Approach to Assessing the Impact of Energy Conservation Policies on Transportation Demand

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The federal government and many state governments are considering a number of policies that will alleviate the impacts of fuel shortages. To the extent that these policies deal with the use and supply of motor fuel they may have important impacts on transportation systems. This paper examines a number of energy-conservation policies and assesses, at a general level, their likely transportation impacts. The ability of existing transportation modeling techniques to rigorously assess the impacts of these policies is also examined. In particular, where available modeling devices appear unable to deal with the impact of energy policies on the overall demand for travel and on the choice of mode, preliminary suggestions on revisions to the models are offered.

The oil embargo of 1973-1974 generated the first serious curtailment of energy supplies in the United States. The Northeast, which is particularly dependent on petroleum fuels, suffered more intensely than did other parts of the country. The difficulties were manifest in terms of gasoline shortages, lines at filling stations, rapid escalation of fuel prices, and an inability of the supply of natural gas to meet demands as consumers shifted from petroleum to gas as a fuel source. The crisis subsided somewhat when the embargo was released, but for the first time the United States became aware of the critical aspects of diminishing supplies of all types of energy sources. Since that time a number of federal programs have been proposed or enacted (a) to reduce the consumption of the nonrenewable energy sources and (b) to reduce the dependency of the nation on foreign supplies of energy. Examples of this are Project Independence and the National Energy Conservation Act of 1974.

Several studies have been made of the estimated impact of these federal programs on the overall consumption of energy and on the various sectors of consumption. These studies have necessarily been aggregate in nature and have not gone into the detailed aspects of how the reductions in consumption would actually take place or the kinds of behavioral consequences associated with various programs. This paper examines these energy-related policies in the context of the state of New Jersey and anticipates the consequences in terms of travel behavior.

Changes in the availability and cost of energy, particularly gasoline, will have consequences on the ways in which people travel. If energy policies are going to have major consequences on individual travel behavior and the demand for various kinds of transportation services, an estimate, in advance, of the kinds of transportation services that will be needed is necessary. Steps to provide those services will have to be taken so that they will be in place and usable as the demand materializes. This paper lists possible energy policies and describes some of the possible behavioral responses to them as they relate to transportation. A number of individual and group responses will be examined and their potential impact on the provision of and demand for transit services will be discussed. Some of these responses represent a marked break from transportation and travel behavior of the past and, therefore, make formal modeling and analysis somewhat difficult. Traditional models used for forecasting transportation demand are described, and the ability of these models to accommodate energy policy responses is explored. Finally, modifications to existing modeling devices are explored and new ones are suggested that will allow a more rigorous analysis of the impacts of these policies on transit demand.

ENERGY POLICIES AND TRANSPORTATION RESPONSES

Some energy policies affect overall travel and others affect the distribution of trips among various travel modes. Potential energy policies can be grouped into seven general classes, depending on the way in which they directly change the transportation system. Within each class fall a number of individual policy actions that various levels of government might consider as ways of reducing or curtailing the consumption of energy by transportation. The policy components of each class are indicated in Table 1.

The effects of these policies on the transportation system can be grouped into a small number of responses by travelers. In the most basic sense, consumers of transportation services can respond to the various policy actions by simply deciding to travel less; that is, by making either fewer or shorter trips. Consumers may also decide to change their modes of travel, at least for some trips, or to acquire more energy-efficient automobiles so that the same amount of travel can be made with less fuel. Another possibility is relocation so as to have fewer travel requirements. Finally, some travelers may find that public policies cause them to change the daily pattern of their trip making and thus modify patterns of peak-hour travel.

Consumers can adopt one or more of these general responses to various public policy actions. Also, different policy classes will generate different patterns of consumer responses. Table 2 presents, in a simple format, the relationships among the seven policy classes and the various categories of consumer responses. This matrix forms the basis of the following analysis of the impacts of energy policies on transportation. The analysis can be approached from two directions. One can examine the rows associated with a particular policy class, or one can consider the column that represents a particular consumer response and look for the policy classes that can be expected to generate that response.

