95

TRANSPORTATION RESEARCH RECORD 952

Technology Assessment of Productive Conservation in Urban Transportation

TRB
TRANSPORTATION RESEARCH BOARD
NATIONAL RESEARCH COUNCIL
WASHINGTON, D.C. 1984

Transportation Research Record 952
Price $8.20
Editor: Scott C. Herman
Typist: Lucinda Reeder

modes
1 highway transportation
2 public transit

subject areas
12 planning
17 energy and environment

Transportation Research Board publications are available by ordering directly from TRB. They may also be obtained on a regular basis through organizational or individual affiliation with TRB; affiliates or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Research Council, 2101 Constitution Avenue, Washington, D.C. 20418.

Printed in the United States of America

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Technology assessment of productive conservation in urban transportation.

(Transportation research record; 952)
1. Urban transportation—Energy conservation—Congresses.
I. National Research Council (U.S.). Transportation Research Board. II. Series.
TE7.H5 no. 952 380.5 s 84-20731
[HE305] [333.79]
ISBN 0-309-03672-0 ISSN 0361-1981

Sponsorship of Transportation Research Record 952

GROUP 1–TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Kenneth W. Heathington, University of Tennessee, chairman

ENVIRONMENTAL QUALITY AND THE CONSERVATION OF RESOURCES SECTION
Carmen DiFiglio, U.S. Department of Energy, chairman

Committee on Energy Conservation and Transportation Demand
David Lloyd Greene, Oak Ridge National Laboratory, chairman
William G. Barker, Martin J. Bernard III, Sydney D. Berwager, Melvyn Cheslow, Sidney Davis, Donald J. Gantzer, David T. Hartgen, Richard Hood, Charles A. Lave, Michael F. Lawrence, H. James Leach, Rasin K. Mufti, Philip D. Patterson, Milton Pikarsky, Axel Rose, William P. Schlarb, Richard H. Shackson, Richard P. Steinmann, Richard L. Strombotne, Thomas J. Timbario, Kenneth H. Voigt

Stephen E. Blake, Transportation Research Board staff

The organizational units, officers, and members are as of December 31, 1983.

952

Contents

Addresses of Authors

Bernard, Martin J., Center for Transportation Research, Argonne National Laboratory, 9700 South Cass Avenue, Building 362 2B, Argonne, Ill. 60439

Bunch, James A., North Central Texas Council of Governments, P.O. Drawer COG, Arlington, Tex. 76011; formerly with Northwestern University

Gur, Yehuda, Transportation Research Institute, Technion, Israel Institute of Technology, Technion City, Haifa, Israel; formerly with Urban Systems, Inc.

Hudson, Charles L., Hudson Associates, 685 Toro Canyon Road, Santa Barbara, Calif. 93108

Johnson, Larry R., Center for Transportation Research, Argonne National Laboratory, 9700 South Cass Avenue, Building 362 2B, Argonne, Ill. 60439

Kaplan, Marc P., Bell Laboratories, Crawford Corner, Room 213612, Holmsdel, N.J. 07733; formerly with Argonne National Laboratory

LaBelle, Sarah J., Center for Transportation Research, Argonne National Laboratory, 9700 South Cass Avenue, Building 362 2B, Argonne, Ill. 60439

Moses, David O., Office of Environmental Analysis, U.S. Department of Energy, Forstall Building, EP-332, Washington, D.C. 20585

Peterson, Bruce E., Energy Division, Transportation Energy Group, Oak Ridge National Laboratory, Building 4500N, H-19, P.O. Box X, Oak Ridge, Tenn. 37831

Putnam, Evelyn S., Priority Research Incorporated, 100 North Hope Avenue, #18, Santa Barbara, Calif. 93110

Saricks, Christopher L., Center for Transportation Research, Argonne National Laboratory, 9700 South Cass Avenue, Building 362 2B, Argonne, Ill. 60439

Stuart, Darwin G., Barton Aschman Associates, 820 Davis Street, Evanston, Ill. 60201

Vyas, Anant D., Center for Transportation Research, Argonne National Laboratory, 9700 South Cass Avenue, Building 362 2B, Argonne, Ill. 60439

Projection of Urban Household Automobile Holdings and New Car Purchases by Type

CHRISTOPHER L. SARICKS, ANANT D. VYAS, and JAMES A. BUNCH

ABSTRACT

In this paper a procedure for modeling the choices made in urban American households among personal vehicles on the bases of cost, passenger capacity, and engine technology is discussed, and those preferences to the years 1990 and 2000 are projected. The results of this disaggregate technique are used by the other predictive research tasks undertaken by Argonne National Laboratory in a project entitled Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT). In these projections vehicles with standard spark-ignition (Otto-cycle) engines continue to dominate automobile holdings and new car purchases in either of two socioeconomic scenarios under any of three settings (an existing policy set and two alternative conservation strategies). From 1990, small cars (which seat four or fewer passengers) dominate urban holdings and sales in two of the three TAPCUT energy strategies (the exception being the strategy that emphasizes individual travel), and this holds true with only a minor variation in both socioeconomic scenarios. Advanced-technology vehicles are most successful under the individual travel strategy. Vehicle characteristics are far more significant than demographic descriptors in estimating household vehicle choice when using this modeling approach.

In this paper the method and results of the household vehicle choice model used to forecast the distribution of automobiles bought and used by urban households in each of two projection years (1990 and 2000) are described. These forecasts in turn led to estimates of total demand for and cost of travel, and of the future economic and environmental impacts of automobile production and operation in urban areas for the Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT) project.

The TAPCUT project had the stated goals of providing (a) a description of several alternative strategies that promote energy conservation in urban passenger transportation, (b) a better understanding of the environmental impacts of such strategies, and (c) identification of the constraints on the implementation of such strategies.

Two productive conservation strategies were designed to save energy in urban passenger transportation when substituted for policies currently in place. A reference set of impact forecasts was then prepared for these two strategies. One conservation strategy stressed group travel (e.g., transit and carpooling), whereas the other promoted individual travel in private automobiles. The strategies were designed to cause minimal disruption of life-styles and the economy while achieving reductions in the consumption of aggregate energy, especially that derived from petroleum.

Travel demand analysis was performed for each of three typical cities under policies currently in place and forecast to continue, and also under the alternative strategies (i.e., group travel strategy and individual travel strategy). Environmental impact analysis of the forecast travel demand under each strategy was city specific and included estimation of air and water pollutant loadings along with their associated impacts on human health. Traffic safety impacts were also estimated. Socioeconomic impacts caused by vehicle use and vehicle production were assessed. Impacts on physical environment, resources, health, and safety caused by vehicle and fuels production and infrastructure construction were also addressed. The final step was the overall comparison of policy-driven results to the results obtained under the in-place policy set.

INTRODUCTION TO MODELING VEHICLE CHOICES BY HOUSEHOLDS

General Approach

Disaggregate statistical modeling of vehicle choices by households has a short but stimulating history (1-5). In his comprehensive review of the topic, Tardiff (6) discusses the requirement that all such models define household and vehicle characteristics so that a sufficient (but not excessive) number of dependent variables are available for estimating coefficients of a choice function. Specification of too many variables may introduce a degrees-of-freedom problem. An appropriate course is to establish variables that are interactions of vehicle descriptors, which do not vary across households, and socioeconomic descriptors, which do vary across households. Variables may also be established to correlate the sensitivity of acquiring or holding vehicles by household to employment opportunities and other measures of accessibility to various modes of transportation.

In the TAPCUT modeling system household and work place locations are predetermined by regional population and employment forecasts and the land use policy for each scenario. Aggregate household travel demand by mode is developed by using an extended version of a sketch-planning transportation model called extended short-range generalized policy (XRGP) from household work-trip records and household characteristics that influence the nonwork travel of its members (see paper by Kaplin, Gur, and Vyas elsewhere in this Record). Household vehicle holdings are part of the record of each household's characteristics. To project total holdings and new car purchases by household class it was therefore sufficient to model only the vehicle choice process of households characterized for the XRGP model.

Only a household-based model of vehicle preferences has an output capable of directly feeding the rest of the TAPCUT modeling sequence, which forecasts travel demand and energy use at the level of the standard metropolitan statistical area (SMSA).

Forecasts of automobile holdings at higher levels of aggregation than the household (e.g., regional or national metropolitan totals) would fall short of the resolution of the travel-demand and energy-use model, which is household based. Moreover, the TAPCUT project required personal vehicle data (size class, technology, materials of composition by percentage of total weight, and so on) of the highest possible resolution in order to forecast the resource and environmental impacts of vehicle-related energy policies.

Empirical Considerations

The 1977 Nationwide Personal Transportation Study (NPTS) provides a detailed cross-sectional data base for the disaggregation of automobile holdings and examination of vehicle preferences (7). This 6,000-household sample also provides considerable information that correlates the demographic characteristics of households (income class, number of people, and age and education of household head) and automobile ownership by vehicle type. The TAPCUT project used the urban household data from this survey as its base file of national urban socioeconomic data. Vehicles included in the survey were aggregated to three size classes in a household descriptor file before their use in TAPCUT.

Unfortunately, the NPTS provides no information on the evolution over time of vehicle holdings by specific types of household. In the absence of consistent longitudinal data, it was therefore assumed that these holdings are stable through time within a socioeconomic category but not within a specific household, which can move from one socioeconomic category to another. For example, the vehicle holdings of low-income households remain constant, but an individual low-income household is assumed to change its holdings as it moves into the middle-income category. This in turn assumes that demographic or economic variables principally determine the total holdings of personal vehicles over time. Thus changes in the demographic structure of the national population, disaggregated to the household level, account for growth or decline in the total fleet of personal vehicles. These changes, represented by increases or decreases in the total households in each category, were estimated for TAPCUT through the technique of iterative proportional fitting (IPF) (8).

From this perspective a given NPTS household type (or cell), which is classified according to car ownership plus the four demographic variables previously mentioned, will hold as many automobiles in 2000 as it does in 1977, although not necessarily the same types of automobiles. This structure permits households of a given type to change total travel but not total holdings in response to changes in highway or level of transit service. The type of vehicles held can change in response to changes in automobile operating characteristics such as fuel economy; but, again, the total number held is assumed to remain unchanged.

Prediction of holdings in year x should be logically consistent with prediction of new car sales in year x - n (n = 5,10) because vehicle types that do not succeed in the marketplace, in competition with alternative types, will not be available as holdings or used cars after 5 or 10 years. Similarly, a projection of household fleet distribution that shows a vehicle virtually disappearing from household fleets in a forecast year points to a cessation in sales of that vehicle before the forecast year, even though a standard logit probability distribution would guarantee it some fraction of sales in that same year. Adjustments to forecast results are required whenever automobile holdings and new car purchases, which are projected independently, do not agree.

Principal Assumptions

In summary the model selected to project urban household automobile holdings and new car purchases had to accommodate two basic assumptions. First, individual households change their total holdings of personal vehicles only as their respective demographic status changes. Second, the characteristics of the vehicles held are a joint function of the household demographic profile specified for a given projection year and the attractiveness or salability of an available type of personal vehicle.

MODEL FORM AND PROCEDURE

Input-Output

The disaggregate vehicle stock allocation model (DVSAM) was used to estimate vehicle holdings for each of the projection years. The model uses an incremental logit equation to estimate vehicle holding probabilities for existing technology vehicles and a simple logit equation to estimate holding probabilities for new technology vehicles. It is derived from a vehicle choice model developed by Lave and Train (4,9).

The principal purpose of using an incremental analysis, as opposed to running the Lave-Train model directly, is to evolve vehicle-holdings patterns from predetermined conditions at a given window in time, thus avoiding the time and cost of generating annual new car sales estimates and applying a cumulative scrappage function. This is accomplished by incorporating given information on the distribution of holdings (in this case, the 576 x 8 NPTS array) and by using the model mainly to predict changes in this distribution. A vehicle-holdings file that uses 1977 NPTS data was created for 1980. For all subsequent projection years, the output vehicle sales file from the DVSAM run for the preceding forecast year was used as the base year file.

To maintain consistency with the vehicle total treated in the Lave-Train choice set and to avoid diluting future probability distributions through the introduction of spurious choices, the maximum permitted size of any vehicle type choice set is 10 in DVSAM.

Given a change in the utility of automobile type a_i, for example, to household type h (as computed by the Lave-Train function), and given the base probability of this utility resulting in a new car sale, the predicted probability of the holding can be expressed as follows:

$$P'h(a_i) = \exp[\Delta U^h_{a_i} P^h_o(a_i)] / \left\{ \exp[\Delta U^h_{a_j} P^h_o(a_j)] \right\} \quad (1)$$

where

A = choice set of vehicle types available in both base and forecast years,
j = all competing vehicle types in the set,
$\Delta U^h_{a_i}$ = change in utility of vehicle type a_i to household h, and
$P^h_o(a_i)$ = base sales probability for vehicle type a_i.

Because this choice set expands in each successive projection year (from 6 vehicles in 1980 to 8 in 1990 and to either 9 or 10 in 2000), it is necessary to partition the logit procedure to predict the share of newly introduced vehicles according to their computed absolute utility. Shares of all vehicles in a given year are first distributed according to a standard logit formula (by using absolute utilities); then the normalized percentage share of all vehicles that appear for the first time in that year's choice set (i.e., new technology vehicles) is subtracted from one. The remaining percentage represents the aggregate share for conventional, or established, vehicles. This share is distributed among those vehicles by incremental logit according to the computed change in the utility function from base to forecast year, as shown in Equation 1.

