are rearrayed to create a new, expected trip table for nonwork trips. Thus, the outputs of this part of the simulation are expected trip tables for work trips and nonwork trips. When combined, they form a total trip table that is input for the application of the modal-choice model (model 4).

In model 4, a modal-choice model is used to distribute trips between pairs of zones among the available transportation modes. Although other forms of modal-choice models could be adopted for this purpose, we selected a multidimensional logit model. This is essentially a disutility model that incorporates the time and dollar cost of traveling by each of the various modes. The output of model 4 is a tabulation of trips between each pair of zones by each available mode, given the imposition of a specific policy. This can be compared with similar figures estimated for other policy options or with those estimated in the absence of policy intervention.

Description and Development of Individual Models

Model 1: Total Travel

The first step in simulating the impacts of energy policies is to estimate the change in the total amount of travel generated by the policies. Household travel rates (PT_i) form the starting point for the application of the total travel model. If we let the impact of any policy on total travel be measured as the change in the average number of person miles of travel per household (ΔPT_i), it is obvious that the revised estimate of PT_i is equal to $PT_i + \Delta PT_i$. The most direct way of estimating the impact of energy shortages or conservation policies on total travel is to express the policies in terms of changes in the cost of travel and then apply a simple elasticity model, as follows:

$$PT_i = PT_i \cdot {}_{T}E_{P_T} \cdot \%P_{T_i} \quad (1)$$

where ${}_{T}E_{P_T}$ is the elasticity of demand for travel with respect to the price of travel paid by the consumer and $\%P_{T_i}$ is the percentage change in the price of travel per person mile resulting from energy shortages or conservation policies. The change in the price of travel is a composite price change, composed of changes in each mode weighted by the proportion of all travel carried by that mode, and will thus be specified to each zone of origin i. For purposes of this study, it was important to treat work and nonwork travel separately. Thus,

$$\Delta PT_{i,w} = PT_{i,w} \cdot {}_{T_w}E_{P_{T_w}} \cdot \%P_{T_{i,w}} \quad (2)$$

for work travel,

$$\Delta PT_{i,\bar{w}} = PT_{i,\bar{w}} \cdot {}_{T_{\bar{w}}}E_{P_{T_{\bar{w}}}} \cdot \%P_{T_{i,\bar{w}}} \quad (3)$$

for nonwork travel, and

$$\Delta PT_{i,\bar{w}} + \Delta PT_{i,w} = \Delta PT_i \quad (4)$$

Ideally, estimates of the appropriate elasticities would be available from other studies. A search of the literature, however, revealed that in recent years studies of transportation elasticity have concentrated on gasoline consumption and changes in the price of gasoline. Work and nonwork travel have not been considered independently. It was therefore necessary to construct estimates of the appropriate elasticity based on the work of others (3, pp. 43-54 and Appendices C and D). Based on that analysis, the following elasticity values wre used throughout the simulation process: ${}_{T_w}E_{P_{T_w}} = 0.00$, ${}_{T_{\bar{w}}}E_{P_{T_{\bar{w}}}} = 0.5064$, and ${}_{T}E_{P_T} = 0.3267$.

The actual process used in applying model 1 was to first estimate $\Delta PT_i = PT_i \cdot {}_{T}E_{P_T} \cdot \%P_{T_i}$. Then, $\hat{PT} = PT + \Delta PT$. Now, since ${}_{T_w}E_{P_{T_w}} = 0.0$, $PT_w = PT_w$. Therefore, $PT_{\bar{w}} = PT - PT_w = PT = PT_w$. This $PT_{\bar{w}}$ value was the input to the second model.

Model 2: Trip Rate and Trip Length

One way of determining how the revised estimate of nonwork travel per household is reflected in changes in the number of trips per household and the average trip length is to examine relations between travel volume (by a household or group of households), average trip length, and the average number of trips per day per household (i.e., the trip rate). For these households, the average amount of travel consumed is PT. This total travel, however, may consist of any of an infinite number of possible combinations of trip length ($\overline{TL}$) and trip rate (TR). Since $PT = \overline{TL} \cdot TR$, the locus of all $\overline{TL}$, TR combinations for a particular quantity of travel (PT) corresponds to an indifference curve. As a household moves from one quantity of travel to another, it moves from a point on one indifference curve to a point on another indifference curve along an expansion path composed of $\overline{TL}$, TR pairs. Conceptually, this expansion path can be expressed as $TR \cdot f(\overline{TL})$. If this function can be estimated statistically, a unique pair of values for $\overline{TL}$ and TR can be found for any specified quantity of travel (PT).

For the purposes of this research, it was only necessary to estimate the expansion-path function for nonwork travel since the amount of work travel was assumed not to change. Data for the estimation were taken from a household-interview study of Trenton, New Jersey, conducted in 1973. Examination of these data suggested that the expansion paths might be best represented by either a simple convex function ($TR_{\bar{w}} = A \cdot \overline{TL}_{\bar{w}}^{B}$) or a linear function ($TR_{\bar{w}} = A + B\ \overline{TL}_{\bar{w}}$), where the subscript $\bar{w}$ denotes nonwork travel. Several other functional relations were tested, but the results were less satisfactory.

Figure 2 shows the convex function ($TR_{\bar{w}} = 0.814\ \overline{TL}_{\bar{w}}^{+0.622}$), which accounts for 88 percent of the variance ($R^2 = 0.878$) and includes a standard error of the estimate of 1.027. The fact that the curve has a zero intercept fits well with the reality of zero trip length with zero trips for zero total travel.

