3537

ENERGY SENSITIVITY OF TRANSPORTATION PLANNING TECHNIQUES

by

Debra Grist
Graduate Assistant

and

Michael J. Demetsky
Faculty Research Scientist

(The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the sponsoring agencies.)

Virginia Highway & Transportation Research Council
(A Cooperative Organization Sponsored Jointly by the Virginia Department of Highways & Transportation and the University of Virginia)

In Cooperation with the U. S. Department of Transportation
Federal Highway Administration

Charlottesville, Virginia

June 1981
VHTRC 81-R51

3538

TRANSPORTATION PLANNING RESEARCH ADVISORY COMMITTEE

MR. R. C. LOCKWOOD, Chairman, Transportation Planning Engineer, VDH&T

MR. E. D. ARNOLD, JR., Research Scientist, VH&TRC

MR. D. W. BERG, Assistant Public Transportation Engineer, VDH&T

MR. G. W. BROWN, Assistant City Manager, City of Martinsville, City Hall

MR. G. R. CONNER, Assistant Rail Div. Admin., VDH&T

DR. DONALD R. DREW, Prof of Civil Engineering, VPI & SU

MR. JAMES C. ECHOLS, Executive Director, Tidewater Transp Commission

MR. TOM FAULKNER, JR., Civil Engineering Department, VPI & SU

MR. D. R. GEHR, Regional Transp Engineer, VDH&T

MR. J. N. HUMMEL, Chief, Planning & Engineering Division, Arlington Department of Public Works

MR. D. E. KEITH, Resident Engineer, VDH&T

MR. J. D. PAULUS, Planner I, Transportation Peninsula Planning District Comm.

MR. J. K. SKEENS, Assistant Urban Engineer, VDH&T

MR. F. L. TODD, Assist Planning & Research Engineer, FHWA

ABSTRACT

This report first identifies the behavioral phenomena that underlie traveler responses to the cost and supply of transportation modes and services. Observations on individual travel behavior are aggregated to indicate land use and developmental changes that are anticipated to occur. These findings establish suggested future scenarios from which the requirements that show the ability of transportation planning procedures to address the effects of energy prices, conservation policies, and energy shortages on individual and aggregate travel behavior are derived. Recently proposed methodologies are evaluated and critiqued for their ability to solve the problem. A philosophical interpretation relating energy considerations and transportation planning methods is given in which a mathematical framework is provided for direct application with data or for qualitatively organizing the problem.

3540

ENERGY SENSITIVITY OF TRANSPORTATION PLANNING TECHNIQUES

by

Debra Grist
Graduate Assistant

and

Michael J. Demetsky
Faculty Research Scientist

INTRODUCTION

Current transportation planning techniques were derived from methods developed between 1950 and the early 1970's, a period in which energy was abundant and cheap. There is concern that these procedures for forecasting travel, which are based on previous behavior, cannot be extended to account for long-range effects on travel of increases in the price of energy, the adoption of conservation policies, and energy shortages.(1) Since the United States continues to be a substantial importer of petroleum and with the price of gasoline continually increasing, an analysis to consider modifications to the travel forecasting element of the transportation planning process was needed. This analysis of the so-called 3-C process needs to establish the ability of trip generation, trip distribution, and modal split procedures or substitute methods to forecast travel demand as individuals alter their lifestyles in response to an energy-constrained environment.

Since useful travel forecasting procedures must be easy to understand and reasonably straightforward to apply, and be rapidly disseminated, procedures based on existing approaches appear to be appropriate. Accordingly, this study interpreted data on travel behavior changes during the 1973-74 and 1979 energy shortage periods to recommend criteria for reviewing or redesigning trip generation, trip distribution, and model choice procedures into an energy-sensitive approach to travel demand forecasting.

This report first identifies the behavioral phenomena that underlie traveler responses to the cost and supply of transportation modes and services. Observations on individual travel behavior are aggregated to indicate land use and developmental changes that are anticipated to occur. These findings establish suggested future scenarios from which the requirements that show the ability of transportation planning procedures to address the effects of energy prices, conservation policies, and energy shortages on individual and aggregate travel behavior are derived.

Recently proposed methodologies are evaluated and critiqued for their ability to solve the problem. A philosophical interpretation relating energy considerations and transportation planning methods follows in which a mathematical framework is provided for direct application with data or for qualitatively organizing the problem.

BACKGROUND

Travel Behavior Modifications

Since travel behavior patterns evolve over time, an analysis of how people respond to the travel time, cost, comfort, and reliability of a transportation system does not entirely measure changes in travel behavior. Life cycle, social mobility, and geographic mobility are also influences of change. Typical changes in travel behavior include trip chaining, trip frequency, shifts in modes, limiting activities, and purchasing energy-efficient automobiles.(2) Studies of the 1973-74 crisis have shown that only travelers with some degree of flexibility in their behavior, i.e., travelers exhibiting high automobile ownership and income levels and thus large amounts of discretionary travel, will conserve. The low income and low automobile ownership traveler is not able to alter travel patterns without changing his lifestyle.(3,4)

It is not clear what effect large increases in fuel prices have on travel. During the 1973-74 embargo, the demand for gasoline was inelastic to price. Availability was the key to reductions in travel. However, there may be a threshold price above which demand becomes elastic. Even in areas where the level of transit service was high, it was not utilized or viewed as a viable alternative during the shortage.

During the 1979 crisis people took small, frequent actions to change their travel behavior. These included driving slower, getting tune-ups, combining shopping trips, limiting activities, and reducing discretionary travel. Actions such as riding transit, car pooling and purchasing more fuel-efficient cars were viewed as long-range changes.(5,6) A post-1979 survey conducted in Virginia showed limiting activities and switching modes of travel as the most frequent responses to the increasing price of gasoline.(7)

Thus, experiences with energy shortages and price increases do not show definite changes in travel behavior and activity participation. In the short term, people continue to pursue previously established patterns. Only in the long run will changes such as relocation and the purchase of energy-efficient vehicles take place. Most real travel changes necessitated by the energy crises of the 1970's were short-lived.

Aggregate Development Patterns

The idea that a relationship exists between transportation and land use is not new. Theories such as the concentric zone theory, the sector theory and the multiple nuclei theory explain this relationship.[8] The growth patterns of cities in the United States show that transportation systems have played a major role in urban development. In the early growth stages, transportation networks were in an elementary form. With technological innovations and improved transportation systems, individuals were able to work, shop, and participate in activities away from their residences.[8-11]

Travel characteristics are reflected in the urban form that develops. Trip length, trip frequency, mode choice, and vehicle miles travelled are related to household or neighborhood characteristics, highway infrastructure, availability of public transportation, distance between activities, and distance from the central business district. The distance between activities is directly related to the cost of travel and seems to have the greatest influence on travel behavior.[12] The urban environment created by cheap and abundant fuel supplies will change as the cost of travel increases and individuals are forced to travel less.