Thus for all but one of the strategy and scenario combinations, six established and two new vehicle technologies are defined for 1990, and eight established technologies and one new one are defined for 2000. The exception is scenario I under the individual travel strategy, in which two new technology vehicles are defined for the year 2000. In each case standard and incremental logit formulas are applied sequentially. Figure 1 shows the data file flow of the DVSAM.

brated model must be considered unacceptable for purposes of consistent forecasting.

Therefore, the Lave-Train function was calibrated away from 1977 equilibrium by systematically modifying the dummy variable coefficients for all Otto vehicles in order to replicate available information on 1980 sales and holdings distributions that use the logit function. This was accomplished through use of a recursive technique to alter the utility values. In this technique the upper or lower bounds on the percentage share of holdings are specified for any vehicle type(s) with which a dummy variable is associated; then the current value of the share is multiplied by the log ratio of the nearest desired bound and the current value; subsequently, the utility computation and logit procedure iterates to closure.

PROJECTED HOUSEHOLD AUTOMOBILE FLEET HOLDINGS AND NEW CAR SALES BY SCENARIO

Two economic and social-organization scenarios were defined for the TAPCUT project; they differed in

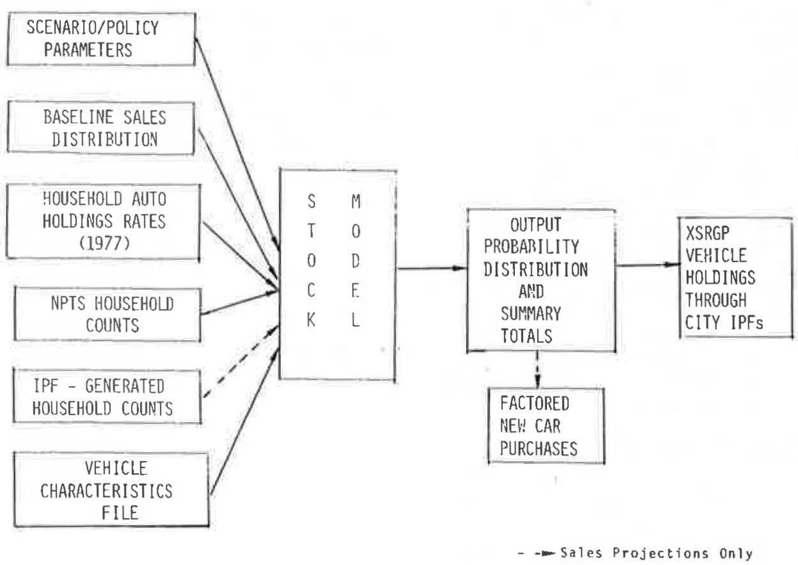

FIGURE 1 Data file flow in DVSAM.

Adjustments

A pronounced and inescapable result of the first stock estimation--developing a 1980 distribution from the empirical 1977 values--was its failure to replicate the dramatic movement to smaller cars since 1978. In the 1977 NPTS holdings the considerable bias toward large cars (the curb weights of more than 43 percent of automobiles and vans exceed 3,700 lb) creates an inertia in the logit distribution that imposes past results on future projections. This is particularly strong when, as in the TAPCUT scenario I individual travel policy setting, mileage and performance improve at a consistent pace across all vehicle types. Indeed, as holdings distributions incremented only on 1977 holdings are modeled beyond 1980, the trend in automobile acquisitions and holdings by size tends in a direction exactly opposite to what has been observed over the past 3 years. Even if the recent move toward smaller vehicles is held to be short term and eventually reversible (which does not appear entirely reasonable given expected changes in household composition and size), this anomalous behavior of the uncali-

gross national product (GNP) growth rate, social organization, retail fuel price, total metropolitan population, average household income, environmental regulations, and types of fuel available for transportation. The two scenarios can be briefly distinguished as scenario I--a wealthy economy with high technological success--and scenario III--a relatively poor economy with low technological success. National urban and city-specific forecasts of population and employment characteristics were prepared under each scenario. Additional data regarding these scenarios may be found in LaBelle et al. (8).

Prototype cities were selected by using a factor-analysis technique that identified extreme cities along three dimensions relevant to transportation energy use (10). One dimension, called Megatown, identifies large cities with satisfactory transit systems. The second dimension, Sprawlburg, typifies newer, fast-growing, sprawl cities. The Slowtown dimension identifies midwestern industrial cities that are smaller in population than the other two. All metropolitan areas in the nation were related to these three dimensions; an expansion method was then developed to make national urban forecasts based on the detailed forecasts of the three typical cities selected to represent the three dimensions.

Automobile and transit vehicle characteristics were projected in detail under several sets of policy and scenario conditions. Three different sets of vehicles were used in the analysis: set C, the expected technologies, was used for the in-place policy and group travel strategy in both scenarios; set A, designed as the best technology for both conservation and performance, was tested for the individual travel strategy in the optimistic scenario; and the third set, a modification of set C, was tested in the other scenario under the individual travel strategy. Vehicles were characterized by size class, engine type, fuel economy, emissions profile, purchase price, operating costs, materials composition, and (for personal vehicles) performance.

Household Fleet Holdings in a Typical City

Figures 2-7 show year-2000 distributions of automobile holdings across several vehicle and demographic characteristics in the SMSA of the TAPCUT city Sprawlburg. Sprawlburg values are given here because this city type is the most influential in the TAPCUT expansion procedure for generating a national profile of urban travel effects.

Figures 2 and 3 show the distribution of the automobile fleet in Sprawlburg by vehicle technology under each policy or strategy in scenarios I and III, respectively. The technology mix is nearly identical under the in-place and group travel settings in both scenarios, but there are significant technological differences between vehicles in the individual travel strategy in scenario I and those in scenario III. In scenario I vehicles are uniformly superior in each technology to those available under the in-place policy, and cars with reciprocating external-combustion (Stirling-cycle) engines are not available under any other policy. Not surprisingly, because of identical vehicle characteristics, the percentage distribution across technologies is similar between scenarios for each of the first two strategies. Vehicles with standard spark-ignition (Otto-cycle) engines dominate all distributions, with diesels achieving their highest penetration (15.5 percent) under the individual travel strategy in Scenario I. Penetration by electric cars reaches only 2.3 percent under the group travel strategy in both scenarios, a performance attributable to relatively high operating cost (which includes replacement of battery packs) and the range limitations of electric cars. Only under the group travel strategy (with high petroleum fuel taxes) does the life-cycle cost of electric cars become competitive with that of heat-engine cars on a per-mile basis.

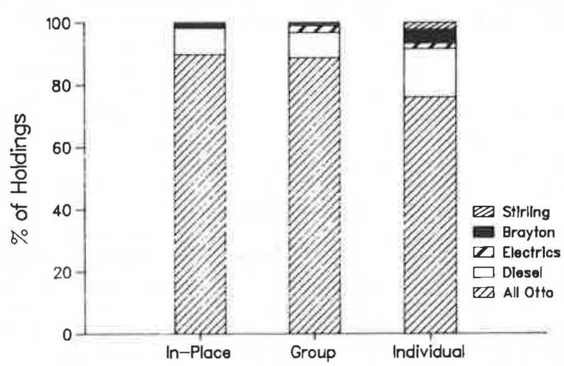

FIGURE 2 Fleet distribution by vehicle technology in Sprawlburg by strategy in scenario I in 2000.

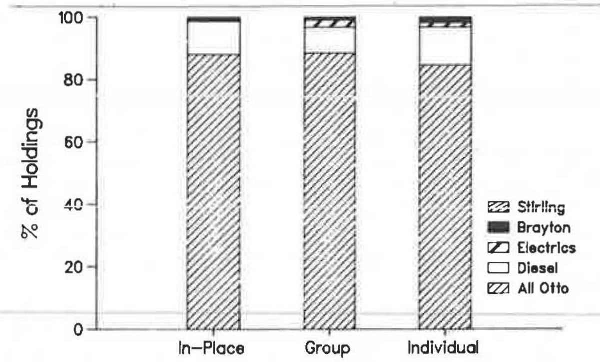

FIGURE 3 Fleet distribution by vehicle technology in Sprawlburg by strategy in scenario III in 2000.

Figures 4 and 5 show the distribution of the Sprawlburg household fleet by vehicle size under each energy strategy in scenarios I and III, respectively. From 1990, small cars dominate urban holdings and sales under the in-place policy and the group travel strategy in both TAPCUT scenarios, and this phenomenon is manifested in the year-2000 fleet distribution. The trend to these four-passenger cars is damped under the individual travel strategy by improved mileage and performance in every vehicle of the choice set.

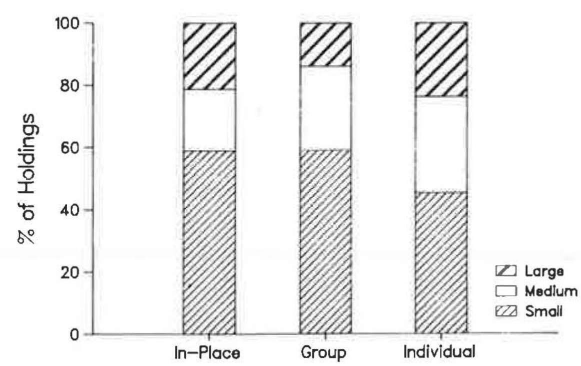

FIGURE 4 Fleet distribution by vehicle size in Sprawlburg by strategy in scenario I in 2000.

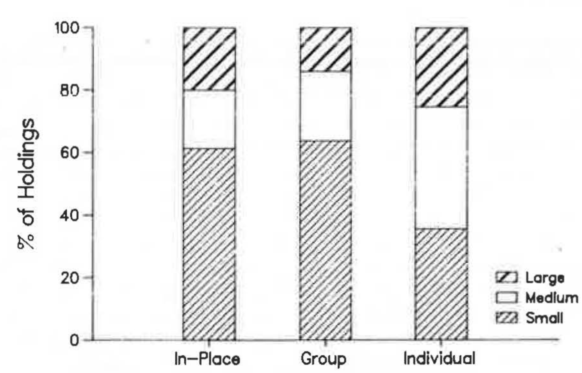

FIGURE 5 Fleet distribution by vehicle size in Sprawlburg by strategy in scenario III in 2000.

Figures 6 and 7 have been included to emphasize that scenario variables--in this case income distribution--do not vary by policy. The number of households allocated to each income group and the number of automobiles held by each are fixed throughout the scenario. This means that although the ownership pattern by size and technology varies across policy settings, the total holdings, and thus the percentage of vehicles held by each income class, are not affected by policy-directed changes.

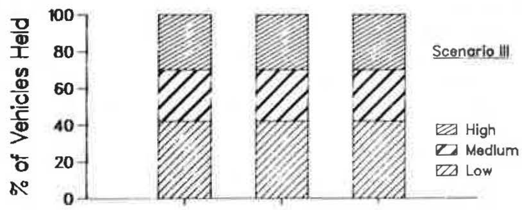

FIGURE 6 Fleet distribution by income class in Sprawlburg by strategy in scenario I in 2000.

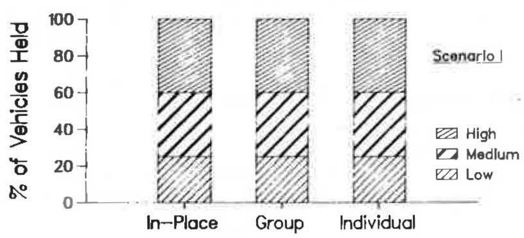

FIGURE 7 Fleet distribution by income class in Sprawlburg by strategy in scenario III in 2000.

Sales Projections

Overview

To assess the resource and production impacts of the vehicle technologies defined for the TAPCUT project it was necessary to generate estimates of new car sales by type to urban households for each of the calendar projection years. Because in a new car market only the specific utility of each vehicle type relative to its competitors in the same model year is of interest, a standard logit function that incorporates the computed utility of each new vehicle in the choice model was used to estimate the distribution of new car sales.

The Lave-Train function calibrated to a 1980 sales distribution (obtained from the Oak Ridge National Laboratory "Market Shares" report for February 1981) was used. Resulting sales shares are given in Table 1. Vehicle characteristics were obtained directly from the parameters of new model-year vehicles characterized for 1990 and 2000. Future-year demographics (i.e., number or distribution of household cell types) were obtained through IPF of the 1977 NPTS file distribution as augmented by national urban totals for each demographic dimension forecast for each TAPCUT scenario in 1990 and 2000. Vehicle totals are obtained from the IPF-determined household cell totals multiplied by the NPTS automobile ownership rate by cell, and urban vehicle sales are then assumed to be equal to this total times 0.1109 (that is, 11.09 percent of vehicles in a fleet for a calendar year are sold during that calendar year according to the urban vehicle age distribution developed for TAPCUT). This procedure forces a convention that each household type participates in the new car market in proportion to the average number of vehicles it held in the base year. No vehicle-holding household type is excluded from that market, irrespective of income group.