Figure 3 shows the estimated linear function ($TR_{\bar{w}} = 1.566 + 0.170\ \overline{TL}_{\bar{w}}$), which accounts for 91 percent of the variance ($R^2 = 0.9099$) and includes a standard error of the estimate of 0.979. The nonzero intercept may reflect walking trips not included in the data. Thus, caution may be warranted in using the lower range of this function.

Since the linear function was easier to use and had a higher R^2 value, it was accepted as the best form for model 2. The solution process consists of solving the following two simultaneous equations:

$$TR_{\bar{w}} = 1.566 + 0.170\ \overline{TL}_{\bar{w}} \quad (5)$$

$$PT_{\bar{w}} = TR_{\bar{w}} \cdot \overline{TL}_{\bar{w}} \quad (6)$$

Thus,

$$PT_{\bar{w}} = 1.566\ \overline{TL}_{\bar{w}} + 0.170\ (TL_{\bar{w}})^2 \quad (7)$$

This can be solved for $\overline{TL}_{\bar{w}}$ by using the quadratic equation for unknown values of $PT_{\bar{w}}$. The positive, and only acceptable, root of the equation can then be used to compute $TR_{\bar{w}}$.

In summary, the basic input to model 2 is average household nonwork person miles of travel, and the model output is the daily number of nonwork trips per household and the average household trip length.

Model 3: Trip Distribution

The third model in the sequence is the trip distribution model. Its purpose is to revise existing nonwork trip distribution forecasts to reflect the modifications to the average nonwork trip length estimated by model 2. Observations of nonwork trip length distribution curves suggested that they might be represented by one of a variety of functional forms of established probability distributions, such as chi-square, Pearson Type III, Weibull, gamma, Poisson, and lognormal. All of these distributions satisfied the requirement that the parameters be related to average nonwork trip length--i.e., the output of model 2. Previous research (4,5) indicated that, of the first four distributions mentioned above, the gamma gave the best results. Since the Poisson is a special case of gamma, it was only necessary to examine the use of the gamma and lognormal distributions for this project.

For the gamma distribution, let x be a random variable representing trip length. Then F(x) can be expressed as follows:

$$F(x) = (x)^{c-1}/b\ \exp(-x/b)/b\Gamma(c) \quad (8)$$

where c,b are the parameters of the distribution and $\Gamma(c)$ is the gamma function with parameter c. The mean and variance of the gamma distribution are related to its parameters as follows:

$$\mu = b \cdot c$$

$$\sigma^2 = b^2 c$$

Figure 2. Nonlinear travel consumption path.

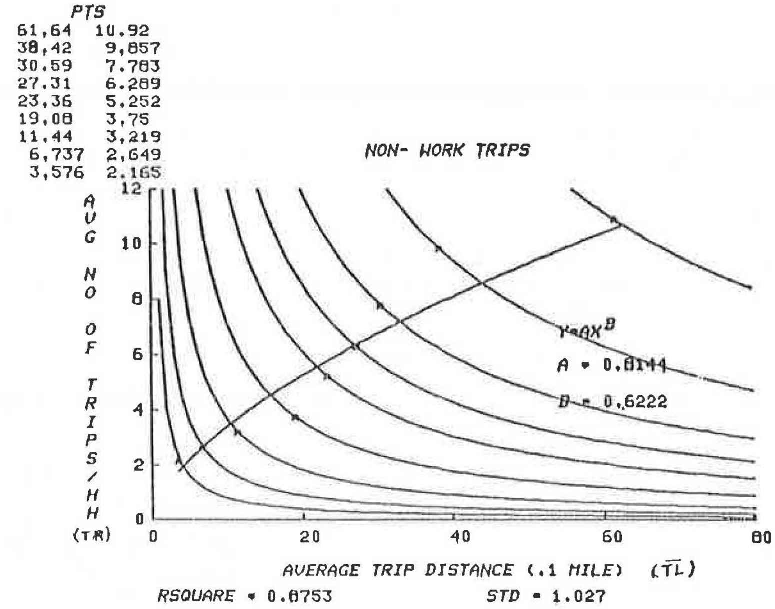
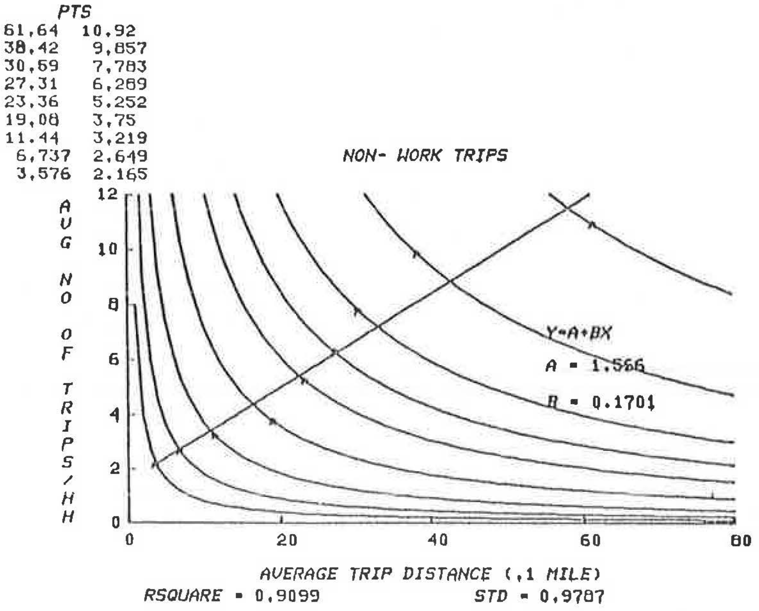


Figure 3. Linear travel consumption path.