Policies That Increase the Cost of Automobile Travel Relative to Travel by Other Modes

This class of policies includes increases in both the fixed and operating costs of automobile travel, increases in the costs of storing the vehicle at destinations, and decreases in the costs of nonautomobile modes of travel. It is associated with the most comprehensive set of consumer responses of any of the seven policy

Table 1. Energy policy classes and their policy components.

Class	Component
1. Policies that increase the cost of automobile travel relative to travel by other modes	Increase in fuel cost, either by tax or market rises in price Increase in automobile storage (parking) costs via parking fees Increase in automobile purchase price by tax or market price increases Increase in the time cost of automobile travel by enforced lower speed limits Reduced costs of other modes by changes in production technology or direct fare subsidy
2. Policies that limit the supply of gasoline available to travelers	Government imposed fuel rationing systems Market shortages (probably caused by external events or price controls) Restrictive queuing process for gasoline purchase (i.e., odd and even days)
3. Policies that physically limit the use of automobiles	Enforced automobile-free zones at major trip destination zones Highway lanes reserved for buses only Drastically reduced parking capacity at major trip-destination zones More restrictive driver licensing regulations
4. Policies that change the characteristics of automobiles	Excise tax or rebate system based on fuel efficiency Enforced fuel-efficiency regulation on new vehicles Annual registration fees based on fuel efficiency Encouragement of new technology
5. Policies that change characteristics of nonautomobile transportation systems	Subsidies for expanded or improved existing transit systems Encouragement of vanpooling by subsidy, graduated tolls, or graduated parking fees Encouragement of new systems such as demand-activated minibus systems or people movers
6. Policies that affect the geographic distribution of trip ends	Encouragement of industrial parks Encouragement of large commercial centers Encouragement of higher-density residential development in close proximity to work and shopping centers
7. Policies that attempt to directly change travel patterns	Modified workweek Staggered work shifts

Table 2. Policy-response matrix.

Policy		Response					
Class	Component	Reduced Travel	Trip Purpose Change	Mode Shift	More Efficient Automobiles	Relocation	Peak-Hour Shift
1	Gasoline tax, tolls, parking fees, high automobile prices, speed limit, transit fare subsidy	Yes	Yes	If available	For gasoline tax only	Possibly	
2	Rationing, shortage policies	Yes	Yes	If available	Yes		
3	Automobile-free zone: exclusive lanes, limited parking	Not clear		If available		Possibly	
4	Excise tax, distance regulations, technical change, registration fees on efficiency				Yes		
5	Transit subsidies (service) encourage vanpooling	Possible increase		Slight			
6	Density: industrial or office parks, land patterns	Yes		If available		Yes	
7	Modify workweek, staggered shifts	Not clear	Yes	Possibly			Yes

classes. In the most general sense, policies that increase the cost of automobile travel will cause an overall reduction in travel, all other things being equal. This may result from a shift from single-purpose trips to multipurpose trips, elimination of marginal trips, and, in the extreme case, relocation so that necessary trips are shorter. If alternatives to automobile travel are available, some of the reduction in automobile travel may be countered by an increase in travel by other modes—a mode-shift response. This, of course, is dependent on the quality of services offered by the alternative modes.

Perhaps more important, policies that increase the fixed or operating costs of automobile travel (i.e., increased gasoline prices or increased vehicle prices) may result in consumer decisions that reduce those costs without requiring a reduction in travel. An example of this kind of response is the purchase of more fuel-efficient automobiles that may also have lower fixed costs (such as purchase price, registration fee, and insurance premiums). Looked at from this perspective, policies that encourage more fuel-efficient automobiles counter policies that encourage reduced travel or shifts to mass transit, even if high-quality transit service is available.