TABLE 1 New Cars with Otto-Cycle and Diesel Engines Sold in Urban Areas During 1980, by Size

Car Size	Engine Type	Market Share (%)	Total No. Sold
Small	Otto	36.73	2,703,466
Medium	Otto	42.13	3,100,927
Large	Otto	15.15	1,115,097
Van	Otto	3	220,811
Small	Diesel	0.71	52,259
Medium	Diesel	1.40	103,045
Large	Diesel	0.88	64,771
Total			7,360,376

Estimated sales of new diesels by size are distributed within the technology according to the distribution by size of new Otto vehicles, except as follows. Maximum sales constraints have been imposed on diesel (and electric) vehicles in 1990. Assume that for diesels this maximum is equal to 16 percent of total sales (as the TAPCUT approach specifies for scenario I) and that the utility of the diesel vehicle as characterized results in a 35 percent share in the first iteration of the model. Therefore, 19 percent has to be given back to competing modes. After a finite number of iterations (usually less than eight) the diesel share is reduced to the desired 16 percent. This share is then distributed within the diesel technology to size classes according to the normalized portion of the 19 percent returned to each Otto vehicle at the end of the iterations. Thus the constrained 16 percent takes on the characteristics of the shadow market for diesel cars represented by the unconstrained 35 percent. In many cases this is at variance with the size-class distribution of the Otto market, which is often more oriented to larger vehicles (which should be expected because the size of the benchmark diesel car is characterized as intermediate). Such a result embeds the assumption that the thrust of current size-class trends in the diesel vehicle market will continue into the future. It does not admit the possibility of a small, super-efficient diesel capturing most of the four-passenger (and smaller) market.

Vehicles of nonconventional or emerging technology that were included in choice sets were not distributed by size class after their respective total sales shares were determined. Rather they retained the size class of the target-market prototypes of U.S. Department of Energy research and development programs that focus on personal vehicles. Thus a car with a gasoline-turbine (Brayton-cycle) engine is always a large vehicle (including some vans in scenario I under the individual travel strategy). Similarly, cars with reciprocating external combustion (Stirling-cycle) engines and electric cars are always classed as medium-sized (five-passenger) vehicles. The decision not to distribute these vehicles across size classes was based in part on their relatively small penetration in both TAPCUT scenarios and, for heat-engine cars, the late date of their market entry (making size diversification largely uneconomic in the TAPCUT time frame). There are also severe technological problems inherent in attempting to downsize cars with Brayton and Stirling engines to two- and four-passenger capacities.

In a few instances the decline in holdings of certain conventional vehicle types between 1990 and 2000 precluded their participation in the 2000 new vehicle market. The sales share for these types in 2000 was simply subtracted from total vehicles sold; no substitute vehicle was selected to fill this gap, and thus the absolute total of sales in these instances is less than the value given by the following formulation: (0.1109 • urban vehicle total).

Scenario I New Car Sales

The results of the personal-vehicle sales model and size-class distribution applied to scenario I automobiles and vans for each strategy setting in 1900 and 2000 are given in Tables 2-4. Figures 8-10 show the purchase trends over time by size class across all technologies for each scenario I strategy setting.

As indicated by the data in the tables, unconventional-technology vehicles achieve modest gains in sales through 2000 under the in-place policy and group travel strategy, but they perform strongly under the individual travel strategy best-technology fleet. Electric cars account for 2 and 6 percent of year-2000 sales, respectively, under the in-place policy and the group travel strategy, whereas the corresponding results for the Brayton-cycle car are 3.7 and 3.3 percent.

Under the individual travel strategy only the advanced battery-powered car with the lithium-metal sulfide battery succeeds among electric cars in competition with heat-engine cars in the year 2000 (3.75 percent of sales). Braytons and Stirlings in the same year penetrate 9.4 and 15 percent of the new car market, respectively. This would appear to be consistent with the adventurous cast of scenario I and the resulting attitudes of both car manufacturers and the car-buying public toward vehicles in the marketplace.

As the data in Figures 8-10 illustrate, the sale of small cars to urban households increases under all strategy settings, with the rate of increase lowest under the individual travel strategy. There, medium-sized cars lead in total sales. By contrast, the sales collapse of the medium Otto-cycle under the in-place policy, and the group travel strategy is consistent with its virtual disappearance from

TABLE 2 Projected Urban Sales of New Cars by Size and Engine Type in Scenario I Under In-Place Policy

		1990 Estimates[a,b] (10^6)				2000 Estimates[a,c] (10^6)			
Car Size	Engine Type	Uniform Charge	Stratified Charge	Turbo-charge	All Units	Uniform Charge	Stratified Charge	Turbo-charge	All Units
Small	Otto cycle	1.719	1.509	0.964		3.354	2.945	1.882	
Medium	Otto cycle	1.415	1.242	0.794		0.219	0.192	0.123	
Large	Otto cycle	0.636	0.559	0.357		0.604	0.531	0.339	
Mini	Otto cycle	-	0.151	-		-	0.284	-	
Small plus mini	Diesel				0.220				0.572
Medium	Diesel				0.402				0.036
Large	Diesel				0.449				0.099
Van	Diesel				0.035				0.074
Medium	Electric (lead-acid battery)				0.034				0.171
Medium	Electric (nickel-zinc battery)				0.260				0.064
Large	Brayton cycle				-				0.439

[a]These are manufacturing estimates, with equivalent sales assumed.
[b]Total urban nonfleet sales of new cars projected for 1990, all sizes and engine types = 10,512,000.
[c]Total urban nonfleet sales of new cars projected for 2000, all sizes and engine types = 11,928,000.

TABLE 3 Projected Urban Sales of New Cars by Size and Engine Type in Scenario I Under Group Travel Strategy

		1990 Estimates[a,b] (10^6)				2000 Estimates[a,c] (10^6)			
Car Size	Engine Type	Uniform Charge	Stratified Charge	Turbo-charge	All Units	Uniform Charge	Stratified Charge	Turbo-charge	All Units
Small	Otto cycle	1.453	1.276	0.815		2.624	2.303	1.472	
Medium	Otto cycle	1.961	1.722	1.101		0.422	0.370	0.236	
Large	Otto cycle	0.424	0.381	0.245		0.142	0.125	0.080	
Mini	Otto cycle	-	0.130	-		-	0.265	-	
Small plus mini	Diesel				0.357				0.282
Medium	Diesel				0.450				0.151
Large	Diesel				0.082				0.014
Van	Diesel				0.028				0.022
Medium	Electric (lead-acid battery)				0.043				0.401
Medium	Electric (nickel-zinc battery)				0.034				0.169
Large	Brayton cycle								0.439

[a]These are manufacturing estimates, with equivalent sales assumed.
[b]Total urban nonfleet sales of new cars projected for 1990, all sizes and engine types = 10,512,000.
[c]Total urban nonfleet sales of new cars projected for 2000, all sizes and engine types = 9,389,000.

TABLE 4 Projected Urban Sales of New Cars by Size and Engine Type in Scenario I Under Individual Travel Strategy

		1990 Estimates[a,b] (10^6)				2000 Estimates[a,c] (10^6)			
Car Size	Engine Type	Uniform Charge	Stratified Charge	Turbo-charge	All Units	Uniform Charge	Stratified Charge	Turbo-charge	All Units
Small	Otto cycle	1.601	1.406	0.899		1.548	1.360	0.868	
Medium	Otto cycle	1.479	1.298	0.830		0.756	0.664	0.424	
Large	Otto cycle	0.605	0.530	0.339		0.476	0.417	0.267	
Mini	Otto cycle	-	0.036	-		-	0.039	-	
Small plus mini	Diesel				0.510				0.785
Medium	Diesel				0.466				0.379
Large	Diesel				0.191				0.239
Van	Diesel				0.317				0.329
Medium	Electric (lead-acid battery)				0.004				0.004
Medium	Electric (nickel-zinc battery)				0.001				0.005
Medium	Electric (lithium-metal sulfide battery)								0.447
Large	Brayton cycle								1.042
Van	Brayton cycle								0.082
Medium	Stirling cycle								1.793

[a]These are manufacturing estimates, with equivalent sales assumed.

[b]Total urban nonfleet sales of new cars projected for 1990, all sizes and engine types = 10,512,000.

[c]Total urban nonfleet sales of new cars projected for 2000, all sizes and engine types = 11,924,000.

household fleet preferences in the holdings model (Figures 8 and 9). This is in part attributable to its unsatisfactory competitive position over time, specifically with reference to vehicle characterization in the stock model; that is, its market is squeezed from both sides as large cars are downweighted and small cars improve dramatically in performance. It is also partly an effect of the demographic changes that actually occur in the scenario. These changes apparently preclude creation of a viable market for a spartan general-purpose car targeted for low-income households.

Surprisingly, medium-sized (five-passenger) cars are shown to retain the momentum of thé healthy 1980 sales performance of this size class right up to 1990--with especially strong results in the early years of the group travel strategy--in response to steeply rising fuel costs. This trend accords with encouragement of multiple-person occupancy of vehicles under the group travel strategy, but it is not driven by that encouragement. However, the momentum is not sustained as household size diminishes and fast-growing operating costs ultimately move the great majority of car owners to choose four-passenger cars.

Diesel car sales stabilize at 5 to 15 percent of total sales by 2000; they perform best, as expected, under the individual travel strategy. The penetration is low relative to some current forecasts of diesel market share; this is explained by the ceiling imposed on 1990 sales of diesel fuel as a supply

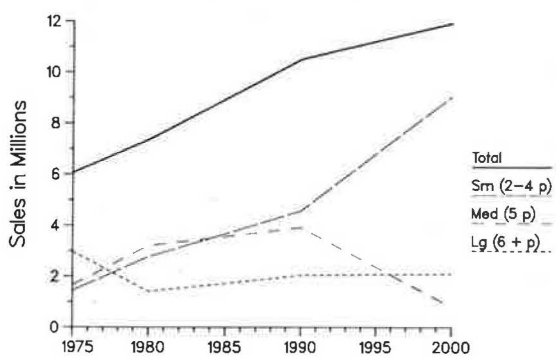

FIGURE 8 Projected urban sales of new cars by size in scenario I under in-place policy.

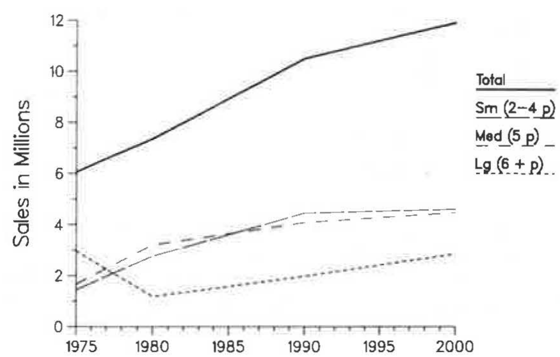

FIGURE 10 Projected urban sales of new cars by size in scenario I under individual travel strategy.

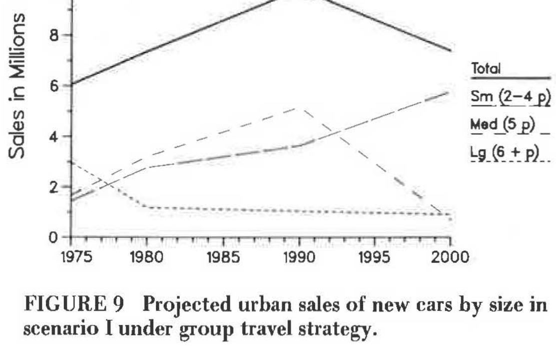

FIGURE 9 Projected urban sales of new cars by size in scenario I under group travel strategy.

constraint, a constraint that effectively caps post-1990 diesel car sales also. Diesel technology was represented in the vehicle choice model by a single surrogate with the combined characteristics of five- and six-passenger diesel cars, and the diesel cars therefore competed primarily against Otto-cycle cars in the large and medium-sized classes. However, the progress of diesel fuel economy, price, and performance is low after 1990 relative to improvements in most other vehicles in the choice model. Combined with the declining market for large cars after 1990, the diesel fares rather poorly under all strategies.

Scenario III New Car Sales

The data in Tables 5-7 project car-size and engine-type distributions to vehicles in scenario III under each of the three strategy settings, respectively. Figures 11-13 project sales of cars by size class (for 1990 and 2000) for the same three strategies in the same scenario. Scenario III vehicle options and level of technology available to buyers under the in-place policy and group travel strategy are identical to their scenario I counterparts. That is, buyers under the in-place setting as applied in scenarios III and I have the same new car options to choose from, the only difference being the respective scenario new car purchase prices, which reflect the differing cost of financing (8 percent in scenario I and 12 percent in scenario III). Group travel options are also the same in the two scenarios; group travel vehicles differ from those of the in-place setting only in that the medium-sized Otto is improved in each scenario. Therefore, it is not surprising that scenario III forecasts (Figures 11 and 12) are similar to those for the corresponding strategy settings applied in scenario I (Figures 8 and 9).