For the purpose of estimating a nonwork trip length distribution, an unbiased estimate of μ is x, which is equal to $\overline{TL}_{\bar{w}}$ as generated by model 2. For calibration purposes, estimates of the mean and variance can be derived from the original survey trip records. However, without going back to these raw data, a vector of S^2 values can be tested and that providing the best fit selected. Although this approach deviates from the classical curve-fitting techniques, it was adopted because it ensured that the relation between the parameters and the observed trip length would be maintained. A chi-square test was used to select the value of s^2 that gives the best fit.

For the lognormal distribution, again let x be a random variable representing trip length. The expression for f(x) becomes

$$f(x) = [1/x\sigma(2\pi)^{1/2}] \cdot \exp[-\log(x/m)^2/2\sigma^2] \qquad (9)$$

where m is the median of the distribution and σ is the standard deviation. Both of the parameters can be estimated directly from a data set for calibration. Fitting both of the above functions against data derived from a 1963 home-interview survey conducted by the Tri-State Regional Planning Commission indicated that the lognormal curve was most appropriate for this study.

The next step was to estimate the curve for each relevant zone of origin. To do this, the shape parameter m was held constant while σ was modified to reflect changes in $\bar{x}$ or $\overline{TL}$ (3, Appendices D and E). The geographic setting of the case-study area and the available travel data for that area created a number of obstacles to the calibration. The most important factors causing these difficulties are the following:

1. We are dealing with an area composed of three counties that includes a number of medium and large cities but at the same time constitutes only a partial corridor within a much larger urban area. This

fact caused the presence of a number of smaller distributions within the overall distribution.

2. The available data within the corridor are aggregated at the MCD level so that large fractions of the trips are concentrated at township centroids.

The sensitivity of the chi-square goodness-of-fit test to the number of observations (number of trips), combined with the constraint on destinations resulting from the aggregation level stated earlier, made it difficult to test potential distributions. Had the individual trip records, including the true trip length, been available for a typical urban area, fitting an acceptable distribution to the data would have been a much simpler task.

The essence of the model is to develop a mathematical function that describes the relation among the data points and is capable of modifying that distribution in response to changes in the parameters. Although it was not possible to find a distribution that exactly describes the data, it is possible to use the best possible lognormal distribution as a basis for generating a modified distribution. To do this, the following procedure was observed:

1. By using a number of computer programs and a range of parameter sets estimated from the first moment of the distribution, 1963 travel data for each MCD were fitted to the best lognormal distribution. Assuming that the variates are lognormally distributed, the first moment of the distribution is equal to the mean; i.e., $\bar{x} = m \exp(\sigma^2/2)$. Because only MCD-level data were available, the calculated value of m (initially), the median of the distribution, was only approximate. Therefore, a vector of m values, surrounding the value derived from the data, was constructed. By solving the first moment expression for a vector of m values, a corresponding vector of σ^2 values was produced.
2. For each pair of m, σ^2, the lognormal distribution was computed and compared with the observed data by using the chi-square test.
3. The parameter pair that produced the minimum chi-square was selected as the best fit, and the m value was considered the best estimate of the median.
4. For each MCD of the best-fit pair of parameters, the shape parameter m was held constant while the scale parameter σ was modified to reflect the estimated 1990 mean trip length for each policy. Appropriate modifications to the scale parameter were based on the first-moment equation in item 1 above.
5. At every x value (distance to a destination centroid), the probability density of the modified distribution was computed. These probabilities (scaled to sum 1.0) were multiplied by the estimated number of nonwork trips for each origin to provide a new trip destination table for nonwork trips. The nonwork trip tables were added to the work-trip table to create estimated total trip tables for each policy. These became the input to model 4, the modal-choice model.

Model 4: Modal-Choice Model

Distributing the total number of trips at each interchange of the trip table among the various available modes of travel is an important element in this research because modal choice is the second point where energy conservation policies are expected to have an impact on travel behavior. However, since various types of modal-choice models have been in existence for some time, it seemed appropriate to use an existing model rather than attempt to develop a new one. Selection of an existing model was based on several criteria:

1. The model had to be operational. Conceptual models that had not yet been used were dropped from consideration.
2. The model had to accommodate a number of modes, including various sizes of carpools.
3. The model had to be sensitive to input variables related to energy conservation policies, such as the time and unit cost of travel, parking costs, waiting time, pickup and drop-off time, and automobile availability.
4. The model had to be transferable to other areas with minimal recalibration.

The model selected was developed as part of ongoing research by the Transportation Program staff of Princeton University for the Urban Mass Transportation Administration (UMTA) and uses the UMTA Urban Transportation Planning System (UTPS) computer package. It is a multinomial-logit-based model that estimates the probability that a given trip will be made by any of several potential modes. The probability of a trip being made by mode m(P_m) is given by the following expression:

$$P_m = \exp D_m \Big/ \sum_{i=1}^{m} \exp D_i \qquad (10)$$

where D_i is the disutility of mode i and D_m is the disutility of mode m.