In order to predict the impacts of this class of energy policies, it is important to specify the responses more carefully. Reduced travel can result from a modified pattern of trip generation and trip length, both of which are dependent on the cost per vehicle kilometer. Thus, the increased cost of fuel must be modified by increases in fuel efficiency. Also, changes in the distribution of trip purposes will be dependent on the relative value of trips of different purposes and the cost per vehicle kilometer of travel. Relocation will occur if the change in the cost of travel is sufficient to overcome the benefits of the existing location and if alternative desirable locations are available. Similarly, mode-shift decisions are dependent on the availability of alternatives and on the relative levels of service of automobile vis-à-vis the alternatives.

Policies That Limit the Supply of Automobile Fuel Available to Travelers

The amount of automobile fuel available to travelers may be limited by a number of factors, such as publicly imposed fuel-rationing systems, market shortages resulting from disequilibria in the supply and demand structure of gasoline (a situation that usually results from some outside stimulus such as the embargo or publicly imposed price controls), or limitations on the purchase of fuel by forced queuing processes or maxima or minima limits on the amount of fuel to be purchased at one time. In many ways, this class of policy actions is an extreme case of the first class, which increased the cost of automobile travel, and the responses are also similar. If the limits on supply are severe, travel will undoubtedly be reduced, although the likelihood of mode shift is probably greater since satisfaction of all demand for automobile travel becomes impossible. People will tend to use more efficient automobiles in order to get more travel out of the available fuel. Unnecessary or marginal trips will be eliminated, and the number of multipurpose trips will probably increase. Necessary travel in excess of that allowed by available automobile fuel will be forced to other modes. Relocation is a distinct possibility if the situation is persistent.

Prediction of the impacts of this class of policies is similar to that for the previous class. There are, however, two major differences. First, the estimated shift from automobile to other modes of travel will be dependent not only on relative monetary costs of the various modes but also on the time and psychic costs of queuing and waiting to buy the limited amount of gasoline available. Also, after the amount of fuel available is adjusted to account for more fuel-efficient automobiles, it will be necessary to determine the excess amount of travel demand over that allowed by automobile. This excess will probably be shifted to alternative modes.

Policies That Physically Limit the Use of Automobiles

A number of energy-related policies attempt to limit the use of automobiles by prohibiting them in specified areas. Automobile-free zones have been implemented in several cities, and severe limitations on the actual number of parking spaces have also been proposed. In both cases, the intent is to shift travel from automobiles to other modes. If the use of automobiles is prohibited at important destination points, travelers will have to use other modes of travel to reach destinations. This assumes that alternative modes of travel exist and that the quality of services that they provide is reasonably high. It also assumes that there are no significant alternative destinations that are not encumbered by the automobile restrictions. For the most part, these assumptions can only hold for certain kinds of work trips since it is unlikely that all nonwork destinations can be covered by the restrictions.

Prediction of consumer response to policies of this type is difficult. If alternative transportation modes exist, it can be assumed that a large portion of work trips can be diverted from automobiles if the cost of the alternatives is not greatly higher than that of automobiles. These policies will probably not generate a reduction in travel. In fact, the opposite may occur. Automobiles may be left home, free for other uses during the day. For nonwork trips, consumers may opt to drive to competing nonrestricted destinations that are farther from their origin than are the restricted destinations. Another possible response, particularly likely if transit service is nonexistent or of low quality, is the relocation of employment and commercial establishments out of the restricted area in order to facilitate automobile commutation. In sum, the impacts of this type of policy will have to be estimated on the basis of the relative attraction of the restricted destination and the availability of alternative modes of travel.