In order to understand the significance that decreases in travel have placed on the urban transportation planning process, scenarios are developed which reflect a costlier energy environment, shortages in the supply of gasoline, and less travel. These scenarios synthesize anticipated changes in travel behavior and associated actions taken by government and private agencies. From these scenarios, criteria for evaluating the urban transportation planning process are developed.

REQUIREMENTS OF A PLANNING METHODOLOGY

The individual travel reactions to energy constraints which were observed during the energy-constrained environment of the 1970's are listed in Table 1.[2-7] Over the long run the net effect of the behavioral changes cited in Table 1 appears to be a decrease in travel demand. Individuals will car pool more for all types of activities, use public transportation where there is a viable system, trip chain, and even purchase more energy-efficient automobiles. Individuals will shop, work, and participate in activities closer to their residences. Within a longer time span, moving closer to employment centers may become a viable alternative.[2-7]

3544

Table 1

Impacts of Energy Constraints on Travel

Constant Automobile Ownership Levels — Changes in Travel

	Work Trips	Non-Work Trips
Trip maker	Car pooling	Trip chaining
Reactions	Mode shifts	Trip frequency
		Car pooling
		Mode shifts

Changes in Activity System — Determinants of Travel

Activity	Automobile Ownership	Residence and Work Site Interrelationships
Location	Switch to smaller and more efficient vehicles	Move closer to employment
Frequency	Reduce number of automobiles in the household	Change place of work

Government can pursue both short- and long-term programs to expedite energy conservation and hence modifications in travel behavior. Short-term actions which can be implemented in three to five years include the following.

1. Actions to discourage automobile work trips. These include incentives to use high-occupancy vehicles combined with disincentives to use automobiles.

2. Incentives for alternative work schedules. Flexible work hours and compressed work weeks reduce automobile work trips and spread out the peak periods.

3. Better travel information to the public. Transit route schedules and maps and car pooling assistance are two appropriate measures.

4. Data on gasoline supply and consumption.

5. Expanded transit services. The use of school buses for corridor and park and ride service and longer peak service could be implemented.[13]

6. Enforcement of speed limits.

7. Support for transit operating deficits.

8. Gasoline pricing or rationing.

9. Traffic improvements through transportation systems management.[13,14]

The long-term policy should deal with decreasing energy-intensive travel. Expansion of transit service and land use planning are policy options available at the local and regional levels. The state can accelerate shifts to more energy-efficient automobiles through regulating vehicle registration fees. The government can continue to provide funding for transit projects; consider gasoline rationing, since modest price increases have not discouraged travelers from consuming available gasoline; and promote the use of energy-efficient automobiles and alternative fuels.[13]

Future Scenarios

Travel demand has generally increased throughout the United States from 1970 to 1981, while gasoline consumption has been on a downward trend.[15,16] However, the periods where energy shortages occurred from May 1973 to May 1974 and from May 1979 to May 1980 showed decreases in travel over the previous periods. In order to link these fluctuations in travel and reduced fuel consumption to the urban transportation planning process, scenarios are developed which reflect a costlier energy environment, shortages in the supply of gasoline, and less travel.

The scenarios are based on observed changes in travel behavior and on government policies. They are developed in order of the least responsive to the most severe. Each includes the temporal context in which it will take place. The first one assumes that individuals will continue with the immediate changes they made during the 1979 crisis. This is a short-term scenario in which individual-action profiles include car pooling, trip chaining, switching modes, and reducing trip frequency.

The second scenario is a change in automobile ownership levels. It is medium-range in terms of the temporal context and includes such actions as purchasing more energy-efficient automobiles or even decreasing the number of automobiles in a household. The more energy-efficient automobiles are utilized in serving dispersed land uses.

The third scenario is also medium-range. Alternative work hours and compressed workweeks lead to greater levels of conservation. Car pooling and mode shifts are important actions taken.

The fourth scenario has individuals moving to live closer to their employment centers or getting work closer to their residences Temporally, it is long-run. Increases in energy costs create increases in travel costs, leading to mode shifts and a denser population. Here, individuals shop and participate in recreational activities closer to their place of residence. Public transportation is of great importance.

The fifth scenario is based on the worst energy environment. In the long-run, gasoline rationing is a must. A very dense population is created and only essential trips are made.

The sixth scenario occurs over the long-run. Deregulation of oil occurs and technological innovations in fuel are competitively priced.

Criteria that must be met for a planning methodology to be sensitive to increasing energy prices and shortages in energy supplies can be extracted from these scenarios. Policies enacted by government and employers in response to an energy-constrained environment will create changes in travel behavior by consumers. Certain consumer responses to a costlier, energy-constrained environment, without direction from government or employers, will also occur. These consumer reactions will create changes in travel demand. The anticipated measures of change are shown in Table 2 and are proposed to test model sensitivity to energy considerations. Table 2 shows the travel models and specifies model outputs that are associated with consumer responses to energy constraints. The table also gives the particular policy actions that encourage the specific consumer responses.

Table 2

Energy Sensitivity Criteria

Policies or Actions	Consumer Response	Travel Models	Measure of Change Criteria
A. Government			
Decrease transit fares	Increase transit ridership	Trip generation, trip distribution, mode split	Decrease in auto trips per household, decrease in miles travelled, increase in transit ridership, increase in travel time
Charge for parking	Car pool, shift mode, change destinations	Mode split, destination choice, auto occupancy	Increase in automobile occupancy rates, increase in transit ridership, origin-destination changes, decrease in auto trips per household
High-occupancy-vehicle lanes	Car pool	Trip generation, mode split, auto occupancy, trip distribution	Decrease in travel time, decrease in vehicle miles travelled, decrease in auto trips per household, increase in automobile occupancy rates, decrease in transit ridership
Auto restricted zones	Change destinations, shift mode	Trip distribution, mode split, urban land use	Origin-destination changes, increase in travel time, increase in transit ridership
Gas tax/gas rationing/odd-even purchase restrictions/Sunday driving ban	Purchase fuel-efficient autos, limit activities, trip chain, shift mode, decrease trip lengths and trip frequency, car pool	Trip generation, trip distribution, mode split	Decrease in average trips per household, decrease in trip lengths, decrease in trip frequency, decrease in travel time, increase in transit ridership
Van pool/car pool programs	Van pool/car pool	Trip generation, mode split, auto occupancy	Decrease in vehicle miles travelled, increase in automobile occupancy rates, decrease in average trips per household
B. Employers			
Four-day work week/Flexible work hours	Change time of travel	Trip generation, trip distribution	Decrease in travel time, decrease in auto trips per household
Van-pool/car-pool programs	Van pool/car pool	Trip generation, mode split, auto occupancy	Decrease in vehicle miles travelled, increase in automobile occupancy rates, decrease in auto trips per household
Charge for parking	Car pool, shift mode	Mode split, destination choice, trip distribution, auto occupancy	Decrease in average trips per household, increase in automobile occupancy rates, increase in transit ridership, origin-destination changes

3548

Table 2 (cont.)