The model, as used, considers five potential travel modes that are ubiquitous to the study area (and to most study areas): (a) automobile drive alone, (b) one-passenger carpool (driver and one passenger), (c) two-passenger carpool, (d) carpool with three or more passengers, and (e) transit, which includes both bus and rail systems. As input variables, the model required the following: automobile cost (including parking, tolls, etc.), transit fare, automobile travel time (including pickup and drop-off time for carpools), transit travel time, income (earnings per month), and automobile availability (automobiles per household).

Although the model was originally developed for the Shirley Highway corridor in Washington, D.C., calibration for the study area proved to be relatively straightforward. The first phase was to estimate the most suitable disutility expression for each mode for the Shirley Highway corridor. In the second phase, the model was tested against the 1963 MCD average data for the study area. Two modifications were found to be necessary: (a) The constant term in the transit disutility expression had to be modified to reflect local transit conditions, and (b) the various constants representing carpool pickup and drop-off times and transit waiting and transfer times had to be modified, again to reflect local conditions (3, pp. 71-74). With these modifications, the model reproduced the 1963 modal splits for the selected MCDs in the study area with accuracy sufficient for use in the study. This completed the development of the modeling structure. The next step was to apply it to a selected set of energy conservation policies in a selected study area.

SIMULATING TRAVEL RESPONSES TO SELECTED ENERGY CONSERVATION POLICIES

The study area for the project was a three-county transportation corridor within the region served by the Tri-State Regional Planning Commission in northern New Jersey. The three counties--Middlesex, Essex, and Union--follow the Pennsylvania Railroad main line, the New Jersey Turnpike, and US-1 going southwest from New York City and are thus part of a major transportation corridor. Within this study area, nine MCDs, three in each county, were selected as sample zones of origin: Metuchen, South Amboy, and South Plainfield in Middlesex County; Caldwell, South Orange, and Verona in Essex County; and Berkeley Heights, Cranford, and Summit in Union County. Zones of destination included all MCDs in the three counties plus several external zones. The field test was to include the prediction of changes in 1990 modal travel demand for trips from each of these zones of origin as a result of the imposition of a selected set of energy conservation policies.

The data requirements of the modeling structure are quite modest: 1990 population estimates of each MCD, 1990 estimates of the number of households, average household income, and automobiles per household. In addition, it is necessary to know household travel rates (person miles of travel per household for work and nonwork) estimated in the absence of the energy policies and the split between automobile and nonautomobile travel. In most cases, a transportation planning agency would produce most of these data as part of their ongoing demand forecasting process. In the case of the study area, the level of aggregation differed from that used by the Tri-State Regional Planning Commission, and it became necessary to prepare separate estimates of the needed data by making use of as much Tri-State data as possible (3, pp. 87-94). The estimated household and travel characteristics are given in Table 1 (3, Tables 9 and 11).

Finally, it was necessary to estimate the costs of travel in 1990, both in terms of vehicle miles of automobile travel and person miles of transit travel. For the purposes of this project, it was deemed sufficient to use projections of historical trends, checked against estimates by others (3, pp. 95-96 and Appendices E and F). On this basis, it was estimated that a vehicle mile of automobile travel in 1990 would cost $0.23 in 1975 dollars and a person mile of transit travel in 1990 would cost $0.087 in 1975 dollars. These costs were assumed to hold for all MCDs, although composite costs (based on the mixture of automobile and nonautomobile travel) would vary.

Six potential energy conservation policies (in addition to a baseline policy defined as a market solution in the absence of government action) were selected for the case-study analysis:

1. Government-imposed gasoline tax,
2. Market shortages with imposition of queuing discipline,
3. Government-imposed gasoline rationing,
4. Parking taxes at major destinations,
5. Annual automobile registration fees based on fuel efficiency, and
6. Subsidies to encourage carpooling.

The intent was to compare the estimated travel demand under each of these policies with that of the baseline or nonintervention situation.

The various policies input into the modeling structure at one or both of two places:

1. Policies that change the unit cost of travel (cost per person mile) affect the total travel consumed as estimated by model 1.
2. Policies that change the relative cost of various modes enter through the modal-choice model, model 4.

Thus, it is necessary to specify the policies in terms of their impacts on travel costs [more details are provided elsewhere (3, pp. 100-122)].

Government-Imposed Gasoline Tax

It was assumed that a flat tax of $0.50/gal is imposed and that this tax remains in place until at least 1990. It is thus necessary to express the value of $0.50 in 1990 in terms of 1975 dollars--a value of $0.16. If allowances are made for increases in fuel efficiency, this translates into a 1.3 percent increase in the unit cost of automobile travel. It was assumed that this policy would not affect the cost of transit travel, since gasoline is not a common fuel for transit systems.

Market Shortages with Queuing

It was assumed that a market shortage of 5 percent (the equivalent of the 1973-1974 experience) occurred and that various kinds of queue disciplines would be established to impose order on the waiting lines. Two approaches were used to estimate the effective cost of queuing as an addition to the pump price of gasoline. The first simply used the price elasticity of gasoline consumption to estimate the long-run price increase that would be associated with a 5 percent decrease in consumption. This was corroborated by estimating the expected queuing time, converting it to a dollar cost, and then expressing it in terms of an increase in the cost of automobile travel. Both approaches generated an increase in the unit cost of automobile travel of 2.7 percent. Again, this policy does not affect the cost of transit travel.