Policies That Change the Characteristics of Automobiles

A number of policies have been proposed or implemented that attempt to reduce fuel consumption by changing the fuel-efficiency characteristics of automobiles. Examples include the graduated excise tax or rebate system proposed in the national energy plan, the specified fuel-efficiency requirements for new automobiles established by the National Energy Conservation Act of 1974, annual registration fees based on fuel efficiency, and policies to encourage research into more efficient automobile technologies. For the most part, these policies will have only one major impact on transportation consumers—they will begin to drive more efficient vehicles. There is no reason to expect these policies to generate a reduction in travel (in fact, they might generate an increase in travel as the cost per kilometer of travel decreases, unless savings are completely offset by increases in fuel cost), shift in mode of travel, or a shift in the distribution of trip purposes. Indeed, this class of energy-related policies, by itself, will have relatively little impact on the overall transportation situation.

Policies That Change the Characteristics of Nonautomobile Transportation Systems

Policies in this class generally take two forms: those aimed at expanding and upgrading existing transit systems and those aimed at encouraging the development of new systems, such as carpooling, vanpooling, or demand-activated minibus systems. In all cases the expected impact on transportation consumers is the diversion from automobile travel to travel on these alternative modes. In some cases, where access to transportation services is significantly increased, overall travel may actually increase as consumers use the expanded or new systems to make trips that they would otherwise not have made. These policies will only have a noticeable impact on transportation energy consumption if they generate a significant diversion from automobile travel. However, it is unlikely that this will occur without the concomitant implementation of other policies that actively discourage automobile use.

Policies That Affect the Geographic Distribution of Trip Ends

Policies in this class are basically land-use control activities aimed at creating more compact patterns of development that require less travel for both work and nonwork purposes. If these policies are effectively implemented, they would cause some relocation of both jobs and residences and reduce total travel. If alternate modes of transportation were developed in conjunction with the land use policies, the result could also be a substantial shift from automobile to alternative modes of travel.

Policies That Attempt to Directly Change Travel Patterns

These policies generally attempt to change the number and timing of work trips by modifying work schedules. Examples are staggered work shifts and four-day workweeks. The former policy will distribute peak travel loads over a longer period of time and thus reduce congestion, improve traffic flow, and reduce fuel consumption. This, however, may have perverse results as it also tends to reduce the cost of automobile travel and may cause more people to travel by automobile or to extend the length of their commute. The result may well be a net increase in total travel.

The implementation of four-day workweeks, even with a constant level of actual work time, is intended to reduce the number of weekly work trips from 10 to

8 per person, thus reducing the energy consumed by work commutation. Again, the results may be perverse. Work trips might be reduced, but the increased amount of leisure time may generate more nonwork trips. Another possibility is that workers will find it possible to have two jobs, and thus the number of work trips will increase. Altogether, the net impact on total travel is quite uncertain. It is unlikely, however, that policies in this class will have any impact on mode shift or automobile efficiency.

The previous pages have provided a qualitative discussion of the ways in which consumers of transportation services might respond to various energy-related policies. It is clear that there is a wide variety of such responses and that not all of them will result in a shift away from the use of automobiles. They may not actually generate a reduction in total travel. Still, in order to effectively anticipate the consequences of implementing the various energy policies, it is important to be able to predict those consequences as systematically as possible. Ideally, this would be done by using rigorous models of transportation systems. The next section discusses basic transportation demand-forecasting models and examines their capability for dealing with the kinds of responses to energy policies described above.

DEMAND FORECASTING

Classical demand-forecasting models can be classified as aggregate or disaggregate and sequential or simultaneous. All of them use socioeconomic variables to model the decision-making process of trip makers. The socioeconomic variables act as surrogates for the true behavioral phenomena of trip-making decisions. As in all modeling of social phenomena, a trade-off must be made between the number of variables included in the modeling process and the economic feasibility of collecting the required data for corroborating the model. This limits the number of variables used and makes it difficult to apply the models to situations other than those for which they were originally designed.

Aggregate models differ from disaggregate models in that they use as variables measures of the mean value of specific characteristics for the geographic units that make up the study area. Disaggregate models, on the other hand, use as variables specific characteristics of individual trip makers. Simultaneous models use a single-step process to forecast trip origin, destination, and mode of travel. Sequential models use the classical four-step process of trip generation, distribution, mode choice, and trip assignment. The latter is the most commonly used in urban transportation planning; however, recent studies have combined two or more of these steps.