Individual travel vehicles in scenario III differ from their scenario I counterparts in that they represent modest across-the-board technological improvements relative to in-place vehicles rather than significant new departures in technology or materials utilization. The medium Otto under group travel in scenario III is the same as the medium Otto under individual travel in that scenario; all available vehicles under individual travel have improved in fuel economy and performance comparable to that of the medium Otto defined for the group travel strategy, but they have done so at the expense of increased weight and purchase cost. Not surprisingly then, the year-2000 sales distribution among the three size classes under the individual travel strategy does not indicate the massive swing

TABLE 5 Projected Urban Sales of New Cars by Size and Engine Type in Scenario III Under In-Place Policy

		1990 Estimates[a,b] (10^6)				2000 Estimates[a,c] (10^6)			
Car Size	Engine Type	Uniform Charge	Stratified Charge	Turbo-charge	All Units	Uniform Charge	Stratified Charge	Turbo-charge	All Units
Small	Otto cycle	1.598	1.404	0.896		2.843	2.497	1.595	
Medium	Otto cycle	1.369	1.202	0.768		-	-	-	
Large	Otto cycle	0.516	0.454	0.289		0.516	-	-	
Mini	Otto cycle	-	0.165	-		-	0.336	-	
Small	Diesel				0.318				0.529
Medium	Diesel				0.348				0.035
Large	Diesel				0.364				0.068
Van	Diesel				0.036				0.068
Medium	Electric (lead-acid battery)				0.050				0.372
Medium	Electric (nickel-zinc battery)				0.038				0.133
Large	Brayton cycle								0.394

[a]These are manufacturing estimates, with equivalent sales assumed.
[b]Total urban nonfleet sales of new cars projected for 1990, all sizes and engine types = 9,815,000.
[c]Total urban nonfleet sales of new cars projected for 2000, all sizes and engine types = 9,386,000.

TABLE 6 Projected Urban Sales of New Cars by Size and Engine Type in Scenario III Under Group Travel Strategy

		1990 Estimates[a,b] (10^6)				2000 Estimates[a,c] (10^6)			
Car Size	Engine Type	Uniform Charge	Stratified Charge	Turbo-charge	All Units	Uniform Charge	Stratified Charge	Turbo-charge	All Units
Small	Otto cycle	1.359	1.193	0.762		2.156	1.893	1.209	
Medium	Otto cycle	1.841	1.617	1.034		-	-	-	
Large	Otto cycle	0.339	0.297	0.190		0.619	-	-	
Mini	Otto cycle	-	0.145	-		-	0.279	-	
Small	Diesel				0.168				0.223
Medium	Diesel				0.531				0.131
Large	Diesel				0.189				0.011
Van	Diesel				0.029				0.022
Medium	Electric (lead-acid battery)				0.069				0.421
Medium	Electric (nickel-zinc battery)				0.052				0.158
Large	Brayton cycle								0.245

[a]These are manufacturing estimates, with equivalent sales assumed.
[b]Total urban nonfleet sales of new cars projected for 1990, all sizes and engine types = 9,815,000.
[c]Total urban nonfleet sales of new cars projected for 2000, all sizes and engine types = 7,367,000.

TABLE 7 Projected Urban Sales of New Cars by Size and Engine Type in Scenario III Under Individual Travel Strategy

		1990 Estimates[a,b] (10^6)				2000 Estimates[a,c] (10^6)			
Car Size	Engine Type	Uniform Charge	Stratified Charge	Turbo-charge	All Units	Uniform Charge	Stratified Charge	Turbo-charge	All Units
Small	Otto cycle	1.118	0.982	0.627		1.553	1.364	0.871	
Medium	Otto cycle	1.315	1.156	0.739		1.083	0.951	0.607	
Large	Otto cycle	1.024	0.900	0.575		0.639	0.561	0.359	
Mini	Otto cycle	-	0.137	-		-	0.310	-	
Small	Diesel				0.183				0.497
Medium	Diesel				0.507				0.321
Large	Diesel				0.462				0.189
Van	Diesel				0.029				0.028
Medium	Electric (lead-acid battery)				0.037				0.029
Medium	Electric (nickel-zinc battery)				0.024				0.009
Large	Brayton cycle								0.904

[a]These are manufacturing estimates, with equivalent sales assumed.

[b]Total urban nonfleet sales of new cars projected for 1990, all sizes and engine types = 9,815,000.

[c]Total urban nonfleet sales of new cars projected for 2000, all sizes and engine types = 10,275,000.

to small cars observed under the group travel strategy and in-place policy, although the emergence of a similar, if damped, trend is evident (Figure 13).

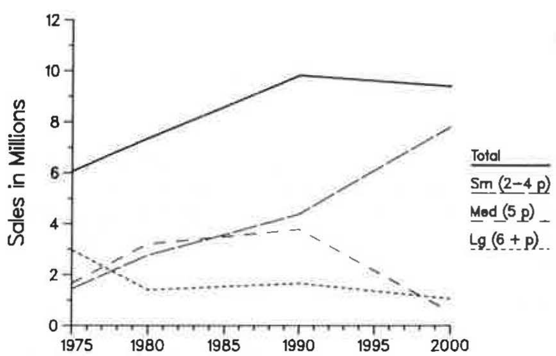

FIGURE 11 Projected urban sales of new cars by size in scenario III under in-place policy.

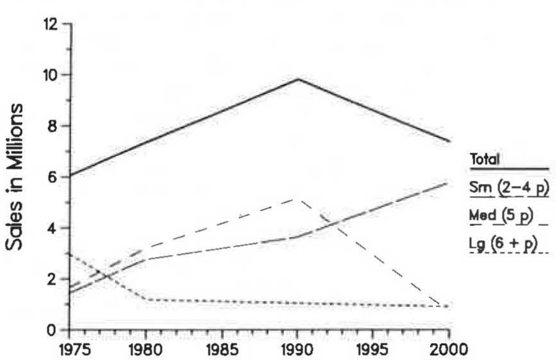

FIGURE 12 Projected urban sales of new cars by size in scenario III under group travel strategy.

As in scenario I, new technologies achieve modest gains in sales through 2000. In scenario III under in-place policy electric vehicles reach a 5.4 percent sales penetration of the urban household market. The group travel strategy, in which total car sales are lower, raises that penetration to 7.9 percent in 2000. However, electric cars are overwhelmed by superior heat-engine technology in scenario III under the individual travel setting, in which their penetration falls to less than 1 percent

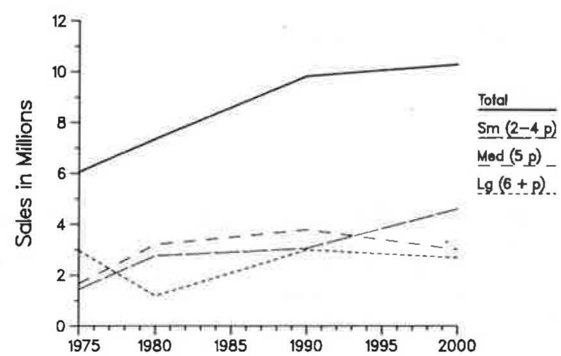

FIGURE 13 Projected urban sales of new cars by size in scenario III under individual travel strategy.

of year-2000 sales. The six-passenger car with a Brayton-cycle engine attracts 8.8 percent of urban car buyers under the individual travel strategy in 2000; it fares less well (but credibly) under the other two strategies. Diesel, again, achieves only 5 to 10 percent of sales across the strategy settings in 2000.

Given the slightly improved technology set of the individual travel strategy, size-class trends in Figure 13 exhibit a pattern similar to that under individual travel in scenario I (Figure 10). Large and medium-sized cars remain in the market after 2000, although small cars are clearly in the ascendant.

COMPARISON OF TAPCUT RESULTS AND PREVIOUS FORECASTS

Distributions

The data in Table 8 compare DVSAM results against certain other published year-2000 forecasts of vehicle stock and sales by technology share and size mix. In all cases DVSAM distributions are urban-only, whereas others are nationwide. Moreover, aggregation to size classes in several of the studies followed procedures different from those used for

TAPCUT. For example, Shackson and Leach (11) used 1979 model-year body platform rather than U.S. Environmental Protection Agency (EPA) classifications to define vehicle size, which resulted in many EPA midsized cars being classified as large by Shackson and Leach, but they were classified as medium sized in TAPCUT. The Shackson and Leach mix-shift case, in which the share of large car sales declines to 10 percent by 2000 whereas midsized and small car sales increase, is given in the data in Table 8.

TABLE 8 Comparison of Vehicle-Size and Engine-Technology Market Shares for the Year 2000 in TAPCUT and Five Other Projections (percentage of total market)

		Vehicle Size (%)									
		Sales Mix			Fleet Mix (holdings)			Engine Technology (%)			
Source of Projection	Date	Small	Medium	Large	Small	Medium	Large	Otto	Diesel	Electric	AHE[a]
TAPCUT, scenario I, in-place policy	1/82	76	7	17	61	19	20[b]	87	7	2	4
TAPCUT, scenario I, individual travel strategy	1/82	39	37	24	36	39	25[b]	57	15	4	24
TAPCUT, scenario III, in-place policy	1/82	83	6	11	59	20	21[b]	83	8	5	4
Mellon Institute (11)	8/80	52	38	10	-[d]	-[d]	-[d]	57	30[e]	-[d]	13
Lawrence Livermore Laboratory (12)	12/80	-[d]	-[d]	-[d]	-[d]	-[d]	-[d]	70	28	2	0
Energy and Environmental Analysis, Inc. (13)	7/81	-[d]	-[d]	-[d]	-[d]	-[d]	-[d]	73	27	0	0
Oak Ridge National Laboratory (14)	5/81	33	47	20	-[d]	-[d]	-[d]	85	15	0	0
Argonne National Laboratory (15)	8/79	-[d]	-[d]	-[d]	40	25	35	-[d]	-[d]	-[d]	-[d]

[a]Advanced heat-engine technology.
[b]Sprawlburg only.
[c]Imports assumed by Argonne National Laboratory to be evenly divided between small and medium-sized cars.
[d]Data unavailable.
[e]May include high-technology Otto share.

Technology Penetration

With the exception of the scenario I individual travel strategy, TAPCUT forecasts appear somewhat pessimistic on the future of light-duty diesel vehicles (in household use) relative to other published projections. This is attributable in the context of year-2000 sales to the superior qualities of TAPCUT Otto-cycle cars competing with diesels: diesels retain the sales share achieved by 1990 but do not increase that share thereafter. In contrast, TAPCUT is relatively optimistic on electric vehicles; the stock model has identified a market (generally in the low- to middle-income range) in which the overall characteristics of electric cars characterized for TAPCUT are found to be desirable. Nevertheless, operating cost and performance limitations of all but the very high technology electric vehicles (available only in scenario I, individual travel strategy) inhibit significant market growth.

Advanced heat-engine vehicles capture a high market share only in the scenario I individual travel strategy, where two such vehicles are available in 2000. In all strategy and scenario combinations, Otto-engine vehicles continue to account for no less than 57 percent, and up to almost 90 percent, of sales in the year 2000.

Size Mix

In five of the six TAPCUT strategy and scenario combinations small Otto (primarily four-passenger) vehicles dominate both fleet and sales shares by the year 2000. The explicit presence of a small diesel car in the DVSAM choice set might have divided the small-car share more evenly between technologies, but small cars would still account for a majority of the fleet at the end of the century. By this projection, medium-sized and large cars could not realistically be scrapped fast enough, and domestic production lines would have to be devoted almost exclusively to four-passenger car production unless this huge market is to be conceded to imports. This size mix is probably the most controversial result of the DVSAM and the one at greatest variance with most other published forecasts, which envision a continued strong showing by the midsized and compact (five- and six-passenger) vehicles through the end of the century. However, none of these other forecasts were driven by fuel price increases as steep as those under the TAPCUT strategies. The failure of the medium-sized car in the TAPCUT projection stems from the unsatisfactory performance characteristics of that car relative to the competition in all but scenario I under the individual travel strategy.

Final Observation

Throughout the stock-modeling process the characteristics of a vehicle, rather than scenario demographics, determined its fleet share and its ultimate fate. Such marginal effects as the number of two-person households, which appears to influence the slight difference between scenario I and scenario III under the in-place policy in the small car share of the market, also play a role. But such effects are secondary in the central decision-making process modeled across the entire spectrum of households. That process consists of determining whether a car is a winner or a loser relative to the competition. Apparently there is no natural household market for any type of vehicle in the DVSAM. Although its results may not articulate a future plausible to all analysts, the model clearly indicates that car owners will continue to seek the best value for their personal transportation dollars, irrespective of the socioeconomic or political tenor of the times.

ACKNOWLEDGMENT

Three individuals merit special credit for facilitating the preparation of this paper. Joe Perl of Northwestern University laid the groundwork for the use in this study of the incremental logit form of the Lave-Train model in several technical memoranda documenting and defending its selection for TAPCUT. He also prepared the initial version of the FORTRAN code for the model as used with NPTS household cell data and performed the baseline holdings distribution by cell. Marc Kaplan contributed methodological assistance, support, and direction to the development of the final form of DVSAM. Sarah LaBelle assisted in early documentation of DVSAM and provided a valuable editorial critique of early drafts of this paper. To these persons the authors extend their gratitude. The work reported in this paper was sponsored by the Office of Environmental Analyses, U.S. Department of Energy.