Table 1. Estimated 1990 baseline household and travel data for selected MCDs.

MCD	Population	Household	Household Income[a] ($)	Automobiles per Household[b]	Travel Rate (person miles per household)			Automobile Travel/ Total Travel[b]
					Total	Work	Nonwork	
Middlesex County								
Metuchen	20 052	6771	14 541	1.67	38.14	24.18	13.96	0.968
South Amboy	11 676	3927	11 463	1.67	38.54	24.43	14.11	0.968
South Plainfield	26 441	7744	13 554	1.67	38.54	24.43	14.11	0.968
Essex County								
Caldwell	8 837	3300	20 591	1.23	25.20	15.90	9.30	0.906
South Orange	17 202	5668	27 788	1.23	24.36	15.37	8.99	0.906
Verona	15 273	5298	20 116	1.23	25.16	15.88	9.28	0.906
Union County								
Berkeley Heights	13 597	3818	22 904	1.46	25.06	16.64	8.42	0.919
Cranford	28 476	9013	17 500	1.46	23.68	14.94	8.74	0.919
Summit	24 557	8838	21 882	1.46	22.61	14.27	8.34	0.919

[a] In constant 1977 dollars.

[b] From Tri-State Regional Planning Commission reports. It was assumed that county figures would apply to all constituent MCDs.

Government-Imposed Gasoline Rationing

The assumption behind the gasoline-rationing policy is consistent with the requirements behind the authorization for the President's standby rationing program--i.e., an estimated shortage of 20 percent. By using the inductive approach described above for market shortages, the effective increase in the price of travel associated with a shortage of this magnitude was estimated to be 32.6 percent. Since only gasoline is affected, this policy also has no impact on the cost of transit travel.

Parking Taxes at Major Destinations

The intent of the parking-tax policy is to make travel by automobile to certain destinations undesirable. To accomplish this, a 100 percent tax on parking spaces in certain destination zones was imposed. It was assumed that, since the tax was not ubiquitous, it would not affect the overall cost of travel. However, it would increase the cost of travel by automobile in certain interchanges of the trip table, thus affecting modal choice. For use in the modal-choice model, parking fees and taxes were specified in terms of 1975 dollars. This policy obviously does not affect the cost of travel by transit.

Annual Automobile Registration Fees Based on Fuel Efficiency

A rather drastic fee schedule was assumed for the policy calling for annual automobile registration fees based on fuel efficiency: from a high of $1000/year for cars averaging 10 miles/gal or less to a low of $50/year for cars averaging 40 miles/gal. Between these two points, the fee structure is linear. It was assumed that the result of such a policy would be to encourage people to buy and operate more fuel-efficient cars and that they would do this in such a way that the fee plus gasoline expenses would remain unchanged--i.e., the cost per vehicle mile would remain constant. Thus, the impact on total travel was zero. In regard to modal-choice decisions, however, it was recognized that it was the out-of-pocket costs that affected decisions, that more efficient cars would have reduced operating or out-of-pocket costs, and that this reduction would amount to 12.5 percent.

Subsidies to Encourage Carpooling

In addition to the natural benefits of ridesharing, the carpool-subsidy policy provided a graduated subsidy structure designed to favor large carpools over small ones. Thus, it was assumed that the government would reimburse the costs of automobile commuting according to the following schedule:

Number of Persons per Vehicle	Percentage of Costs Reimbursed
1	0
2	20
3	30
≥4	40

Expressed in terms of the cost savings relative to driving alone, with and without the policy, the effect of the policy is as follows (C = cost per vehicle mile):

	Savings	
Number of Persons per Vehicle	Without the Policy	With the Policy
1	0.000	0.000
2	0.500C	0.600C
3	0.667C	0.766C
4	0.750C	0.850C
6	0.833C	0.900C
8	0.875C	0.925C

It was assumed that this policy would have no impact on the overall cost of travel and would thus not affect total travel demand. It will, however, affect the modal-choice decision.

Summary

Table 2 summarizes the estimated impact of the six potential policies expressed in terms of inputs to the total travel model and the modal-choice model.

SIMULATED IMPACTS OF POLICIES ON TRAVEL BEHAVIOR

Table 3 gives the modal distributions produced for the nine selected communities for each of the sample policies and for the baseline situation. Table 4 gives relevant automobile-travel-related statistics in a similar format. The apparent impacts of each of the sample policies are outlined below:

1. Government-imposed gasoline tax of $0.50/gal--Policy 1, which is very modest, generated a virtually negligible change in travel behavior in the nine MCDs. Total travel declined very slightly, primarily at the expense of the automobile-drive-alone mode. The transit share of total trips tended to increase very slightly. Total automobile person miles held constant while total vehicle miles of travel (VMT) declined slightly. It is apparent that a policy of this magnitude will not generate a substantial change in travel demand. If a gasoline tax is to be effective in generating changes in travel demand, it must account for a much greater proportion of gasoline costs.

2. Market shortages with imposition of queuing discipline--Policy 2 generated a noticeable shift in travel demand among the various modes. The transit share of total trips increased, on the average, by 0.47 percent while the share of automobile drive

Table 2. Policy impacts expressed as model inputs.