The first step in the analysis is to review potential linkages between consumer responses and demand-forecasting techniques. Table 3 is similar to Table 2, but the entries in the various cells indicate whether or not existing demand-forecasting techniques are capable of modeling the particular policy response. For this analysis, each response will be discussed. It is hoped that this procedure will eliminate the chance of considering a policy in a manner that examines only one of several possible trip maker's responses. Furthermore, the relationship of the matrix to demand forecasting seems more consistent when viewed along the response line than along the policy line.

Reduction in Travel

Reduction in travel can result from reduction in trip rates or reductions in trip length. The former response falls in the trip-generation phase of the traditional demand-forecasting process. Trip rates used in disaggregate trip-generation models are based on historical data and may not be appropriate for predicting the effects of energy policies that are not simply extensions of past behavior. Trip-generation techniques that use regression equations that include independent variables to represent transportation costs relative to income might be suitable for predicting responses to policies that affect the cost of automobile travel. Simultaneous models might be capable of dealing with this response more readily if the response was the result of policies that limit automobile use or change the characteristics of the transit system. Responses to changing land-use patterns would follow naturally from the exogenous land-use forecasts. Some aspects of the responses to all policies that cause reduced travel can be seen in the interzonal attractiveness factors included in most trip-distribution models.

The work schedule can be modified by shifting the workweek or staggering the working hours. Since most forecasting efforts are based on a typical workday, reducing the number of working days does not change the daily forecast of work trips even though weekly or annual travel demand might change. Nonwork trips, however, may change substantially.

In all of the above, the elasticity of demand for travel with respect to cost of travel is assumed to hold constant over the entire range under consideration. If this assumption is inadequate, it is unlikely that any of the currently existing models can be used to forecast the responses to policies that increase the relative price of automobile travel.

Changes in trip lengths are generally included in the trip-distribution phase of the forecasting process and are based on the relative location of trip origins and destinations. Assuming that origins do not change (at least for home-based trips), changes in trip length will reflect changes in the desirability of various destinations. Trip makers attempting to make a single trip for several purposes will look for a destination that has more shops or activities than they would if they were making a single-purpose trip. Also, trip makers who have budgetary or fuel constraints will select nearby destinations, even if these destinations are slightly less desirable than alternative destinations at a greater distance. Given appropriate data on types and desirability of various potential destinations, current trip-distribution models could accommodate trip length changes.

Change of Trip Purposes

This response falls primarily in the trip-generation phase of transportation demand forecasting. The response (as Table 2 suggests) is the potential consequence of three classes of energy policies. As a response to the first (increasing the relative cost of automobile travel), it can be modeled in the framework of a set of trip-generation equations that are stratified by purpose and include travel cost as independent variables. Few, if any, current trip-generation models can readily be used.

Modifying work schedules (especially shortening the workweek) introduces the possibility of long weekends. Existing modeling processes have rarely, if ever, addressed the question of weekend travel, primarily because work trips have dominated peak-period travel, and peak-hour capacity and demand have always been the primary forecasting concerns. The change in the trip-purpose distribution as a result of changing

Table 3. Forecasting models and responses to energy policies.

Forecasting Model Component	Reduce Travel	Change Trip Purpose	Mode Shift	More Efficient Automobiles	Relocation	Peak-Hour Shift
Trip generation	In travel cost, in socio-economic variables	In travel cost if generation is stratified by purpose		In travel cost		
Trip distribution	In interzonal impedance		For land use policies	In interzonal impedance	May change trip rates	
Mode choice			For the cost, service levels, and transit availability	In relating costs		
Trip assignment						Change in peak-hour factor
Exogenous forecasts					Land use, employment, or population forecasts	Independent prediction

the workweek is a new area for research.