Policies or Actions	Consumer Response	Travel Models	Measure of Change Criteria
C. Consumer Initiated Responses			
	Change residence	Trip generation, trip distribution, mode split, urban land use	Increase in walk trips with increases in density, decrease in per household
	Change work site	Trip distribution, mode split, urban land use	Decrease in trip length, decrease in vehicle miles travelled, decrease in travel time, increase in transit ridership, more self-contained development, origin-destination changes
	Buy fewer autos per household/ purchase fuel-efficinet autos	Trip generation, trip distribution, mode split, destination choice	Decrease in vehicle miles travelled, decrease in auto trips per house- decrease in trip frequency, increase in transit ridership
	Limit activities	Trip generation, trip distribution, mode split	Decrease in auto trips per household, decrease in trip frequency, decrease in vehicle miles travelled, origin-destination changes, increase in transit ridership
	Trip chain	Trip generation, trip distribution	Decrease in trip frequency, origin-destination changes, decrease in auto trips per household
	Decrease trip frequency and lengths	Trip generation, trip distribution	Decrease in vehicle miles travelled, decrease in auto trips per household, decrease in average trip length

EVALUATION OF CURRENT PLANNING PROCEDURES

Current methodologies utilized in urban transportation planning are tested against the criteria given in Table 2. Each of the three stages of demand analysis in the urban transportation planning process is explicitly addressed.

Trip Generation

In trip production models, the independent variables most commonly used are income, automobile ownership, and household size. Trip units are either person or automobile driver. Automobile ownership is a function of income. Vehicle purchases and travel are highly elastic to income; and as density increases, a trade-off between walk and vehicle trips often occurs.[17-20] Several of the measures of change criteria that should be incorporated in the trip generation models are shown in Table 3.

Table 3

Energy Criteria in Trip Generation Models

Consumer Action	Measure of Change Criteria
Increase transit ridership	Decrease in auto trips per household, Increase in transit trips
Car pool	Decrease in auto trips per household
Trip chain	Decrease in auto trips per household
Van pool	Decrease in auto trips per household
Change time of travel, make fewer work trips	Decrease in auto trips per household
Change residence	More walk trips as density increases, decrease in auto trips per household
Buy fewer autos per household	Decrease in auto trips per household, decrease in trip frequency
Limit activities	Decrease in auto trips per household, decrease in trip frequency

A decrease in travel demand occurs as total trips per household decrease. The decrease in total household trips is caused by a decrease in trip frequency, average trips per household, and auto trips per household. Work trips remain fairly constant. However, a big decrease occurs in non-work trips or discretionary travel. This is caused by households decreasing trip frequency, combining trips, and car pooling for more activities. Household characteristics and land use density are major determinants in the amount of total travel reduction. The implication from this analysis is that trip production for an energy-constrained environment can be determined with the current methodologies. It is important to remember that the relationship between trips, land use, and socioeconomic variables is assumed to be stable over time. The accuracy of the forecast of trips generated is dependent on the stability of this relationship. Changes in travel behavior occurred in the 1970's in response to increasing gasoline prices. In the long range, these changes will be reflected in changes in the life-style of the urban traveler. The latter changes will evolve from less travel and locational changes.

Trip Distribution

The change criteria that apply to the trip distribution models in the urban transportation planning process are shown in Table 4. These criteria are origin-destination changes, decrease in vehicle miles travelled, decrease in travel time, and decrease in trip lengths. The implication of these criteria is that the Fratar model and the gravity model can be used in forecasting trip distributions in an energy-constrained environment. As long as the appropriate data are adjusted, the decrease in trip rates needs to be distributed with special consideration to household and development characteristics. Trips decrease, are shorter in length, and are to different destinations. Changing the trip ends, which are a function of the spatial distribution between zones in the Fratar model, can reflect changes in travel demand. The input trip table also needs to be adjusted as origins and destinations change. However, the decrease in trip lengths can not be reflected in the Fratar model. By changing the friction or travel time factor in the gravity model, changes in travel time can be addressed on the zonal level.[19] That individuals are travelling shorter distances to participate in activities can be reflected by decreases in travel time.

Table 4

Energy Criteria in Trip Distribution Models

Consumer Action	Measure of Change Criteria
Increase transit ridership	Decrease in vehicle miles travelled
Car pool	Increase in travel time
Change destination	Origin-destination changes, change in travel time
Change residence/change work site	Decrease in vehicle miles travelled, decrease in travel time, origin-destination changes, decrease in trip length
Buy fewer autos per household	Decrease in vehicle miles travelled
Limit activities	Decrease in vehicle miles travelled, origin-destination changes
Trip chain	Decrease in vehicle miles travelled, origin-destination changes
Decrease trip lengths	Decrease in vehicle miles travelled, change in destinations

Modal Choice

The measure of change criteria previously developed that need to be considered for modal choice are indicated in Table 5. These criteria affect the distribution between zones as well as the percentage modal split. The increase in car pooling for all types of activities warrants additional discussion of automobile occupancy rates. These rates are applied to auto person trips after the modal split. On a high-volume facility, a 10% error in the automobile occupancy rate used can generate an error in volume projections of at least 10,000 vehicles per day. These rates are a function of trip purpose, size of the urbanized area, time of day, travel length in terms of time or distance, trip maker income level, parking costs at the destination point, and major land use areas. Currently, an automobile occupancy rate is determined from the base year data by trip purpose and is used in all planning efforts.[18,20,21] This may not be an accurate reflection of what occurs. Different geographic and socioeconomic areas will also show automobile occupancy rates for each trip purpose. Automobile occupancy will continue to increase for certain types of trips with the increasing price of gasoline, shortages in supply, and the adoption of conservation policies.

Table 5

Energy Criteria in Modal Split Models

Consumer Action	Measure of Change Criteria
Increase transit ridership	Increase in transit ridership, increase in travel time
Car pool	Increase in auto occupancy rates
Shift mode	Increase in transit ridership
Van pool	Increase in auto occupancy rates
Change residence/change work site	Increase in transit ridership, increase in auto occupancy rates
Buy fewer autos per household	Increase in transit ridership, increase in auto occupancy rates

In the next section, four approaches to developing travel forecasts that are sensitive to energy policy and supply are described. The ability of the methods to perform up to the requirements identified in this section is assessed.

RECENT APPROACHES TO ENERGY-SENSITIVE PLANNING

Four approaches for transportation planning that reflect energy considerations have been independently proposed. The first method was used by the Virginia Department of Highways and Transportation to reflect energy policy in transportation planning by adjusting current travel forecasting models. The second procedure consists of a series of household level disaggregate choice models developed for the U. S. Department of Energy by Cambridge Systematics, Inc.[22,23] The third approach is reported in NCHRP Report 229 entitled Methods For Analyzing Fuel Supply Limitations on Passenger Travel.[24] This strategy is based on recent findings from travel behavior research, primarily modal choice. Finally, the Chicago Area Transportation Study (CATS) has used a limited approach that focuses on a way to account for the ultimate energy consumption that results with a certain transportation plan.[25]

Virginia Department of Highways and Transportation's Approach

The Department takes the position that there will continue to be a plentiful supply of energy for transportation fuel, although this fuel supply may not necessarily be oil. The Department acknowledges that if projections of the energy situation for the year 2000 can be made, and if the effects this situation will have on transportation systems and land use can be determined, then the implementation of energy considerations into the planning process can take place. It is assumed here that the energy scene in the year 2000 will result from incremental actions on the part of government, employers, and consumers.