REFERENCES

1. S.R. Lerman and M. Ben-Akiva. Disaggregate Behavioral Model of Automobile Ownership. In Transportation Research Record 569, TRB, National Research Council, Washington, D.C., 1976, pp. 34-55.
2. S.R. Lerman. Location, Housing, Automobile Ownership, and Mode to Work: A Joint Choice Model. In Transportation Research Record 610, TRB, National Research Council, Washington, D.C., 1976, pp. 6-11.
3. T.F. Golob and L.D. Burns. Effects of Transportation Service on Automobile Ownership in an Urban Area. In Transportation Research Record 673, TRB, National Research Council, Washington, D.C., 1978, pp. 137-145.
4. L.A. Lave and K. Train. A Disaggregated Model of Auto Type Choice. Transportation Research, Vol. 13A, 1979, pp. 1-9.
5. C.F. Manski and L. Sherman. An Empirical Analysis of Household Choice Among Motor Vehicles. Transportation Research, Vol. 14A, 1980, pp. 349-366.
6. T.J. Tardiff. Vehicle Choice Models: Review of Previous Studies and Directions for Further Research. Transportation Research, Vol. 14A, 1980, pp. 327-336.
7. R.H. Asin. 1977 Nationwide Personal Transportation Study: User's Guide for Public Use Tapes. FHWA, U.S. Department of Transportation, April 1980.
8. S.J. LaBelle et al. Technology Assessment of Productive Conservation in Urban Transportation, Final Report. Report ANL/ES-130. Argonne National Laboratory, Argonne, Ill., Nov. 1982.
9. K. Train. The Potential Market for Non-Gasoline-Powered Automobiles. Transportation Research, Vol. 14A, 1980, pp. 405-414.
10. B.R. Peterson. City Decomposition and Expansion. Report ORNL/TM-8502. Oak Ridge National Laboratory, Oak Ridge, Tenn., Sept. 1982.
11. R. Shackson and H.J. Leach. Maintaining Automotive Mobility: Using Fuel Economy and Synthetic Fuels to Compete with OPEC Oil. Energy Productivity Center, Mellon Institute, Arlington, Va., Aug. 1980.
12. L.G. O'Connell; Laurence Livermore Laboratory. Energy Storage Systems for Automotive Propulsion, Final Report--Volume 4: National Impact Issues. U.S. Department of Energy, Dec. 1980.
13. The Highway Fuel Consumption Model. Fourth Quarterly Report. Energy and Environmental Analysis, Inc., Arlington, Va., July 1981.
14. D. Greene et al. Energy Savings Impacts of DOE's Conservation and Solar Programs. Report ORNL/TM-7690-V2. Oak Ridge National Laboratory, Oak Ridge, Tenn., May 1981.
15. R. Knorr and M. Millar. Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline. Report ANL/CNSV-4. Argonne National Laboratory, Argonne, Ill., Aug. 1979.

Projection of Typical Characteristics of Automobiles and Transit Vehicles for Policy Analysis

CHARLES L. HUDSON and EVELYN S. PUTNAM

ABSTRACT

In this paper the characteristics of three future automotive technology sets are described, starting from historical data and projected forward in time along paths suggested by given alternate future socioeconomic environments. The characterizations include quantified projections of automobile and transit vehicle weight, performance, fuel economy, consumer price, operating cost, materials of construction, fuels and environmental residuals associated with their manufacture, operating pollutants, and infrastructure-related energy expenditures, emissions, and cost. Brief descriptions of rationale and calculational procedures are also given, and selected results are presented. The breadth of the vehicle characterizations permits the effects of policy options on most facets of the urban transportation section to be examined. The methodologies developed in this work are generalized, and hence can be used with alternate assumptions in a variety of investigations. For purposes of the Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT) policy analysis, each technology set consisted of six sizes of personal automobiles, each propelled by conventional

Otto, stratified-charge Otto, turbocharged Otto, diesel, Brayton, or Stirling heat engines; and lead-acid, nickel-zinc, or lithium-sulfide battery-electric systems. The characteristics of 13 types of urban transit vehicles and systems were also projected for each technology set. Thirty-one current and potential materials of vehicular construction were identified. From the bills of materials developed for each vehicle, the amounts of 6 types of fuels used and 31 kinds of residuals produced in their production were also projected for each set, and then disaggregated into extraction, manufacturing, and recycling-production phases.

The characteristics of vehicles and the cost of fuels influence consumer choice and hence the composition of the vehicle fleet. In turn, fleet characteristics are major determinants of the fuel consumed in transportation, and they influence the effectiveness and direction of policies designed to encourage productive conservation. In this paper the methods used and the results obtained in projecting the technical characteristics of future vehicles as they might evolve under the conditions embodied in three alternative socioeconomic environments are described. The resulting technology data sets are expressed in terms of the performance, price, fuel efficiency, and other technical characteristics of alternative future vehicle stocks. These data sets were used as input data for the policy analysis models.

Materials of manufacture, vehicular manufacturing practices, and construction of infrastructure also influence energy consumption and the production of environmental residuals. These variables also were characterized for each technology data set, thus providing a basis for making alternative projections of direct and indirect urban transportation energy consumption and concomitant environmental effects.

APPROACH

Figure 1 shows how the vehicle characterization task was organized. First, to provide a manageable data base, the enormous existing number of personal and transit vehicle types were aggregated into typical vehicle size classes. The U.S. Environmental Protection Agency (EPA) size classification system (1) was used for personal automobiles, and predominate existing sizes were used for transit vehicles. Then 1980 model automobiles were characterized by using sales-weighted average values for nonspecialty domestic and foreign vehicles in the selected size classes. Baseline transit vehicle characteristics were estimated by averaging available data in the appropriate size categories.

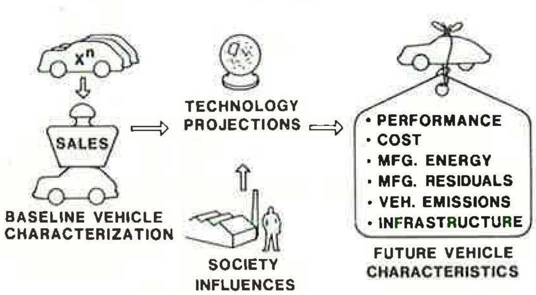

FIGURE 1 Major vehicle characterization tasks.

Qualitative judgments were made on how the alternative socioeconomic environments, including the projected fuel prices, might influence consumer demand and how industry might respond. Next, based partly on published estimates and partly on engineering judgment, the type of change in automotive technology that might take place in each alternative environment was quantified. By using these projections of technological change for vehicle subsystems, the technical characteristics of personal and transit vehicles comprising three potential vehicle stocks were defined.

BASELINE VEHICLE CHARACTERIZATION

The baseline vehicle characteristics are given in Table 1 and were calculated from published statistics (2). Engine weights were estimated from the following equations derived from Dowdy et al. (3):

$$\text{Otto engine weight (lb)} = 11.878(\text{hp})^{0.761}.$$

$$\text{Generic diesel engine weight (lb)} = 9.659(\text{hp})^{0.888}.$$

The calculated generic diesel engine weights may be somewhat heavier than actually installed in 1980 automobiles because many of these are modified-Otto engines and are slightly lighter than generic diesels. Transit vehicle electric motor weights were estimated from published technical data. The body weights given in Table 1 represent the difference between curb weight and the calculated engine and motor weight.

Total automobile operating costs were not estimated because they depend on fuel cost, which was allowed to vary in the policy analysis. However, fuel efficiencies were characterized, and major repair, maintenance, and tire-replacement costs were estimated by using curb weight and price-related equations derived from Liston (4). Estimates were also made of engine-specific service costs.

Although generic diesels are expected to require less repair and maintenance, the modified-Otto diesels and generic diesels in the fleet are trouble prone (5). Therefore, the same repair and maintenance equation was used for both vehicle types.

Transit operating costs were estimated from statistical data (6) and personal interviews with several transit operators.

ALTERNATE SOCIOECONOMIC ENVIRONMENT INTERPRETATION

To initiate the characterization it was necessary to project the kinds of vehicular performance likely to emerge in the given socioeconomic environments. In each of these environments fuel costs were projected to be considerably higher than experienced today, thus providing a major driving factor in the vehicle characterization. Specific fuel prices were projected for each scenario, whereas the amount of tax was varied by policy. The forecast prices are described in separate reports (7, and paper by Moses, LaBelle, and Bernard elsewhere in this Record). A dynamic, competitive society was interpreted to result in consumer demand for high performance and the best possible fuel efficiency. It was also interpreted to result in a business and industrial climate conducive to investment in research and development. As a result, satisfaction or consumer demands by the automobile industry was premised through the use of advanced materials, engine technology, and design methods. The vehicles characterized under these societal conditions were referred to as technology set A (the best vehicles) in the policy analysis.

In contrast, the community-oriented spirit of an

TABLE 1 Baseline (1980) Vehicle Characterization

Engine, Motor Type, and Size Class	Engine and Motor Weight (lb)	Body Weight (lb)	Curb Weight (lb)	Power (hp)	Performance[a] (hp/lb)	Fuel Efficiency[b] (miles/gal)	Price[c,d] ($)	Operating Cost[c] ($/mile)
Automobile								
Otto								
Mini[e]	330	1,826	2,156	79	0.032	28	3,495	0.032[f]
Small[e]	343	2,026	2,369	83	0.031	24	4,002	0.034[f]
Medium[e]	425	2,686	3,111	110	0.032	19	4,918	0.039[f]
Large[e]	468	3,235	3,703	125	0.031	16	6,215	0.045[f]
Van[e] (15 passengers)	491	3,197	3,688	133	0.033	14	4,930	0.038[f]
Van[g] (9 passengers)	291	2,884	3,175	67	0.019	16	7,013	0.049[f]
Diesel								
Small[h]	305	1,549	1,853	48	0.022	40	4,597	0.037[f]
Medium[e,i]	561	2,859	3,420	97	0.026	25	5,554	0.043[f]
Large[j]	602	3,479	4,081	105	0.024	20	6,779	0.049[f]
Diesel buses								
25-28 ft	713	12,087	12,800	127	0.010	7	62,600	1.76[k]
35-40 ft	1,112	22,388	23,500	210	0.009	3.5	115,000	1.76[k]
Rail, heavy electric	5,500	76,000	81,500	NA	NA	8.4[l]	500,000	2.00

[a] 300-lb load.
[b] Automobiles, EPA urban cycle; transit vehicles, experienced.
[c] Price and cost in 1975 dollars.
[d] Basic vehicle with automatic transmission.
[e] Sales-weighted data.
[f] Less fuel cost.
[g] Volkswagon van.
[h] Volkswagon Rabbit.
[i] 1980 Oldsmobile diesel price (deflated).
[j] 1980 Olds 98 data (deflated).
[k] Approximate; depends on labor costs.
[l] kWh/car mile.

environmentally concerned and family-centered society would cause consumers to be willing to sacrifice performance for improved fuel economy and reduced emissions. This inferred extremely light, low-power vehicles designed to maximize internal volume at the expense of styling. Nevertheless, intensive research and development would be required to attain maximum engine efficiency and weight reduction. In this consensus society automobile manufacturers would attain the same technological success in achieving these goals as in the competitive society, but would select different materials and promote greater material recycling. The resulting vehicle stock is referred to as technology set B (the conservation vehicles) in the policy analysis.

In a divisive society characterized by a lack of national purpose and sharply stratified economic classes, consumer automobile demands might split into prestige vehicles with high-performance, fair-to-good fuel economy at a high price, and utilitarian vehicles with good fuel economy at a low price. In this uncertain and socially inefficient climate an aversion to risk taking would develop within industry, thereby resulting in substantially lower technological achievement. In general, technological progress might range from 50 to 75 percent of that projected for the other alternative socioeconomic environments, with most of that progress driven by the federal fuel economy laws now in effect (Energy Policy and Conservation Act of 1975). This vehicle stock projection is referred to as technology set C (the expected vehicles) in the policy analysis.

Transit vehicle technology was judged less sensitive to socioeconomic pressures because of traditional industry conservatism; thus it was projected to follow slow evolutionary trends. No radical designs would be offered, but relevant technology improvements from the automobile industry would be adopted.

TECHNOLOGY PROJECTIONS

In projecting characteristics of future urban transportation technologies, the market entry of new engine types [program combustion (PROCO) and Texico control combustion system (TCCS) stratified charge, Brayton, and Stirling] and lead-acid, nickel-zinc, and lithium-sulfide battery-electric and hybrids was considered in addition to existing Otto and diesel engines. Intrinsic engine-efficiency improvements were projected separately from improvements gained through engine weight reduction. Body weight reductions were considered as the sum of downsizing and material substitutions. Improvements in timing and technology entry dates were driven by industry capacity and other considerations appropriate to the alternate-socioeconomic, environment-derived technology sets. Figure 2 shows the projection method, and Figures 3-10 show anticipated changes in engine and body technology for each technology set. In Figures 3-10 curves derived from published estimates are presented as solid lines. Curves generated in the course of this study are shown as dashed lines. Rationale and supporting bases for these subsystem projections are described in the following subsections.

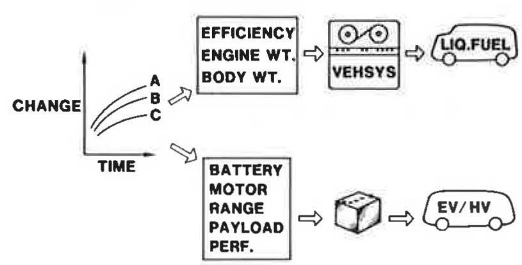

FIGURE 2 Projection method.

Specific Horsepower

In Figure 3 the 10 percent improvement in specific horsepower by 1985 and the 15 percent improvement projected by 1990 for technology sets A and B are estimates given by Renner and Siegel (8) for the uniform-charge Otto engine. The 15 percent improvement correlates with the projections given by Ciccarone (9). It was estimated that technology set C, in 2000, would approach the 1990 efficiency of sets A and B. Although few such specific projections for other engine technologies were located, it was assumed that competitive forces would generally result in similar efficiency improvement curves for all technologies in a specific technology set.