	Policy					
Item	1	2	3	4	5	6
Input to total travel model						
Increase in unit cost of automobile travel (%)	1.3	2.7	32.6	-	-	-
Increase in composite unit of travel (%)						
Middlesex County	1.26	2.61	31.56	-	-	-
Essex County	1.18	2.45	29.54	-	-	-
Union County	1.19	2.48	29.96	-	-	-
Input to modal-choice models						
Change in per mile cost of automobile travel (%)	+1.3	+2.7	+32.6	-	-12.5	
1 person/vehicle						0
2 persons/vehicle						-60
3 persons/vehicle						-76
≥4 persons/vehicle						-90
Change in automobile travel time per trip (min)	-	+0.36	-	-	-	-
Change in parking costs (%)	-	-	-	+100[a]		

[a] In selected destination zones.

Table 3. Summary of travel demand estimates: baseline and by policy.

		Trips									
		Drive Alone		One Passenger		Two Passengers		Three Passengers		Transit	
MCD	Policy	No.	Percent	No.	Percent	No.	Percent	No.	Percent	No.	Percent
Metuchen	B	37 324	63.1	11 182	18.9	1635	2.8	1499	2.5	7467	12.6
	1	37 166	63.0	11 147	18.9	1635	2.8	1495	2.5	7464	12.7
	2	36 889	62.8	10 994	18.7	1606	2.7	1467	2.5	7748	13.2
	3	33 555	61.9	10 294	19.0	1533	2.8	1403	2.6	7382	13.6
	4	36 402	61.6	10 940	18.5	1634	2.8	1485	2.5	8651	14.6
	5	37 502	63.4	11 161	18.9	1637	2.8	1492	2.5	7319	12.4
	6	37 132	62.8	11 371	19.2	1664	2.8	1526	2.6	7416	12.6
South Amboy	B	20 989	60.8	6 193	18.0	892	2.6	820	2.4	5615	16.3
	1	20 892	60.7	6 182	18.0	891	2.5	819	2.4	5616	16.3
	2	20 892	60.4	6 104	17.8	875	2.6	806	2.4	5777	16.9
	3	18 836	59.6	5 731	18.1	845	2.7	776	2.5	5423	17.2
	4	20 767	60.2	6 189	18.0	891	2.6	823	2.4	5809	16.9
	5	21 085	61.2	6 174	17.9	890	2.6	815	2.4	5514	16.0
	6	20 820	60.4	6 325	18.3	911	2.6	839	2.4	5585	16.2
South Plainfield	B	43 477	63.9	13 041	19.2	1880	2.8	1738	2.6	7857	11.6
	1	43 349	63.9	13 015	19.2	1879	2.8	1736	2.6	7859	11.6
	2	43 349	63.8	12 868	19.0	1842	2.7	1706	2.5	8085	12.0
	3	39 254	63.0	12 032	19.3	1759	2.8	1624	2.6	7660	12.3
	4	42 940	63.2	12 942	19.0	1879	2.8	1736	2.6	8496	12.4
	5	43 646	64.2	13 006	19.1	1877	2.8	1728	2.5	7736	11.4
	6	43 234	63.6	13 257	19.5	1916	2.8	1772	2.6	7814	11.5
Caldwell	B	16 084	62.0	5 150	19.9	891	3.4	760	2.9	3053	11.8
	1	16 039	62.0	5 138	19.9	889	3.4	758	2.9	3047	11.8
	2	16 039	61.9	5 096	19.8	878	3.4	750	2.9	3089	12.0
	3	14 881	61.7	4 809	19.9	840	3.5	762	3.0	2876	11.9
	4	15 938	61.4	5 137	19.8	891	3.4	762	2.9	3211	12.4
	5	16 108	62.1	5 146	19.8	891	3.4	758	2.9	3034	11.7
	6	16 052	61.9	5 177	20.0	897	3.5	758	3.0	3047	11.8
South Orange	B	25 577	59.1	8 092	18.7	1289	3.0	1157	2.7	7190	16.6
	1	25 663	59.0	8 125	18.7	1292	3.0	1162	2.6	7227	16.7
	2	25 663	58.9	8 047	18.6	1275	2.9	1174	2.6	7353	12.0
	3	23 685	58.4	7 597	18.8	1224	3.0	1183	2.7	6923	17.1
	4	24 415	56.4	8 009	18.4	1286	3.0	1183	2.8	9411	19.4
	5	25 623	59.2	8 087	18.7	1289	3.0	1154	2.7	7152	16.5
	6	25 526	59.0	8 139	18.8	1298	3.0	1154	2.9	7177	16.6
Verona	B	25 833	62.2	8 276	19.9	1384	3.3	1205	2.9	4890	11.8
	1	25 759	62.1	8 256	19.9	1381	3.3	1202	2.9	4884	16.8
	2	25 759	62.0	8 190	19.8	1362	3.3	1188	2.9	4987	12.1
	3	23 815	61.6	7 713	19.9	1301	3.4	1203	2.9	4713	12.2
	4	25 282	60.8	8 164	19.6	1380	3.4	1203	2.9	5560	13.4
	5	25 282	60.8	8 164	19.6	1380	3.4	1203	2.9	4850	11.7
	6	25 775	62.0	8 329	20.0	1395	3.4	1203	2.9	4875	11.7
Berkeley Heights	B	17 568	63.9	4 753	17.3	587	2.1	570	2.1	4013	14.6
	1	17 509	63.9	4 739	17.3	585	2.1	568	2.0	4012	14.7
	2	17 509	63.7	4 542	17.0	586	2.1	563	2.0	4175	15.3
	3	15 890	63.0	4 344	17.2	528	2.1	568	2.1	3954	15.7
	4	17 193	62.5	4 694	17.1	585	2.1	568	2.0	4445	16.2
	5	17 640	64.1	4 744	17.3	586	2.1	567	2.1	3953	14.4
	6	17 493	63.6	4 825	17.6	597	2.2	567	2.1	3996	14.5
Cranford	B	40 302	63.8	12 190	19.3	1861	3.0	1670	2.7	7156	11.3
	1	40 171	63.8	12 156	19.3	1856	3.0	1668	2.6	7150	11.4
	2	40 171	63.6	12 029	19.2	1823	2.9	1642	2.6	7361	11.7
	3	36 796	63.1	11 266	19.3	1723	3.0	1664	2.7	6972	12.0
	4	39 696	62.8	12 035	19.1	1855	2.9	1664	2.7	7931	12.6
	5	40 420	64.0	12 170	19.3	1859	2.9	1666	2.6	7065	11.2
	6	40 153	63.6	12 325	19.5	1884	3.0	1666	2.7	7125	11.3
Summit	B	38 879	64.5	10 406	17.3	1221	2.0	1211	2.0	8558	14.2
	1	38 748	64.5	10 376	17.3	1217	2.0	1208	2.0	8549	14.3
	2	38 748	64.2	10 203	17.1	1177	2.0	1175	2.0	8880	14.8
	3	35 472	63.2	9 623	17.3	1121	2.0	1214	2.0	8338	15.0
	4	38 152	63.3	10 332	17.1	1220	2.0	1214	2.0	9358	15.5
	5	39 025	64.7	10 383	17.2	1219	2.0	1205	2.0	8443	14.0
	6	38 713	64.2	10 561	17.5	1243	2.1	1205	2.1	8524	14.1