Mode Shift

The classical demand-forecasting process is best suited to address this response. Regardless of whether the process is aggregate or disaggregate, simultaneous, or sequential, most forecasting models include a modal-choice component. The ability of the models to deal accurately with this response, however, is dependent on the type of policy being studied. Increases in the relative price of automobile travel and changes in the characteristics of the nonautomobile transportation system can readily be modeled (1-3), again assuming that the elasticity of demand with respect to price and service continues to hold. The modal-shift response to physical limitations on automobile use in certain areas can be modeled if there is an alternative mode of travel available and if the area of concern can be considered as separate analysis zones.

Assessment of modal shift as a result of changing land-use patterns, assuming the availability of alternative modes, is the central point of trip-distribution and modal-choice models.

Modal shift as a result of modification to daily work schedules can indirectly be assessed on the supply side by extending the peak period and reducing peak-hour factors. However, only periodic monitoring can produce the data necessary to carry out model adjustment. Shortening the workweek might have tangible impacts on mode choice that cannot currently be modeled. It is also likely to be accompanied by lengthening of the workday, which, in turn, might increase peaking characteristics because of shorter options on starting and quitting times. This consequence is equally applicable to highway and transit, but has little impact on modal choice.

The longer workday leaves less time for trips for other purposes in the evening but provides more time on weekends. Some changes in mode choice might take place as automobile commuters may decide to leave their automobiles home to be used for other purposes. Alternatively, some transit commuters might opt to drive due to reluctance to use transit during late hours.

More Efficient Automobiles

Policies that encourage the use of more efficient automobiles have the effect of reducing the cost of automobile travel vis-à-vis other modes. This can be incorporated in the trip-generation, trip-distribution, and mode-choice segments of the demand-forecasting process.

Relocation

This response shows up in one of two ways: residential relocation or employment relocation. The prevalence of one or the other is a function of the type of residential area. Either of the two types of relocation can be given consideration in the process of forecasting household and employment location. Activity allocation models include variables such as budget constraints and transportation costs, as well as land availability and existing land patterns. Clearly, this type of analysis should include the relocation response to energy policies, but it is generally considered as exogenous to the transportation demand-forecasting process.

Peak-Hour Shift

This response (as Table 2 suggests) is the result of modifying the work schedule. It is an intermediate response and may or may not induce other responses. Shortening the workweek but lengthening the workday only shifts peak periods. However, longer workdays may reduce second-job opportunities and thus change travel patterns somewhat. On the other hand, three-day weekends may encourage second jobs. None of these secondary responses can be predicted by the traditional travel-forecasting models. In fact, peaking is usually an input into the process rather than an output. Thus, peak-hour shifts must be considered exogenously to demand forecasting.

MODAL SHIFT AS A POLICY RESPONSE

Past and Current Work

Investigation of modal shifts that result from energy-related transportation policies is relatively new, and only a limited number of studies have emerged. Some of these studies use data collected during the 1974 energy shortage to assess the impact of the shortage on highway and transit travel, to draw conclusions regarding modal shift and elasticity of demand with respect to gasoline prices, and to suggest areas for further research (4-8).

Peskin, Schofer, and Stopher (7) report on a survey conducted in a northern suburb of Chicago in the spring of 1974. They found no increase in the use of transit during the shortage and showed that work trips were the most resistant to change. The availability of gasoline, not its price, was found to be the determining factor in the decision to make a trip. Keck (5), in a survey of three small urban areas in New York during and immediately after the energy crisis, showed that automobile users responded to the shortage by reducing speed, combining nonwork trips, and, to a lesser extent, by carpooling. Hartgen (4), in comparing the data from the two previous surveys, showed that the joint elasticity of price and availability for work trips in both studies was -0.1. The elasticity for nonwork trips in the Chicago study was -0.25.