The Department's approach focuses on changes in travel demands that show in the traffic assignment process. Before the traffic assignment is run, a trip table is developed for the following trip purposes:

Home-to-work

Home-to-shop

Home-to-personal business

Home-to-social/recreation

Non home-based

The probable effects of an energy shortage on each of these trip purposes are considered and summarized in Table 6.

The Department contends that an energy policy must be explicitly stated before a planning procedure is developed. This policy will have to include what the course of action will be in terms of energy — specifically, the level of availability for which transportation facilities should be planned. When a level of anticipated fuel consumption is determined, then the necessary assumptions regarding trip length, trip frequency, and mode of travel can be made. This implementation will require incorporating the energy effects into the planning process in terms of travel demand. According to the Department's approach, the effects of the energy situation can be incorporated into the planning process through adjustments made at the trip purpose level. These adjustments are manipulated by the planner and not calibrated. Models are forced to forecast in the anticipated directions by adjustments until the projected level of fuel consumption is obtained.

3554

Table 6

Probable Impacts of Energy on Trip Purposes

Trip Purpose	Change	Planning Model Sensitivity Parameter
Home-to-work	Increase car pooling	Automobile occupancy rate
	Move closer to jobs or mass transit	Socioeconomic and land use data
Home-to-shop	Shop less frequently	Production and attraction rates
	Shop closer to home	Gravity model friction factor
Home-to-personal business	Combine with other trips	
Home-to-social recreation	Fewer recreational trips (frequency of length)	Production and attraction rates
	Increase car pooling	Vehicle occupancy ratios
Non home-based	Fewer trips	Production and attraction rates

The following steps summarize this approach in the event an energy policy is adopted or thrust upon the state by the federal government.

1. Assume a desired fuel consumption level and its effects

2. Adjust the socioeconomic and land use data if the change in consumption level is critical

3. Make adjustments to trip purposes

4. Run a traffic assignment on the existing plus committed network

5. Check the energy consumption level

6. Repeat steps 3 through 5 if necessary

7. Develop an alternative plan

In evaluating the Department's methodology of including energy price and supply effects in the planning process, it is found to be cursory and expedient. It lacks any direct sensitivity to government, employer, and consumer responses to an energy-constrained environment. The basis of the method is a balance between an estimated level of fuel consumption and a desired level of fuel consumption. A given fuel consumption level can result from different mixes of many variables which reflect different facility requirements and trip-making frequencies. Example variables include:

automobile fuel efficiency

transit demand

ride sharing

multimodal travel (e.g., auto feeder, rapid transit line haul)

trip length

trip chaining

trip purpose interactions

The approach begins with results that should be forecasted, such as trip productions, trip attractions, trip length, trip distribution, mode choice, and automobile occupancy rates. It is based on adjustments which are aggregate scaling factors to less aggregated models. It is, however, operational and data requirements are minimal. These make it a valid strategy, although a limited one, for comparing alternative transportation plans.

Disaggregate Choice Models Developed for Department of Energy

The approach developed for the Department of Energy is based on the decision structure shown in Figure 1. The first group of decisions comprises the long-range or land use/locational decisions. Work place location changes, residential location changes, and housing type changes are included. The second group includes automobile ownership levels and work trip mode choice. These decisions are classified as medium-range. The third group centers around non-work trips. The flexibility of non-work trips with regard to

3556

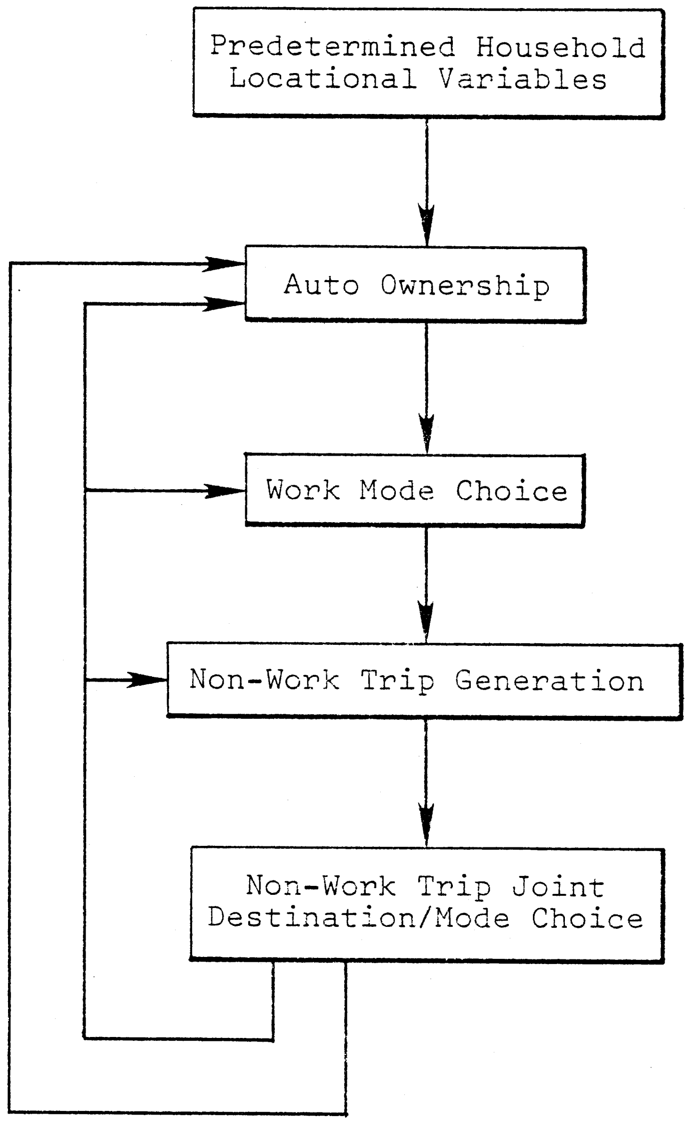


Figure 1. Interrelationships of travel demand models. (From reference 22, p. 3.)

their destination and frequency distinguish them from work trips, which have a fixed origin, destination, and frequency in the short run. All household locational and travel decisions must be examined in demand models if proposed transportation services are to be analyzed. The integration of eight disaggregate travel demand models into one system allows short-range policy analysis within this travel behavior framework. The models are:

1. Auto ownership model for one or more worker(s) households

2. Auto ownership model for no worker households

3. Work mode choice model

4. Car pool size model for work trips

5. Shopping trip generation model

6. Social-recreation trip generation model

7. Simultaneous destination and mode choice model for shopping trips

8. Simultaneous destination and mode choice model for social-recreational trips

These models are multinomial logit models based on an individual choosing the alternative with the greatest utility, with the exception of three of them. Nonlinear regression models are used for the two non-work trip generation models and a linear regression model is used for the car pool size model.