Note: B = baseline.

alone declined, on the average, by only 0.22 percent. This suggests that half of the shift to transit came from the carpool modes. As expected, a policy of this type generates a general shift from automobile-based travel to transit, but the shift is relatively small. Still, automobile VMT decreased by 1.75 percent while automobile occupancy rates remained virtually constant.

3. Government-imposed gasoline rationing--Policy 3 was the most severe of the policies examined, generating a reduction in automobile VMT of slightly more than 100 percent for the nine communities in the simulation. This decrease reflects a very slight increase in the automobile occupancy rate and a marked shift away from the drive-alone mode. The share of this mode declined by 0.87 percent while the transit share increased by 0.69 percent. There was a slight tendency for the share captured by one-passenger carpools to increase, but this was not consistent across all of the sample MCDs. Even though the share of trips going to transit increased, the actual number declined, which reflects the decrease in total travel. Thus, even this, the most severe, policy does not appear to place a se-

Table 4. Summary of automobile statistics: baseline and by policy.

MCD	Policy	Automobile Person Miles	VMT	Automobile Person Trips	Automobile Trips	Automobile Occupancy Rate[a]
Metuchen	B	498 878	437 987	51 644	43 789	1.179
	1	499 541	436 352	51 444	43 615	1.181
	2	487 708	426 862	50 957	43 248	1.178
	3	435 175	378 372	46 786	39 526	1.184
	4	460 383	402 498	50 460	42 749	1.180
	5	508 260	444 926	51 792	43 955	1.178
	6	504 237	438 002	51 693	43 713	1.183
South Amboy	B	287 353	251 871	28 861	24 535	1.176
	1	285 581	250 270	28 784	24 455	1.177
	2	279 995	245 731	28 506	24 413	1.168
	3	248 091	216 577	26 189	22 154	1.182
	4	282 446	246 973	28 670	24 342	1.178
	5	289 868	254 651	28 965	24 649	1.175
	6	287 885	250 708	28 394	24 470	1.181
South Plainfield	B	541 034	468 752	60 136	50 863	1.182
	1	538 523	466 513	59 979	50 858	1.179
	2	530 839	460 797	59 520	50 535	1.178
	3	478 126	412 974	54 679	46 218	1.183
	4	517 794	448 114	59 497	50 424	1.180
	5	543 564	471 620	60 257	51 158	1.178
	6	541 984	467 133	60 179	50 900	1.182
Caldwell	B	106 292	91 338	22 885	19 124	1.197
	1	105 902	91 005	22 825	19 678	1.196
	2	104 565	89 982	22 684	18 964	1.196
	3	95 230	81 751	21 247	17 726	1.199
	4	102 026	87 381	22 727	18 974	1.198
	5	106 617	91 693	27 904	19 145	1.196
	6	106 389	91 192	22 391	19 111	1.198
South Orange	B	242 314	208 861	36 114	30 304	1.192
	1	242 303	208 829	36 134	30 331	1.191
	2	239 216	206 565	36 008	30 244	1.191
	3	219 431	188 926	33 604	28 142	1.194
	4	219 437	187 362	34 893	29 113	1.199
	5	242 943	209 548	36 152	30 352	1.191
	6	248 514	213 562	36 127	30 308	1.192
Verona	B	192 040	163 904	36 699	30 718	1.195
	1	191 297	163 253	35 493	30 329	1.203
	2	188 380	160 902	36 390	30 466	1.194
	3	171 094	145 666	33 962	28 357	1.198
	4	173 969	147 963	36 029	30 094	1.197
	5	192 857	164 739	36 739	30 743	1.195
	6	192 329	163 692	36 714	30 680	1.197
Berkeley Heights	B	313 176	277 015	23 477	20 266	1.158
	1	312 380	276 291	23 287	20 179	1.154
	2	307 327	272 397	23 124	19 988	1.157
	3	290 654	256 665	21 283	18 352	1.150
	4	338 738	263 750	23 040	19 862	1.160
	5	314 610	278 574	23 537	20 334	1.158
	6	314 156	276 405	23 494	20 235	1.161
Cranford	B	451 268	392 843	56 025	47 386	1.182
	1	449 883	391 607	55 671	47 091	1.182
	2	443 387	387 124	55 460	47 053	1.179
	3	413 342	359 177	51 342	43 345	1.184
	4	430 139	374 472	50 917	46 703	1.183
	5	453 213	394 981	56 116	47 499	1.181
	6	451 794	391 737	56 056	47 328	1.185
Summit	B	697 473	624 063	51 717	44 754	1.156
	1	695 450	612 233	51 372	44 473	1.155
	2	686 231	605 369	51 041	44 246	1.154
	3	644 502	566 204	47 341	40 907	1.157
	4	667 427	585 817	50 917	43 995	1.157
	5	699 691	615 289	51 832	44 387	1.155
	6	698 145	612 731	51 751	44 688	1.158
Sum of MCDs	B	3 329 826	2 906 634	367 558	311 739	1.179
	1	3 329 826	2 896 353	366 039	310 409	1.179
	2	3 268 148	2 855 729	363 690	309 157	1.176
	3	2 995 645	2 606 402	336 433	284 727	1.182
	4	3 192 359	2 744 335	351 483	306 256	1.180
	5	3 351 359	2 744 335	351 483	396 256	1.180
	6	3 339 433	2 900 210	367 799	311 426	1.181