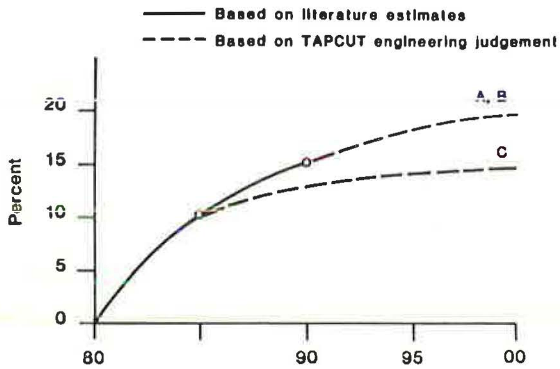

FIGURE 3 Increase in engine-specific horsepower, percentage by year and technology set.

Otto-engine efficiency improvements are expected to result from modifications such as closed-loop combustion control, low-friction lubricants, fuel injection, combustion-chamber shape, knock sensing, and improved power train matching. Diesel engine efficiencies are projected to improve from higher speed [revolutions per minute (rpm)] capabilities, better injector and combustion chamber design, increased structural rigidity, and improved power train matching. Although Brayton and Stirling engines are currently under development, efficiencies should improve over current estimates by the percentages given in Figure 3 when improved understanding of combustion dynamics, hydrodynamic flows, and high-temperature management techniques is achieved. Electric motors may show a substantial shift to alternating current (ac) operation and control. Turbocharging was considered in this study as a load-leveling add-on (see Figure 5), but it is not included in Figure 3.

Uniform-Charge, Otto-Engine Weight

The technology set A and B curve in Figure 4 represents the total estimated weight reduction that could be achieved through design improvements and substitution of lighter materials. The 1980 baseline weight includes data presented by Bryant (10).

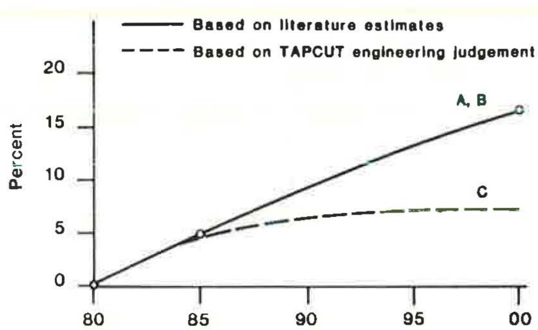

FIGURE 4 Reduction in uniform-charge Otto-engine weight, percentage by year and technology set.

The estimated 5 percent weight reduction by 1985 for Otto engines in all technology sets represents a continuation of the trend to replace cast-iron cylinder heads with aluminum (11), and to replace other lightly loaded parts with either aluminum or plastic materials. The year-2000 weight reduction for technology sets A and B (shown in Figure 4) is based on an estimate that a 12 to 15 percent weight reduction can be achieved by using all-aluminum engines and perhaps magnesium as a crankcase material (12,13). Increased use of high-temperature plastics is also projected.

A recent study reviewed contemporary engines and found that advanced engine power-to-weight ratios were 16 to 17 percent better than in 1978 (note that these data were from a 1981 unpublished draft report by C.L. Hudson of Hudson Associates on an updated aluminum-air vehicle cost procedure; this report was prepared for Lawrence Livermore National Laboratory). This correlates well with the sum of the efficiency and weight percentage projections given in Figures 3 and 4 when extrapolated to 1978. In the same study naturally aspirated advanced diesel engines were found to be about 20 percent heavier than Otto engines of equivalent horsepower in 1981 versus 45 percent heavier in 1980. These data support the estimates shown in Figure 6.

In contrast to the optimized engines projected for technology sets A and B, the engines in set C represent only minor weight-reducing changes after 1985, such as the use of aluminum and plastic radiators, filter housings, and nonstructural bracketing, with no major additional changes to the engine.

Turbocharged, Uniform-Charge, Otto-Engine Weight

The curves in Figure 5 are mostly conjectural and based on 1980 data, which indicate that turbocharging can boost peak horsepower nearly 50 percent (2). If the turbocharger were considered a load-leveler, then the engine could be downsized. However, a weight penalty might be incurred, and the overall weight reduction might be about 35 percent. The shape of the curves reflects the projections of Shackson and Leach (14) that the use of turbocharging will increase significantly between 1987 and 1990.

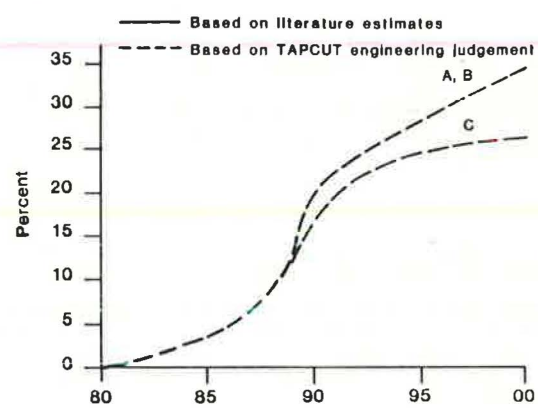

FIGURE 5 Weight reduction in uniform-charge Otto engine with turbochargers, percentage by year and technology set.

Diesel Engine Weight

Domestic (and some foreign) diesel engines are modified production Otto engines designed expressly to attain corporate average fuel economy (CAFE) standards. The durability of these engines is not yet proved. If diesel emission-control technology permits the eventual 0.4 g per mile NO_x and other potential standards for emissions unique to the engine to be met, then a decision is likely to be made before 1990 to aggressively pursue diesel technology (14). Under these conditions generic diesels would probably be developed for domestic automobiles in all three technology sets but for different reasons. In technology set C the underlying cause might be liability reduction, and in sets A and B the cause might be the pursuit of maximum efficiency and reliability.

To obtain Otto-engine weight equivalence, turbocharging of generic diesels may be required (15). This judgment is reflected in the 1990 crossover point in the diesel weight-reduction curve for sets A and B shown in Figure 6. In addition to turbocharging, an estimated weight reduction of about 30 percent for advanced (adiabatic) diesels is also projected (15). However, the less-optimistic estimate of a 20 percent weight reduction made by Dowdy et al. (3) is more realistic and was adopted for the characterization.

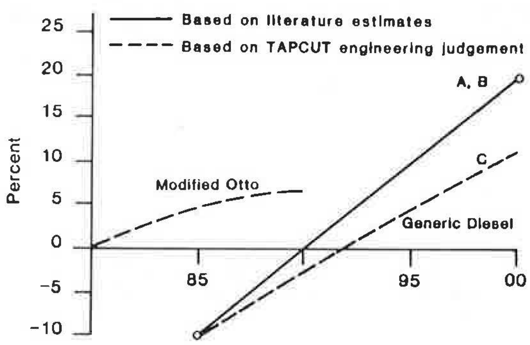

FIGURE 6 Reduction in diesel engine weight relative to 1980 Otto engine, equivalent horsepower, percentage by year and technology set.

Stratified-Charge, Otto-Engine Weight

The PROCO or TCCS type of stratified-charge engine incurs a weight penalty compared to Otto engines (3,15). Nevertheless, the fuel efficiency is considered nearly the same as the diesel (14). The estimates of future weight reduction shown in Figure 7 are conjectural, but follow the same slope as weight-reduction projections for the Otto engines because similar weight-saving techniques might also apply.

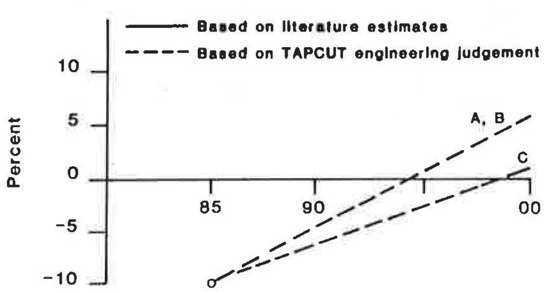

FIGURE 7 Weight reduction in stratified-charge Otto engine, relative to 1980 Otto engine, equivalent horsepower, percentage by year and technology set.

Brayton-Engine Weight

The curve for technology sets A and B in Figure 8 represents average single-shaft and free turbine estimates, adjusted for low and high horsepower. The 1985 datum point is taken from Dowdy et al. (3), and

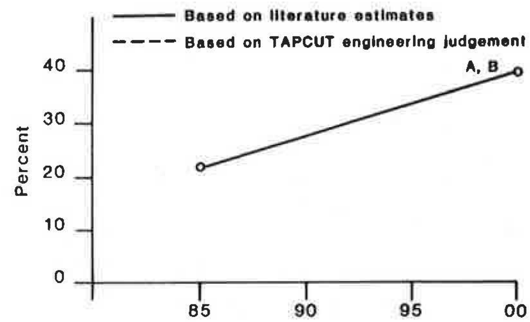

FIGURE 8 Weight reduction in Brayton engine, relative to 1980 Otto engine, equivalent horsepower, percentage by year and technology set (set C may see only limited use).

the 2000 datum point is taken from the Jet Propulsion Laboratory (JPL) (15).

Introduction of Braytons around 1993 for technology sets A and B at about 1 percent per year appears possible (14), although low-horsepower applications may not be viable because of fluid-dynamics limitations. As indicated in Figure 8, Brayton engines probably would not be introduced in set C (except for the possibility of a specialized, very high performance vehicle) because consumer cost would be twice that of an equivalent horsepower Otto (14).

Stirling-Engine Weight

Sources indicate that the specific weight of the Stirling engine is likely to be much greater than that of the Otto engine (3,15). The 2000 datum point in Figure 9 (15) would require extensive use of high-temperature ceramics. Optimism varies as to whether this degree of weight reduction can be attained. Renner and Siegel (8) are optimistic because the thermal efficiency of the engine approaches an ideal Carnot cycle. However, their optimism is tempered when the technological achievements necessary to realize this goal are taken into account. Nevertheless, the potential for reduced emissions is considered excellent.

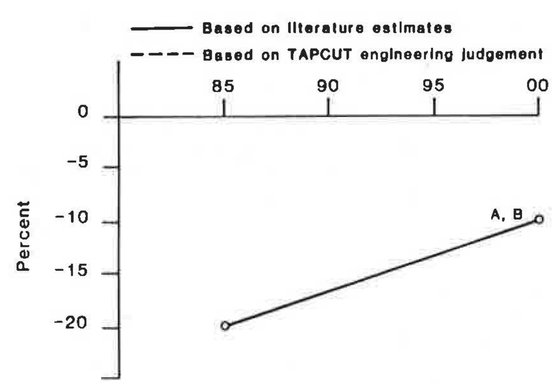

FIGURE 9 Weight reduction in Stirling engines, relative to 1980 Otto engine, equivalent horsepower, percentage by year and technology set.

Shackson and Leach (14) project fleet introduction of the engine at a low market penetration rate, with consumer costs at 2.5 times the Otto engine of equivalent horsepower. These forecasts were adopted for technology sets A and B. Given these technical requirements and cost implications, the Stirling engine was not introduced in technology set C.

Body Weight Reduction

The term body in Figure 10 refers to all components of the vehicle other than the engine; that is, it includes the transmission and drive train. The majority of the vehicle weight is in the vehicle body; the degree of body-weight reduction was an important factor in the vehicle characterization. Many data sources were considered in determining the shape of the curves shown in Figure 10. However, the results of the analyses were fairly summarized by the estimates of Shackson and Leach (14). Therefore, the data points shown reflect their work. The uppermost curve for technology sets A and B represents the maximum weight-reducing effects of downsizing, design changes, and materials substitution. Body-weight reduction for technology set C results primarily from downsizing and design changes; curve C approaches the Shackson and Leach projections for these techniques. The lowest curve applied to vans in all technology sets.

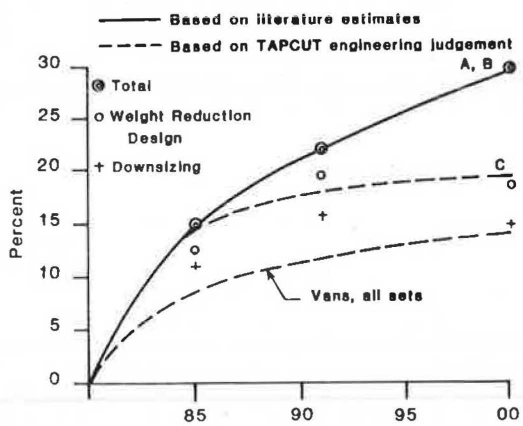

FIGURE 10 Body weight reduction, percentage by year and technology set.

FUTURE VEHICLE PERFORMANCE AND COST CHARACTERISTICS

Performance and Weight Calculations

A computerized iterative procedure (program VEHSYS) was used to calculate the performance and weight of all liquid-fueled automobiles projected for each technology set. Starting with a baseline vehicle of appropriate size, VEHSYS first uses the relationships given in Table 2 to calculate the engine and body weight of a future vehicle with the desired power-to-weight ratio based on 1980 technology.

The technological improvements projected in Figures 3-10 are then used to calculate the new relationship between horsepower and engine weight for the future vehicle. Then the engine and body weight of the future vehicle with the desired body power-to-weight ratio is computed, taking weight-propagation factors into account.

Electric and hybrid automobile weights were computed as a function of performance, vehicle size, battery characteristics, and design range by using a closed-form equation (16). Transit vehicle weight and performance projections were also estimated for each vehicle class and alternate socioeconomic environment (16).