Nizlek and Duckstein (6) studied transit ridership in Tucson, Arizona, during the energy shortage and concluded that "there was negative correlation between gasoline sales and transit ridership and that the demand for gasoline was highly inelastic."

Sanger (8) studied the effect of employment density on the type of response to the short-term energy shortage. He pointed out the logical ways in which responses will differ with employment density and the existing level of transit usage; however, he concluded rather heuristically that, if the supply of gasoline fell 10 percent short of the demand, 60 percent of the shortfall would be made up by increased transit usage (mode shift), 20 percent by carpooling, and the remainder by a reduction in total trips.

Other studies dealt more directly with the modeling of modal choice under the gasoline shortage. Crow and Savit (9) used three different models to predict travel demand between pairs of northeastern cities in light of price increases for gasoline and reductions in speed. All three models used cost, travel time, and service frequency, and all three yielded the expected results in terms of modal shift between automobile, rail, bus, and air travel. These models, however, are not likely to be appropriate for intraurban conditions. Furthermore, although the paper presented results for increases of 50-100 percent in the price of gasoline, the study considered a 200 percent increase. Although they recognized that they had assumed only out-of-pocket costs, and that, in the case of the automobile, gasoline costs amount to about 88 percent of that cost, they expressed no concern for the validity of the model under extremely different pricing conditions.

Navine (10) presented a utility-based modal-split model as well as a gasoline-rationing model based on a trip-purpose preferential model. He concluded from the first model that the percentage of modal shift is approximately one-fourth of the percentage of gasoline price increases. However, his results suggest a threshold below which an increase in the price of gasoline would not produce any tangible change in transit usage. Another intuitive result is the influence of trip length on modal shift. The gasoline-rationing model indentifies those trip makers who have the opportunity to make a modal choice and assumes that they will make modal shifts only in lower-priority trips (social or recreational), not in work trips.

The most conscientious effort at modeling the impact of gasoline shortages is a current study (of the Tri-State region) by the State University of New York at Stony Brook (11, 12). The automobile trip-fraction percentage is regressed against income and a weighted cost of intercounty trips. The cost function includes time, fare, and operating cost. Automobile operating cost includes, in addition to gasoline prices, variables that represent automobile occupancy and gasoline efficiency. These variables, in turn, are assumed to be functions of gasoline prices. Expressions for automobile occupancy and gasoline efficiency were developed in which the function becomes asymptotic to upper and lower bounds. To account for unavailability of gasoline, a search time that is inversely proportional to the probability that a station will have gasoline and a queuing time that reflects the reduced number of operating service stations are included in the total trip time.

This model, however, is somewhat limited. It predicts only changes to modal choice and fails to simulate the effects of fuel shortages on trip generation and trip length. In addition, it is calibrated on large trip interchanges (counties). Finally, a minor mechanical error results from leaving nongasoline automobile cost as a constant and not as a function of automobile occupancy.

This discussion sheds some light on the state of the art in transportation demand forecasting involving energy shortages, transportation policies, and modal change. Most studies have dealt with modal shift as a result of gasoline price increases and assumed constant elasticities. Gasoline rationing or unavailability have each been addressed in only one study. The impact on modal choice of policies such as increased prices of automobile travel, limits on automobile use, and changes in characteristics of nonautomobile travel is absent from the literature.

Approach for Future Work

Table 2 shows modal shift to be a possible response to a number of transportation policies related to a gasoline shortage. The first policy that might generate this response is increasing the relative price of automobile travel, for instance by increasing tolls, parking fees, or prices; by reducing highway speed; or by subsidizing transit fares. With the exception of automobile prices, all costs are considered out-of-pocket costs and are represented in most existing modal-choice models. So far, however, these cost components have been modeled independently of each other. This results in little error if conditions are stable and the costs continue to hold the same positions relative to each other. If a drastic change in the relative costs occurred, though, the independent modeling of all of these costs might cause excessive error. A case in point is the price of gasoline and fuel cost per vehicle kilometer or the high taxes on a non-fuel-efficient vehicle. Therefore, some of these variables must be substituted for by nested functions of other variables in the expression, possibly in the manner used in the Stony Brook model (12). The expression, however, must be incorporated and calibrated within a utility-based modal-choice model.