[a] Automobile occupancy rate equals automobile person trips divided by automobile trips.

vere burden on the existing transit system.

4. Parking taxes at major destinations--Policy 4 is the only policy tested that includes an explicit disincentive to automobile travel. It resulted in an increase, on the average, of 1.4 percent in the share of total trips captured by transit, although the shift varied substantially among MCDs, depending on the proportion of their trips that went to the restricted destinations. Total travel remained constant under this policy, but automobile VMT declined, on the average, by 5.5 percent. This policy appears to be quite effective in generating a shift to transit. Indeed, transit ridership increased by 12.7 percent, an increase that may require increases in service. Clearly, the strategy of taxing parking must not be considered without simultaneously planning to accommodate the increase in transit demand.

5. Annual automobile registration fees based on fuel efficiency--As described above, policy 5 was defined so as not to include any change in the over-

all cost of travel. Thus, total travel remains constant and the simulated changes all appear in the distribution among modes. Most noticeable is a shift from transit to the drive-alone mode of about 0.2 percent. This amounts to less than a 0.5 percent increase in the drive-alone share but a decrease of 1.25 percent in the transit share, which may make it difficult for some marginal transit systems to continue operations.

6. Subsidies to encourage carpooling--Policy 6 was intended to encourage carpooling at the expense of travel by other modes. The changes were very small; the trend was toward one-passenger carpools, even though the subsidy favored the larger carpools. The increase in carpooling was gained almost exclusively at the expense of the drive-alone mode, and the effect on transit ridership and the transit share of total trips was negligible. The decrease in automobile VMT, however, was less than one quarter of one percent. The small increase in carpooling generated a slight increase in the automobile occupancy rate (0.17 percent).

When the set of selected policies is considered as a whole, several interesting findings emerge (it should be noted that the policies are not intended to be comparable in scope). Policy 4 generates the largest increase in the transit share of total trips. Under rationing (policy 3), the transit share increased slightly but ridership declined due to the decrease in total travel. Neither the modest gasoline tax nor the carpooling subsidy generated a significant impact on the share of trips made by the drive-alone mode. Even the shortage policy generated only a modest shift from this mode. Only under the severe rationing policy was a major decrease in drive-alone trips evident. Finally, as expected, only the policy of subsidizing carpooling generated a recognizable increase in the carpool market share, and this amounted to only 1.5 percent for all carpool modes.

Several summary comments can be made at this point. The policies selected for study ranged from modest (the $0.50/gal gasoline tax) to reasonable (parking fees) to radical (rationing). In general, the impact on travel behavior was modest but significant and in the expected direction. Although these policies may reduce gasoline consumption, they have limited impacts on travel behavior and transportation demand. Only two of the policies (shortages and parking fees) generated noticeable increases in transit travel, and only rationing and parking fees generated substantial reductions in automobile VMT. It may be that combinations of policies would be more effective in modifying travel behavior, but this must wait for further work with the model.

SUMMARY ASSESSMENT OF SIMULATION METHODOLOGY

In general, the simulation approach developed for this project seemed successful in estimating the marginal changes in travel demand resulting from energy conservation policies and in converting them to revised estimates of mode-specific demands in the familiar trip-table format. The structure of the modeling approach allows the simulation of a variety of potential policies or combinations of policies and can produce either final demand estimates or intermediate estimates of travel rates, trip rates, and average trip lengths. Also, the model can be easily applied once it is calibrated. The first two models can be run manually while the last two require computer assistance. Finally, most of the required data are readily available in transportation planning agencies or are easily generated. Thus, the methodology should be applicable to a wide variety of transportation study regions. It is expected that the approach will prove useful to energy and transportation planners throughout the country.

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