Even though disaggregate data can be used to satisfactorily estimate individual travel behavior, aggregate behavior must ultimately be shown to evaluate alternative transportation actions. Definitionally, the sum of individual travel demands is aggregate travel demand. Traditionally, traffic zones have been used for aggregating demand for a homogeneous group. This is reasonable, however, if the group of individuals is not homogeneous; in which case a better determination of travel behavior is achieved by the case of joint distributions of the independent variable values in the model; i.e., substituting individual forecast values may bias the aggregate behavior. The random sample aggregation approach is most appropriate in predicting urban travel response to energy conservation policies in disaggregate travel demand models. Data collected from a home interview survey allows the integration process to be extremely accurate. Figure 2 depicts the steps in the random sample enumeration procedure.

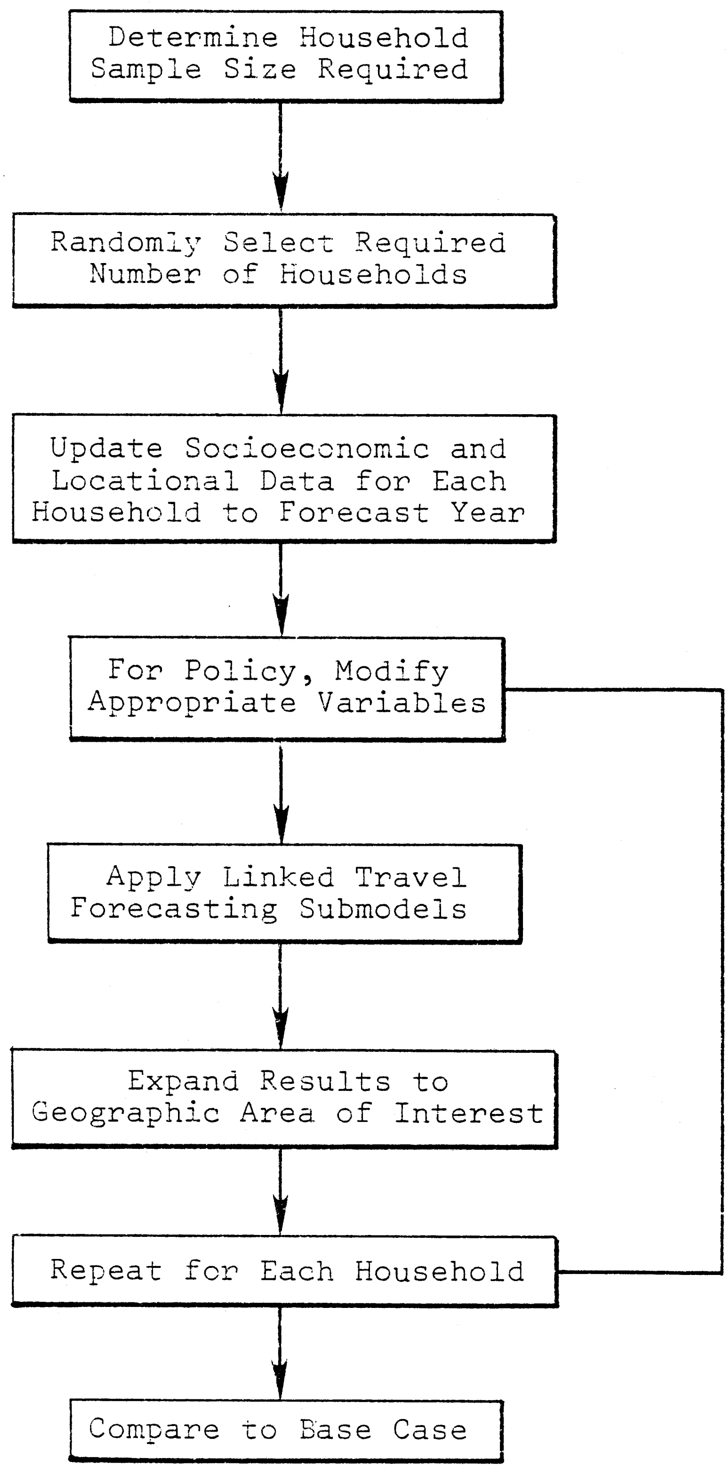


Figure 2. Random sample explicit enumeration forecasting. (From reference 22.).

First, the area population is selected by a random sample which is large enough to be representative of the population distribution. It can be done either by updating a recent survey or conducting a new survey. Second, a new policy is superimposed by altering the values of the independent variables. Third, the application of disaggregate models to each household allows predictions which represent the entire population to be obtained. The changes in travel behavior of individual households obtained give the areawide impacts which result from the new policy.

NCHRP Project 8-23 Procedure

This project was sponsored by the National Cooperative Highway Research Program to develop a quantitative forecasting system for analyzing work and non-work travel behavior impacts.[24] This study recognized the uncertainty resulting from an imperfect knowledge of future fuel supplies and of behavioral responses to fuel shortages. The method that evolved is, as with the Virginia Department of Highways and Transportation's approach, operative if future conditions are known.

In this case, scenarios of alternative fuel supply shortages are used to illustrate the predictive properties of the quantitative model system. Second, the uncertainty of the response of work and non-work travel to changes to the transportation environment is addressed by using the model coefficients. The sensitivity analyses of this type produce a range of possible travel behavior responses. Finally, for the case when everything quantitative fails, 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 the price of energy or limitations on its availability. The qualitative analysis is also used to refine estimates of quantitative impacts using such information as that obtained in surveys conducted during recent periods with fuel shortages and recent data on travel behavior.

The quantitative approach used in this NCHRP study consists of using work trip models and non-work trip models to produce estimates of vehicle miles traveled (VMT) and fuel consumption resulting from fuel shortages and governmental responses to these shortages. Methods that facilitate the use of hand or calculator-assisted analysis are emphasized. This approach is presented by the authors as an alternative to methodologies such as that developed for the Department of Energy[22,23] that require a large set of computer programs.

The basic work trip model is a logit modal choice model that includes single-occupancy vehicle, shared-ride, and transit modes. To enhance 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, and 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. It is a pivot-point approach quite similar to elasticity analysis in its input requirements and interpretation. Finally, because 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 the (1) base level of service variables; (2) forecast period level of service variables — alternatively, the change in level of service variables can be used, which 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.

The non-work 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.

Input requirements include base level non-work 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.