TABLE 2 Relationships Between Horsepower and Engine Weight (lb) Used in Estimating the Initial Performance and Weight Characteristics of Future Vehicles

Engine Type	Equation
Uniform-charge Otto	$WT = 11.878\ (hp)^{0.761}$
Stratified-charge Otto	$WT = 15.750\ (hp)^{0.721}$
Diesel	
Naturally aspirated	$WT = 9.659\ (hp)^{0.888}$
Turbocharged	$WT = 6.232\ (hp)^{0.931}$
Brayton	$WT = 55.4 + 2.265\ (hp)$
Stirling	$WT = 66.667 + 4.333\ (hp)$

Fuel-Efficiency Calculations

The equations derived to estimate automobile fuel consumption are based on empirical data accumulated by the General Motors Corporation (17). These data confirm a previously demonstrated linear relationship between fuel consumption and trip time, namely,

$$FC_w = a + b\,\bar{T} \qquad (1)$$

where

FC_w = fuel consumption, fully warmed engine;
$\bar{T}$ = trip time per unit distance; and
a,b = constants related to the characteristics of the vehicle.

An expression was derived relating constants a and b to vehicle characteristics. Empirical cold-start fuel-consumption data (17) were then used as a basis for deriving factors that were applied to fully warmed fuel-efficiency estimates to project total fuel consumption for various trip distances.

The final form of the fuel-efficiency equation for fully warmed vehicles is

$$FC_w = (0.0304W/B\eta_a) + (0.0753W/B\eta_c) + [(0.0269W)(1 - \eta_c)/B\eta_c]$$
$$= [(11.33C_dA/B\eta_c) + 0.098e_i + 0.140e_b]\,\bar{T} \qquad (2)$$

where

FC_w = fuel consumption, fully warmed engine (gal/mile);
$\bar{T}$ = trip time per unit distance (min/mile);
W_t = vehicle curb weight (lb);
B = energy content of the fuel (Btu/gal);
η_a = system efficiency, acceleration (decimal expression);
η_c = system efficiency, cruise (decimal expression);
C_d = drag coefficient;
A = frontal area (ft²);
e_i = fuel flow rate, idling (gal/min); and
e_b = fuel flow rate, braking (gal/min).

The overall system efficiencies (η_a and η_c) are important contributors to the measure of fuel consumption; their estimation included improvements to transmissions, tires, accessories, and lubricants as well as other factors such as average engine efficiency in the urban driving regime.

The data in Tables 3 and 4 present the engine-specific and vehicle-specific values used in evaluating Equation 2. The data in Figure 11 compare the results of the calculated fuel-consumption relationships to trip time per unit distance (dotted lines) and empirical values for selected fully warmed vehicles.

TABLE 3 Engine-Specific Values Used in Estimating Vehicular Fuel Consumption, Technology Set A

Engine Type	Fuel Flow[a], e_i and e_b (gal/min)	Running Efficiency (acceleration and cruise) Year	η
Otto, uniform charge	$3.78 \times 10^{-3} + [8.9 \times 10^{-5}\ (hp-40)]$	1980	0.14
		1990	0.18
		2000	0.18
Otto, stratified charge	$2.43 \times 10^{-3} + [6.2 \times 10^{-5}(hp-40)]$	1980	0.15
		1990	0.19
		2000	0.19
Otto, turbocharged	$3.78 \times 10^{-3} + [8.9 \times 10^{-5}\ (hp-40)]$	1980	0.13
		1990	0.17
		2000	0.17
Diesel	$1.2 \times 10^{-3} + [2.4 \times 10^{-5}\ (hp-40)]$	1980	0.17
		1990	0.21
		2000	0.21
Brayton			
Diesel fuel	$5.05 \times 10^{-3} + [8.66 \times 10^{-5}\ (hp-40)]$	2000	0.28
JP-4 fuel	$5.24 \times 10^{-3} + [8.98 \times 10^{-5}\ (hp-40)]$		
Stirling	$2.16 \times 10^{-3} + [5.53 \times 10^{-5}\ (hp-40)]$	2000	0.25

[a]Data from Dowdy et al. (*3*).

TABLE 4 Vehicle-Specific Values Used in Estimating Vehicular Fuel Consumption, Technology Set A

Size Class	Year	Frontal Area, A (ft^2)	Coefficient of Drag, C_d
Mini (2 passengers)	1980	16.9	0.50
	1990	18.0	0.35
	2000	18.0	0.35
Small (4 passengers)	1980	18.8	0.50
	1990	20.0	0.35
	2000	20.0	0.35
Medium (5 passengers)	1980	21.8	0.50
	1990	23.0	0.35
	2000	23.0	0.35
Large (6 passengers)	1980	25.5	0.50
	1990	26.0	0.35
	2000	26.0	0.35
Van (9 and 15 passengers)	1980	28.2	0.55
	1990	30.0	0.40
	2000	30.0	0.40

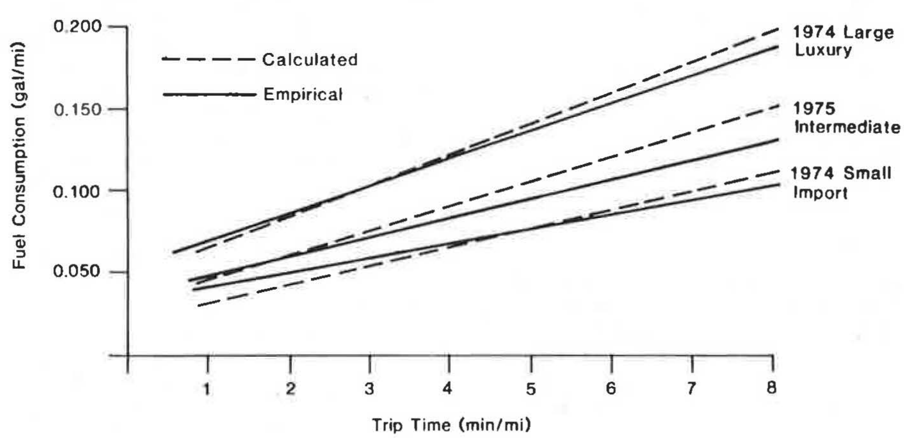

FIGURE 11 Calculated versus empirical relationship between fuel consumption (fully warmed vehicle) and trip time per unit distance.

The cold-start fuel-consumption data (17) result from experiments where short-trip consumption was measured for four vehicles, two with V-8 and two with 4-cylinder engines, both with and without fuel injection. By using these data, it was found that the instantaneous cold-start factor (CSF_i) could be characterized with sufficient accuracy for all engine sizes in all time periods by the following relationship:

$$CSF_i = 1 + 1.83e^{(-1.4D)} \quad (3)$$

where CSF_i is the instantaneous cold-start factor, and D is the trip distance (miles). The cumulative cold-start factor was then defined as

$$CSF_i = \left[\int_0^D (FC_w)d(D)\right] / \left[\int_0^D (CSF_i)(FC_w)d(D)\right] \quad (4)$$

By using the distance and speed characteristics of the city cycle (LA-4) EPA test procedure (18), the fully warmed fuel consumption of each of the vehicles and the cold-start factor for each of the three trip segments was calculated. Finally, the overall trip fuel consumption was calculated according to the following equation:

$$FC = [0.35/(FE_1)(CSF_1)] + [0.37/(FE_2)(CSF_2)] + [0.27/(FE_3)(CSF_3)] \quad (5)$$

where

- FC = trip fuel consumption,
- FE_1 = fuel efficiency (miles/gal), first trip segment, and
- CSF_1 = cumulative cold-start factor, first trip segment.

Figure 12 shows the benchmark fuel economy for new Otto-engine automobiles. A constant new car sales distribution of 50 percent small, 30 percent medium, and 20 percent large Otto-engine automobiles was used for all technology sets to illustrate the effects of technological change. The resulting harmonically averaged fuel economy for new car fleets approximates or exceeds the CAFE required value of 27.5 miles per gallon in 1985.

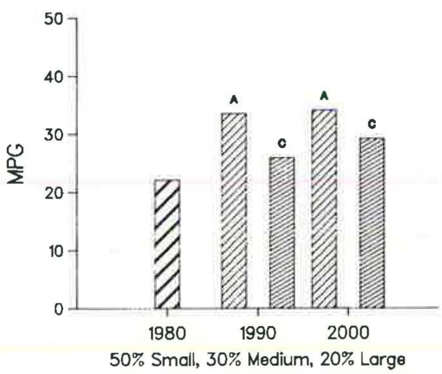

FIGURE 12 Benchmark fuel economy for new Otto-engine cars in two technology sets used for TAPCUT policy analysis.

Purchase Cost Calculations

The methodology used to estimate liquid-fueled automobile purchase cost (in 1975 dollars) was based on the methodology devised for another study (19). It entailed applying regression analyses to historical data to develop equations relating the weight of vehicular components to a vehicle characteristic (e.g., horsepower) and subsequently developing equations relating the manufacturing cost of the components to either their weights or horsepower. The sum of the vehicle manufacturing and assembly costs was then converted to purchase cost (price) by a relationship derived from the difference between actual list prices and computed manufacturing costs of actual vehicles in a given model year. A simple extrapolation of prices derived from regression analyses does not necessarily account for competition-driven improvements in production processes. However, relative price differences influence a household's choice among new vehicles more than absolute price (see paper by Saricks, Vyas, and Bunch elsewhere in this Record). Because of the importance of relative price, this simplification of the price-determination process based on historically traceable data was used for automobiles.

Transit vehicle costs were judgmentally derived from past trends and adjusted for improvements from the use of lighter but more expensive materials. Electric and hybrid vehicle prices were computed by using material percentages by material type and projected costs on a per unit weight basis. A relationship between material cost and consumer price was used to compute final vehicle price (16).

Operating Cost Calculations

Operating costs, less fuel (which was a policy variable), were estimated for repair and maintenance, replacement tires, and lubricating oil. The same operating cost relationships derived for the baseline vehicles represented those costs for future liquid-fueled vehicles except for the cost of lubricating oil changes for the Brayton engine, which was less than conventional engines. The cost of Otto-engine lubricating oil changes was used as a surrogate for that of the Stirling engine.

Selected Cost and Performance Results

The data in Table 5 give the performance and cost characteristics that were projected for medium-sized liquid-fueled vehicles in 2000 for each technology set. The data in Table 6 indicate similar projected characteristics for selected battery-electric automobiles and transit vehicles.

The data in Table 5 indicate that horsepower for vehicles in set A is much higher than in sets B and C. The interpretation of the socioeconomic scenario leading to set A assumed that high-performance vehicles would be demanded by a highly competitive society. Power-to-weight ratios for the average automobile would be considerably higher than current averages, but not beyond the range of the highest performance automobiles now available. [For comparison, a better-than-average 1980 BMW 320I has 101 hp at a curb weight of 2,500 lb (2). Thus 132 hp in a 2,200-lb vehicle as shown in the table is not an extreme increase.] Conversely, the medium-sized vehicle in set C was designed for the segment of that society for which high performance was of little necessity. Further, in set C little attention was given to efficiency improvements even though fuel costs forced a moderate improvement over current conditions. Set B reflects the demand for the utmost in fuel economy. Thus vehicle efficiency was high and performance was deemed unimportant. Therefore, the low power-to-weight set B vehicles gained a significant fuel-economy improvement with respect to the other two sets.

As noted earlier, prices were computed from an extrapolation of regression analyses of current data. Recall that relative prices within a set were a major factor in vehicle choice. However, the only slightly lower price for the set A Otto-engine vehicle, as compared to its weight, is also a function of several observed factors. The regression analyses and comparison with actual list prices indicated that as vehicle weight is lowered, fixed manufacturing costs and return-on-investment expectations assumed a greater proportion relative to variable manufacturing costs, thus resulting in a higher price per pound of vehicle. In set A this effect drove the calculated price upward more than might be expected from its low curb weight. In set B this

TABLE 5 Future Vehicle Characteristics: Medium-Sized Class, 2000

Vehicle and Technology Set	Engine Weight (lb)	Body Weight (lb)	Curb Weight (lb)	Power (hp)	Urban Cycle Fuel Efficiency (miles/gal)	Price[a] ($)
Otto engine, uniform charge						
Set A	358	1,832	2,190	132	27	5,240
Set B	131	1,826	1,957	35	35	5,258
Set C	198	2,100	2,298	52	26	5,321
Otto engine, stratified charge						
Set A	413	1,847	2,260	135	30	5,256
Set B	149	1,831	1,979	35	37	5,262
Set C	214	2,105	2,319	52	28	5,333
Otto engine, turbocharged						
Set A	198	1,792	1,990	123	28	5,551
Set B	75	1,812	1,887	34	33	5,619
Set C	140	2,082	2,222	51	27	5,622
Diesel engine						
Set A	322	1,820	2,141	130	42	5,864
Set B	119	1,822	1,942	35	47	5,765
Set C	182	2,095	2,277	51	37	5,708
Brayton engine						
Set A	214	1,791	2,006	124	41	7,018
Sets B and C	-	-	-	-	-	-
Stirling engine						
Set A	426	1,842	2,268	136	42	6,896
Set B	173	1,837	2,010	36	54	6,160
Set C	-	-	-	-	-	-

[a]Price in 1975 dollars.