Limits on the availability of gasoline can be divided into two broad types: government control (rationing) and market control (scarcity). Rationing implies a limited amount of gasoline (G) available per registered automobile. This, in turn, suggests a limit to the distance that a vehicle can travel. The number of trips (NT) the vehicle can make, then, is a function of trip length (TL) and automobile efficiency (AE).

$$NT = (G \times AE)/TL \quad (1)$$

Upper and lower bounds on TL and AE can be established from observation.

In order to apply this expression, assume first that the gasoline shortage has become sufficiently severe to require rationing. Therefore, assume that all trips that can possibly be made by automobile will be made by automobile, since demand will be much higher than supply. The remaining unsatisfied demand will be forced to shift to available alternative modes. It is more difficult, however, to determine which trip purposes will continue to be served by automobile and which will be shifted to other modes. The Chicago and New York State surveys differ considerably in their findings with respect to the trip purpose most affected by an energy shortage; the first found work trips most affected but the second found them least affected. The Chicago suburb would seem to be more representative of urban conditions. If we accept the Chicago findings, it is possible to determine in gross fashion not only how many but also which trips would be diverted to transit.

The second case, market control, can be modeled in a manner similar to that resulting from an increase in the relative price of automobile travel, but additional terms in the expression of the relative utility of the automobile mode are required. These terms correspond to the searching and queuing time necessitated by the scarcity of gasoline. The expression for the automobile time (T_A) might become

$$T_A = T_t + f(T_s) + g(T_q) \qquad (2)$$

where

T_t = travel time for automobile (A) mode,
T_s = search time for A mode, and
T_q = queuing time for A mode.

Limits or constraints on automobile use can, in general, be modeled on the supply side in the assignment phase of the forecasting process. This would suffice if the area were very small (one street or a number of separate streets). If the limitation applies to a sizable contiguous area, however, the most appropriate procedure is to consider the areas as a separate zone or zones and to heavily penalize automobile time and cost in that zone, leaving only other modes as feasible alternatives.

Transit subsidies and fare reduction are already part of most mode-choice models. Transit subsidies improve the quality of the transit system, and this in turn will be reflected in the travel time by the transit mode. Encouragement of paratransit, such as van-pooling, can be modeled in the case of an energy shortage in the form of an additional mode with its own peculiar characteristics and surrogate variables. A disaggregate modal-choice model of the logit formulation can conceivably accept another mode with little modification.

Changes in land-use patterns have always been an integral part of the demand-forecasting process, although usually as exogenous input to the other models. Unless changes in land use occur in conjunction with changes in the availability of transit, it is unlikely that such changes will, by themselves, result in substantial mode shift. An exception to this is where substantial redevelopment occurs around existing transit facilities, but this is likely to occur only over a relatively long period of time.

Finally, policies that change travel patterns (i.e., modified workweek or staggered work hours) can be expected to have a slight, but uncertain, impact on mode choice. The impact is dependent on the relative quality of transit vis-à-vis automobile and on the impact of the changes in reducing congestion. At the current time, the effects of such policies on mode choice cannot be modeled.

CONCLUSION

Various levels of government may implement many different policies to combat a gasoline shortage. Each of these policies may produce one or more travel responses. Modeling these responses in order to predict travel behavior and system performance as a result of these policies is a relatively new area for research in urban transportation demand forecasting. Modal shift is one of the most probable and highly important responses. Previous work has attempted to address this response and at least one study has attempted to model modal choice as a result of limited fuel availability. However, more work is required to improve the sensitivity of these mode-choice models to energy-conservation policies and to integrate the improved models into the total transportation demand-forecasting process.

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