The NCHRP method supplements the quantitative models with a detailed qualitative analysis approach to investigate travel response to limitations on fuel supply that are beyond the domain of the travel choice models. Also, the long-run impacts of limitations on the fuel supply on land use, income, and geographic groups are considered here. In other words, planners must supplement organized modal choice model procedures with good judgements that result from an understanding of behavioral interactions addressed earlier in this report. The NCHRP study indirectly admits that the quantitative techniques by themselves are limited. The driving focus on travel choices such as changes in residential locations and activity patterns resulting from actual or potential limitations on fuel supply are beyond the scope of available quantitative methods because of the uncertainty of future conditions. The NCHRP procedure thus involves establishing ranges of possible outcomes and examining the consequences of the alternative outcomes on modal choices.

As this method addresses only the modal choice component, when it is examined against the criteria developed in Table 1 it is considered to be an incomplete methodology. It was shown that changes in mode choice are only a small part of the behavioral options that need to be addressed.

Chicago Area Transportation Study

The Chicago Area Transportation Study used a method for calculating energy consumption that was compatible with the technical capabilities, urban transportation planning models, and data sets available to a metropolitan planning organization (MPO).[25] This approach was cited to be a logical and marginal extension of the current "state of the art" urban transportation demand models. All software is compatible with the UMTA/FHWA Urban Transportation Planning System (UTPS) and the FHWA PLANPAC battery of computer programs for urban transportation planning. The authors state that applications of this method are constrained only by the analyst's capability with the urban transportation planning methods.

Although the above sounds impressive, the emphasis of the approach is on the computation of "energy accounts", not on behavioral changes which are necessary prior to the development of such accounts.

In the Chicago Study this process was applied to include travel impacts of alternative energy futures in a year 2000 plan.[26] These energy futures were defined in two scenarios. The first assumes that cost and availability remain stable at current levels. Drastic changes in both the price and availability of gasoline are the premise of the second scenario. Adjustment of model parameters allowed these scenarios to be incorporated in the planning process.

EVALUATION AND RECOMMENDATIONS

Three of the methods presented here for forecasting travel in energy-constrained environments lack any direct behavioral sensitivity. Only the ultra behavioralistic set of models developed by Cambridge Systematics,Inc. for the Department of Energy truly address travel behavior. The problem, however, with that method is that for the practitioner it is a great departure from the conventional forecasting process. Widespread implementation of that approach by metropolitan planning organizations and state departments of transportation is unlikely.

Based on the previously discussed review and interpretation of the problem of forecasting travel in the changing energy environment and recent approaches to its solution, a comprehensive analytical framework is presented. This analytical structure is a basis for upgrading the energy sensitivity of current FHWA and UTPS planning procedures and gives the rationale for supplementing conventional quantitative analyses with qualitative adjustments. This approach exhibits the sensitivity requirements for planning models that were derived from the possible scenarios described earlier. Specifically, the behavioral changes that define the scenarios were translated into the criteria from which the following system of models was structured.

Utility Functions

Impedance is defined as interference with travel and is reflected here by modal utility measures used in each of the three demand forecasting phases of the planning process. The proposed utility functions are similar to those used in current modal split models that are based on the premise that individuals will maximize their utility for travel. A utility factor is developed for each available mode and is a function of travel time (t), access time (x), and travel cost (c). Aggregate utilities can be made sensitive to available modes and applied to a specific trip interchange defined by the trip purpose. This measure explains the suppression of the total number of trips made due to the increasing price of gasoline as reflected in the travel cost coefficient. Also, it is anticipated that the cost coefficients can be made sensitive to vehicle fuel consumption, especially for the automobile mode.

Example specifications for the utility factor considering six modes are shown below.

$$U_{ij}\text{, transit} = t_{ijh} + \Theta_1 X_{ijh} + \Theta_2 C_{ijh}, \quad (1)$$

$$U_{ij}\text{, walk} = t_{ijh} + \Theta_1 X_{ijh} + \Theta_2 C_{ijh}, \quad (2)$$

$$U_{ij}\text{, drive alone} = t_{ijh} + \Theta_1 X_{ijh} + \Theta_2 C_{ijh}, \quad (3)$$

$$U_{ij}\text{, car pool 1} = t_{ijh} + \Theta_1 X_{ijh} + \Theta_2 C_{ijh}, \quad (4)$$

$$U_{ij}\text{, car pool 2} = t_{ijh} + \Theta_1 X_{ijh} + \Theta_2 C_{ijh}, \text{ and} \quad (5)$$

$$U_{ij}\text{, car pool 3+} = t_{ijh} + \Theta_1 X_{ijh} + \Theta_2 C_{ijh}, \quad (6)$$

where

U_{ijh} = impedance factor for travel from zone i to zone j for each mode h;

t_{ijh} = travel time for each mode;

X_{ijh} = access time for each mode;

C_{ijh} = out-of-pocket costs for each mode; and

Θ_1, Θ_2 = parameter estimates on x and c.

These six equations indicate the explicit utility of travel for each mode. Car pool 1, car pool 2, and car pool 3+ reflect the number of passengers in each car pool. The application of these factors at different levels of impedance aggregation in the three phases of travel demand forecasting provides modeling consistency and incorporates the potential to reflect changes in travel behavior that results from changing energy scenarios. The significance of this development to each of the phases of the travel forecasting process is addressed in subsequent sections.

Trip Generation

The measure of change criteria previously established for inclusion in trip generation are a decrease in both auto trips and trip frequency and an increase in transit trips. As auto travel demand diminishes, the total number of trips will decrease. Potential independent variables for an energy-sensitive trip generation model are automobile ownership, income, household size, employment, and the impedance factor. Therefore, trips per household are a function of these variables. An example of a procedure to obtain utility weights for use in determining trip productions and trip attractions for each zone is

3564

$$W_{j|i} = \text{(trip productions)} = \sum_j \sum_h U_{ij,h}$$

$$= \sum_j U_{ij}\text{, transit} + U_{ij}\text{, walk} + U_{ij}\text{, drive alone} +$$

$$U_{ij}\text{, car pool} + U_{ij}\text{, car pool 2} +$$

$$U_{ij}\text{, car pool 3+.} \qquad (7)$$

$$W_{i|j} = \text{(trip attractions)} = \sum_i \sum_h U_{ij,h}$$

$$= \sum_i U_{ij}\text{, transit} + U_{ij}\text{, walk} + U_{ij}\text{, drive alone} +$$

$$U_{ij}\text{, car pool} + U_{ij}\text{, car pool 2} +$$

$$U_{ij}\text{, car pool 3+.} \qquad (8)$$

The trip production factor or weight, $W_{j|i}$, is a sum of the impedance factors for all available modes to all the destination zones, j, from origin zone i. The trip attraction factor or weight, $W_{i|j}$, is a sum of the impedance factors for all available modes for all the origin zones, i, to the destination zone, j. The application of these weights in the trip generation process yields the following regression equations.

$$P_i = a + b_1 AO + b_2 I + b_3 HHS = b_4 W_{j|i} \text{ and} \qquad (9)$$

$$A_j = a + b_1 E_j + b_2 W_{i|j}, \qquad (10)$$

where

P_i = trip productions at zone i;

A_j = trip attractions at zone j;

AO = automobile ownership;

I = income;

HHS = household size;

$W_{j|i}$, $W_{i|j}$ = summation of the impedance factors for all modes over all trip interchanges;

E_j = employment at zone j;

a = constant term; and

$b_1, \ldots b_4$ = parameters of independent variables.

Trip Distribution

The measure of change criteria relevant to trip distribution include decreasing trip lengths, travel time, vehicle miles travelled, and origin-destination changes. Trip lengths are expected to be shorter as individuals shop and participate in activities closer to their residences. It is proposed that a modified gravity model reflects the anticipated origin-destination changes and shorter trip lengths.

$$T_{ijp} = \frac{P_i A_j W_{ij}}{\sum_{j=1} A_j W_{ij}}, \qquad (11)$$

where T_{ijp} = trips produced in zone i and attracted to zone j for purpose p;

P_i = trip productions at zone i;

A_j = trip attractions at zone j; and

W_{ij} = summation of the impedance factors for all modes over the trip interchange between i and j

$= \sum_h U_{ij,h}$, for each i, j.

This formulation is similar to that of the conventional gravity model but carries the impedance term a step further to include a utility function of increasing travel costs. An alternative strategy would be to distribute trips by mode as well as purpose.

Modal Choice

Increases in automobile occupancy rates, transit ridership, and travel time are the change criteria for the modal split methodology. In this phase, individuals maximize utility in choosing among the various available modes. The mode choice analysis is accomplished with the logit model

$$P_{ijm} = \frac{U_{ijm}}{\sum_{j=1}^{n} U_{ijh}}, \qquad (12)$$

where P_{ijm} = probability of choosing mode m between zones i and j;

e = base for the natural logarithm; and

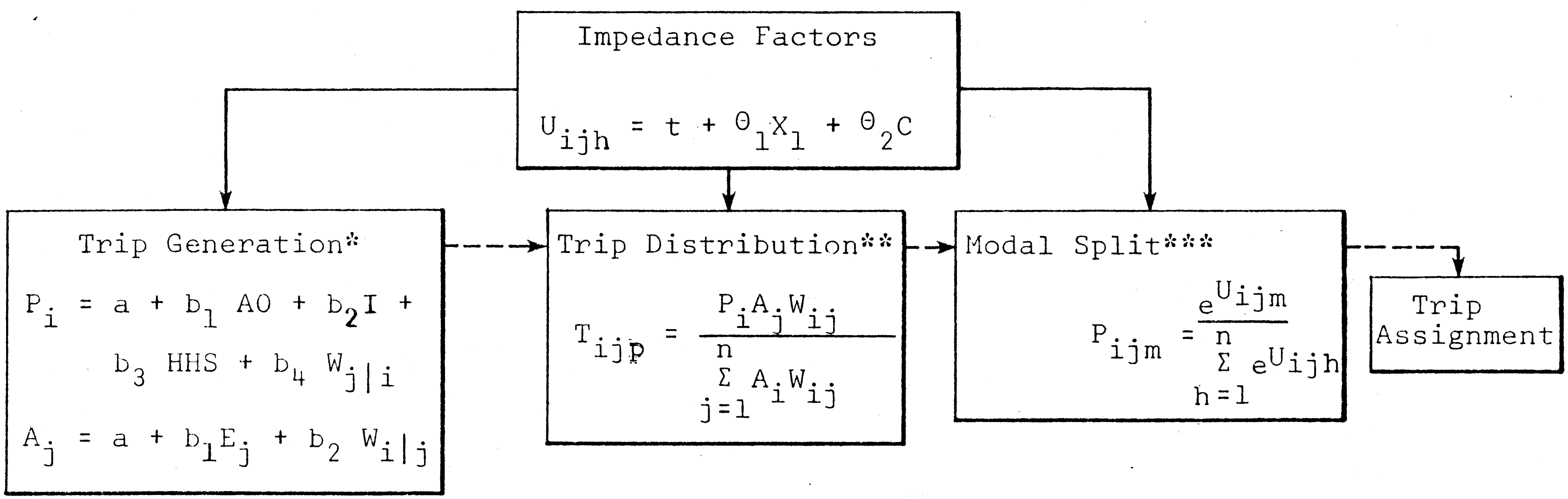
U_{ijh} = impedance factor for mode h between zones i and j.

This equation follows the conventional logit model in the ULOGIT user manual of the UTPS. This probability is applied to the trips already distributed to obtain the percentage of trips by each mode.

Evaluation of the Recommended Approach

Data needed for testing the proposed methodology include different data elements for work and non-work trips. There are basically two groups of data: (1) zonal inventories of automobile ownership, income/household size, and employment; and (2) trip interchange values for trips, and travel time, access time, and travel cost for each available mode. These data are not any more extensive than those required in traditional methodologies. Generalized impedance factors are estimated for mode choice and used in all three phases of the demand forecasting process. The complete model structure is shown in Figure 3. A consistency in the modeling relationship is established via the impedance factor.

The calibration procedure for the generalized utility models is very similar to that used with the UTPS package today. The major difference between the proposed strategy and current practices is the need to calculate the modal choice model, using program ULOGIT, from the origin-destination data prior to the calibration of the trip generation and trip distribution models. The modal choice calibration gives the coefficients for the modal utility functions, which can be used to transform travel times and travel costs into the collective impedance terms recommended for the trip generation and trip distribution models. The calibration of trip generation is performed with standard regression models and trip distribution calibration utilizes the gravity model program.



*$W_{j|i}$, $W_{i|j}$ = summation of the impedance factors for all modes over all trip interchanges.

**W_{ij} = summation of impedance factors over all modes for an origin, i, destination, j.

***U_{ijh} = impedance factor for mode h between zones i and j.

Figure 3. Model structure of the recommended approach.

CONCLUSIONS AND RECOMMENDATIONS

All of the methods reviewed here require that conditions be specified and input in a qualitative manner in the planning process. The Virginia Department of Highways and Transportation and the Chicago Area Transportation Study both use existing UTPS and PLANPAC/BACKPAC programs. Forecasts are made using models calibrated on present data and then adjusted to meet preconceived or qualitative anticipations of vehicle miles travelled. In the Chicago study the average number of non-work trips per household was reduced by 13% and the length of these trips by 9% using data from recent periods of energy shortage as a basis. The double fuel costs that were hypothesized could be, however, input into the correct mode choice model to indicate changes in modal shares. The NCHRP study cited here focused only on modal choice and accomplished changes in trip generation and trip distribution decisions using qualitative scenario specifications. The other available methodology explored exhibited a departure from the conventional modeling approach of the transportation planning process and appears to be presently impractical for planning agencies.

From studies of travel behavior responses to recent periods of energy shortage and historical land use development patterns, the key aggregate responses to steadily increasing energy costs appear to be changes in automotive technology toward higher fuel efficiency and activity modifications exhibiting less frequent travel and shorter distances between residences and urban activities. All of the recent approaches to travel forecasting that are derivatives of conventional procedures do not explicitly consider the development of relationships to explain changes in trip frequency and trip lengths that appear to be the key response to higher energy costs and reduced supplies.

As an alternative approach, a method which fuses concepts from the traditional model sequencing approach with the disaggregate behavioral methodology that has recently dominated modal choice analysis was proposed. This strategy identifies the utility measure of the conventional modal choice model as a generalized impedance factor that influences trip generation and trip distribution decisions in addition to modal choice. This development provides the capability to change trip productions and trip lengths by model inputs, or policy variables, rather than by simply scaling rates or outputs. The proposed method, furthermore, provides appropriate direction for purely qualitative or short-cut assessments of future travel behavior under changing fuel economies.

The study recommendations include the following courses of action for federal and state agencies.

1. That a data set be developed for testing the proposed modeling strategy incorporating the generalized impedance measure. An area which has maintained a good data base from some time prior to 1974 should be used to reflect time-series behavior in the development. Information from a recent origin-destination survey is needed.

2. That a logit mode choice model for trip purposes be calibrated for the data base.

3. That the resulting utility measures for the mode choice models be used to examine the proposed relationships for trip generation and trip distributions.

4. That, if successful in replicating existing data, the modeling process be demonstrated in an example long-range application. Changes in impedance functions over time should be considered using time series data.

ACKNOWLEDGEMENTS

This study was financed with Highway Planning and Research funds administered by the Federal Highway Administration. The authors express thanks to those members of the Council staff, Virginia Department of Highways and Transportation, and the Planning Research Advisory Committee for the timely direction given to this project.

3572

REFERENCES

1. Hartgen, David T., "Long-Range Transportation Planning Under Energy Constraints: A Critical Review of Current Capability", Preliminary Research Report 87., Albany, N.Y.: Planning Research Unit, New York State Department of Transportation, July 1975.

2. Fried, M., J. Havens, and M. Thall, Travel Behavior — A Synthesized Theory. Chestnut Hill, Massachusetts: Boston College, prepared for National Cooperative Research Board, March 1977.

3. Hartgen, David T., "Transportation Energy: An Overview with Emphasis on New York State." Preliminary Research Report No. 141. Albany, N. Y.: Planning Research Unit, New York State Department of Transportation, July 1978.

4. Nevell, Alfred J., "The 1973-1974 Energy Crisis: Impact on Travel." Preliminary Research Report No. 131. Albany, N. Y.: Planning Research Unit, New York State Department of Transportation, December 1977.

5. Hartgen, David T., Alfred J. Nevell, Joanna M. Brunso, John B. Banas, and Jeannemarie Miller, "Changes in Travel Response to the 1979 Energy Crisis." Preliminary Research Report No. 170, Albany, N. Y.: Planning Research Unit, New York State Department of Transportation, December 1979.

6. Hartgen, David T., and Alfred J. Nevell, "The 1979 Energy Crisis: Who Conserved How Much?", Albany, N. Y.: Planning Research Unit, New York State Department of Transportation, March 25, 1980.

7. Crowell, Sharon, and Michael A. Perfater, "Public Attitudes Toward Transportation", Virginia Highway and Transportation Research Council, VHTRC 81-R42, Charlottesville, Virginia, March 1981.

8. Paquette, Radnor J., Norman Ashford, and Paul H. Wright, Transportation Engineering: Planning and Design. New York, N. Y.: The Ronald Press Company, 1972.

9. Kelm, Doug, "Energy, Transportation and Land Use". Passenger Transport, 1 June 1979.

10. Rappaport, Carl S., "Opportunities for Energy Conservation in Transportation", Washington, D. C.: U. S. Department of Transportation, Office of the Assistant Secretary for Policy and International Affairs, January 1980.

3574

11. Nelson, Howard J., and William A. V. Clark, The Los Angeles Metropolitan Experience: Uniqueness, Generality and the Goal of the Good Life. Cambridge, Massachusetts: Ballinger Publishing Co., 1976.

12. Cheslow, Melvyn D., and J. Kevin Neels, "The Effects of Urban Development Patterns on Transportation Energy Use." Presented at the 59th Annual Meeting of the Transportation Research Board, January 1980.

13. Peskin, Robert L., "Policy Implications of Urban Traveler Response to Recent Gasoline Shortages," Prepared for Transportation Research Board, National Energy Users Conference, April 1980.

14. Wagner, Frederick A., and Keith Gilbert. TSM: An Assessment of Impacts. Alan M. Vorhees, Inc. for the Office of Policy and Program Development, Urban Mass Transportation Administration, November 1978.

15. Traffic Volume Trends, U. S. Department of Transportation, Federal Highway Administration, Washington, D. C., May 1981.

16. Monthly Motor Gasoline Reported by States, U. S. Department of Transportation, Federal Highway Administration, Washington, D. C., April 1981.

17. U. S. Department of Transportation, Federal Highway Administration, Bureau of Public Roads, Guidelines for Trip Generation Analysis., Washington, D. C.: Government Printing Office, June 1967.

18. Sosslau, Arthur B., Armin B. Hassam, Maurice M. Carter, and George V. Wicksttom. "Quick-Response Urban Travel Estimation Techniques and Transferable Parameters: Users Guide." National Cooperative Highway Research Program 187. Washington, D. C.: National Research Council, 1978.

19. U. S. Department of Transportation, Federal Highway Administration. Computer Programs for Urban Transportation Planning, Information Manual, April 1977.

20. Weiner, E., "Modal Split Revised." Traffic Quarterly, Vol. 23, No. 1 (1969).

21. Charles River Associates, Inc., Disaggregate Travel Demand Models, Volume 1. Cambridge, Massachusetts: Prepared for the National Cooperative Highway Research Program, February 1976.

22. Atherton, T. J., and J. H. Suhrbier, Urban Transportation Energy Conservation: Analytic Procedures for Establishing Changes in Travel Demand and Fuel Consumption, Volume II. Cambridge, Massachusetts: Prepared for the U. S. Department of Energy by Cambridge Systematics, Inc., October 1979.

23. Atherton, T. J., and J. H. Suhrbier, Urban Transportation Energy Conservation: Case City Applications of Analysis Methodologies, Volume III. Cambridge, Massachusetts: Prepared for the U. S. Department of Energy by Cambridge Systematics, Inc., October 1979.

24. Methods for Analyzing Fuel Supply Limitations on Passenger Travel, NCHRP Report 229, Transportation Research Board, Washington, D. C., 1981.

25. Personal Travel Energy Consumption, Chicago Area Transportation Study, Chicago, Illinois, 1980.

26. Zavattero, David A., "Travel Impacts of Alternative Energy Futures in the Year 2000 Plan", Chicago Area Transportation Study, Research News, September 1980.

3576