TABLE 6 Future Selected Medium-Sized Electric Automobile and Transit Vehicle Characteristics

Vehicle and Technology Set	Engine or Motor/Controller Weight[a] (lb)	Battery Weight (lb)	Curb Weight (lb)	Urban Cycle Fuel Efficiency (kWh/mile)	Price[b] ($)	Range (mile)
Electric (Ni-Zn)						
Set A	306	830	3,294	0.36	7,295	125
Set B	276	761	2,969	0.33	7,198	125
Set C	365	886	3,476	0.42	8,084	125
Transit						
Bus, 35-40 ft (diesel)						
Set A	1,000	-	22,000	2.8[c]	115,000	-
Set B	1,100	-	23,400	2.7[c]	125,000	-
Set C	1,112	-	21,388	3.0[c]	130,000	-
Light rail (electric)						
Set A	3,400	-	61,600	5.7	370,000	-
Set B	3,400	-	61,600	5.7	370,000	-
Set C	3,400	-	62,500	6.2	370,000	-

[a]Motor/controller applies to electric vehicles only.
[b]Price in 1975 dollars.
[c]Miles per gallon.

effect was slightly more pronounced. In addition to the cost-versus-weight function, the manufacturing cost of an engine was found to be a fairly weak function of its power. This finding was partly substantiated by the observation that optimal high-powered engine prices listed by some manufacturers for some vehicles were less than $100 higher than for the lower-powered counterpart. Thus the high horsepower of the set A vehicle did not substantially contribute to its price. The combination of these factors and other subtle influences resulted in the rather narrow range of prices given in Table 5.

CHARACTERISTICS OF FUELS AND RESIDUALS ASSOCIATED WITH THE MANUFACTURE OF VEHICLES

The energy and environmental consequences of vehicle production in each technology set was estimated by quantifying changes in material and vehicle production methods implicit in each of the alternative socioeconomic environments. Result highlights are presented in the following subsections.

Method

A modularized data base was prepared for each material used in baseline and projected vehicles. Then the types and amounts of fuels required to produce these materials in extraction, production, and recycling processes were obtained from many sources (16). These data were then expressed in British thermal units (Btu) per fuel type per pound of material. A similar approach was used to formulate the data base on air and water residuals and solids resulting from the production of 1 lb of material in extraction, manufacture, and recycling phases.

Next a baseline bill of materials was prepared for each major component of each 1980 vehicle (engines, motors, batteries, and bodies). Then projections were made of future vehicles' bills of materials based on interpretation of the probable material substitutions implicit in each alternative socioeconomic environment. Finally the weight percentage of each material in a component was estimated, and component weights derived from the vehicle characterization were converted to weights of materials associated with a specific vehicle, the amounts of fuels consumed, and residuals produced in extraction and manufacturing.

An important aspect of this characterization was that only fuels used and residuals produced in the United States were associated with the production of a vehicle. Estimates of the percentage of imported materials in each alternate socioeconomic environment were made. Estimates of recycled material percentages (i.e., steel, aluminum) were also made, and these had significant impacts because recycling is less energy intensive and environmentally degrading than production from virgin materials.

The amount of fuel consumed (by fuel type) and the extraction and manufacturing residuals was calculated by using a computer program (VEHFR). The program data files contain estimates by technology set of the amount of fuel consumed and residuals produced by type per pound for 31 materials, disaggregated into extraction, manufacture, and recycling, and included assembly plant fuels and residuals. Output data include vehicle technology set, vehicle component and component weight, Btu by fuel type (coal, petroleum, natural gas, electricity, hydroelectricity, and miscellaneous), total Btus, weight of 11 air and 20 water residuals, and total solids. These data are also disaggregated into extraction and manufacture.

Alternate Socioeconomic Environment Influences on Materials Production and Manufacturing Practices

For technology set A, the major effect of socioeconomic conditions and government policies was to increase exports and to initally relax environmental control on manufacturing. Production processes greatly improved and quickly replaced outmoded ones. Imports of ores and fabricated materials were reduced, and recycling increased moderately over 1980 levels. The use of coal would increase, and the use of petroleum would bottom out in 1985. Purchased electricity for use in some materials processing and in-plant operation increased.

The primary effect of socioeconomic conditions on technology set B was to sharply increase the recycling of materials. The conservation ethic resulted in reduced requirements for products and energy. Some ores were imported to reduce environmental degradation. Strict environmental controls were retained, but plant productivity had some improvement, despite controls, and there was a moderate amount of new plant construction. The use of coal increased slowly, with natural gas taking up the slack. Manufacturing sector requirements grew slowly.

For technology set C, little improvement was made over 1980 in conserving either energy or the environment. Lack of environmental control enforcement resulted in some transitory increases in plant productivity. However, few new plants were constructed, and the faltering economy required increased material imports. The amount of recycling also decreased. There was little change in the distribution of fuels used from the 1980 era.

Materials and Residuals of Production: Characterization Highlights

In the area of materials substitution, the projected year-2000 bills of materials show light materials (aluminum, plastics, and magnesium) increasing in Otto engines from 8.5 to 52 percent for technology set A, to 54 percent for set B, and to 35 percent for set C. The use of lighter materials in bodies (aluminum, plastics, and carbon and graphite composites) follows the same pattern, increasing from 8.3 percent in the 1980 base year to 22 percent for technology sets A and B, and to 15 percent for set C.

A somewhat surprising result is shown in Figure 13, where manufacturing energy expenditures per pound of a medium-sized Otto-engine automobile are shown for each technology set. In set A energy use dips slightly between 1980 and 1990 as lighter vehicles are produced and plant efficiency improves. However, energy use rises sharply from 1990 to 2000 as more energy-intensive materials, such as aluminum and magnesium, are substituted and material imports are reduced to gain a favorable balance of trade.

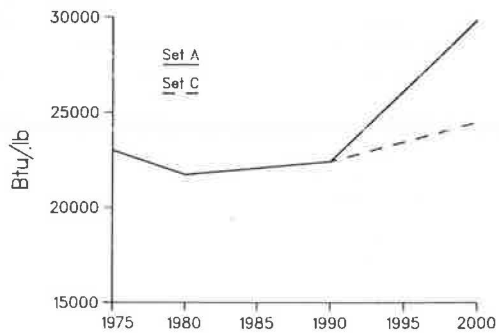

FIGURE 13 Comparison of weight-specific vehicle production energy for a medium-sized automobile with Otto engine in two technology sets.

Technology set B, with its emphasis on conservation and environment, is level between 1980 and 1990, even though plant efficiencies increase marginally and substitution of energy-intensive materials is instituted at an earlier date. Projected increases in recycling is the major reason for energy saving. However, increased use of light materials causes a slight rise in total energy from 1990 to 2000. Manufacturers reduced vehicle operating energy use (the greatest energy expenditure) and, as a result, incurred some increased energy use in production.

For technology set C, increased energy use after 1980 occurs as plant efficiency increases only slowly and productivity decreases. However, the situation is turned around after 1990, when substitution of energy-intensive materials has not been aggressively pursued and increasing material imports shift the energy expenditure and residuals burden outside the United States. The result is that energy use per pound of vehicle in 2000 in technology set C is the same as expended in set B. The difference is that in technology set C the favorable energy expenditure was at the expense of unfavorable trade balances, whereas set B gained it through recycling.

As an example to illustrate how residuals of production change with respect to technology sets, NO_x air residuals associated with the production of a medium-sized automobile in technology set A (2000) decreased 47.5 percent over baseline levels, whereas in set B the decrease is 51.8 percent. The general vigor of the alternate socioeconomic environment leading to the characterization of technology set A resulted in substantial environmental benefits, even though priority research was delayed until late in the century. Technology set C improved 35 percent in spite of an indifferent attitude toward the environment. Here, again, much of the residual burden was shifted outside of the United States.

ON-ROAD EMISSIONS CHARACTERIZATION

It was assumed that the most stringent 50,000-mile standards now proposed by the EPA at the time of this study for future implementation are the maximum practicable. Therefore, for currently regulated pollutants, future motor vehicle emissions were projected in accordance with the phase-in rate for each technology set. New emission standards for CO and NO_x, originally scheduled for 1981, were postponed in all technology sets until 1985. These CO and NO_x standards were projected to remain in force through 1987 for technology sets A and C, with the more stringent, but not final, standards then in effect through 2000. In set B these more stringent standards became effective in 1983 with the final 0.4 g per mile NO_x standard for Otto engines taking effect in 1988.

Diesel HC emissions from 1983 to 1987 were estimated to be 0.41 g per mile for technology sets A and C and 0.2 g per mile for set B. Only nonleaded gasolines were used in all technology sets in 1988, with set B implementing a faster phase-out of leaded fuels.

Among engine-specific projections, Stirling emissions were quite low in all emission categories for all potential fuels. Brayton-engine emissions were projected to be similar to Otto-engine emissions in 2000, with the best emission performance realized from use of diesel and alcohol fuels. Total suspended particulates were projected to be in the 5.2 g per mile range for all engines in all technology sets, except for the diesel to 1987 (about 5.9 g per mile for sets A and C, and 5.3 g per mile for set B), and zero for alcohol-fueled Stirling and Brayton engines. Aldehydes were projected to be within the rather close range of 0 to 0.04 g per mile, except for early technology sets A and C diesels, which were 0.07 g per mile.

INFRASTRUCTURE CHARACTERIZATION

The capital cost, energy cost, and air and water emission burdens attendant to the construction of rights-of-way were assessed. A modularized data base was developed where structures related to light rail, commuter rail, expressway and freeway, and express busway transportation systems were typified according to architecture and other pertinent characteristics. A bill of materials was developed for each typical structure, and tabulations were made of the energy consumed and residuals associated with the production of those materials, the fuels used and emission produced in the construction process, and the capital cost of construction.

This data base permitted a desired infrastructural element to be conceptually constructed and the energy expenditure, emission, and cost of construction to be rapidly calculated. Other than the use of energy and residual projections for materials characterized in vehicular analysis, no attempt was made to relate the infrastructural projections to alternate socioeconomic environments.

SUMMARY

The characterizations presented in this paper describe future automotive technology sets for policy analysis, starting from a baseline vehicle characterization derived from historical data. The baseline characterization was projected forward in time along paths suggested by given alternate future socioeconomic environments supported, where possible, by projections of other researchers in the field. The breadth of the vehicle characterizations permits the effects of policy options on most facets of the urban transportation sector to be examined, including transit, although detailed transit characterizations are not described here. The methodologies developed in this work are generalized, and hence can be used with alternate assumptions in a variety of other investigations.

ACKNOWLEDGMENT

The authors could not have performed the characterization tasks described in this paper without the assistance and contributions of several individuals. In particular, the authors wish to recognize the initial efforts of Marvin Kong and Leo Spogen at the Lawrence Livermore National Laboratory, on which their iterative computational procedure (VEHSYS) and their automobile fuel-efficiency equations are based. The authors also wish to thank Sarah LaBelle of the Argonne National Laboratory (ANL) for her guidance and encouragement to them in developing the characterization parameters; Chris Saricks of ANL, whose on-road emissions work the authors summarized here; Oreste M. Bevilacqua of OMB & Associates, who assisted in the gathering of fuel efficiency and transit operational data; and Martin Bernard III of ANL, who performed the electric and hybrid vehicle characterization and sponsored this work. Finally, the authors wish to acknowledge the interest and contributions of Dan Maxfield of the U.S. Department of Energy (DOE) as well as David Moses, also of DOE, who reviewed the work as it progressed and kept it on track.

REFERENCES

1. 1980 Gas Mileage Guide, 2nd ed. U.S. Environmental Protection Agency, Feb. 1980.
2. Automotive News Market Data Book Issue. Crain Communications, Inc., and Marketing Services, Inc., Detroit, 1980.
3. M. Dowdy et al.; Jet Propulsion Laboratory. Automotive Technology Status and Projections--Volume 2: Assessment Report. Report NASA-CR-157594. National Aeronautics and Space Administration, 1978.
4. L.L. Listen and C.A. Aiken. Cost of Owning and Operating an Automobile. FHWA, U.S. Department of Transportation, 1976.
5. The Car Book. National Highway Traffic Safety Administration, U.S. Department of Transportation, 1981.
6. O.M. Bevilacqua. Development and Application of Transit Operating Characteristics. OMB & Associates, Oakland, Calif., Oct. 1980.
7. S.J. LaBelle et al. Technology Assessment of Productive Conservation in Urban Transportation, Final Report. Report ANL/ES-130. Argonne National Laboratory, Argonne, Ill., Nov. 1982.
8. R. Renner and H.M. Siegel. Fuel Economy of Alternative Automotive Engines: Learning Curves and Projections. SAE Paper 790022. Presented at SAE International Congress and Exposition, Detroit, Feb. 1979.
9. A. Ciccarone. Possible Advances in European Passenger Cars' Fuel Economy. SAE Paper 770846. Presented at SAE International Congress and Exposition, Detroit, Feb. 1977.
10. T.L. Bryant. Two New Eagles from AMC. Road & Track, Sept. 1980.
11. R.G. Fitzgibbons and L.H. Lindgren. Fuel Economy Goals Beyond 1980: Estimated Weights and Manufacturing Costs of Automobiles. Transportation Systems Center, U.S. Department of Transportation, Cambridge, Mass., undated.
12. T.W. Caldwell and H.M. Ward. Automotive Applications for Magnesium Die Castings. SAE Paper

800415. Presented at SAE International Congress and Exposition, Detroit, Feb. 1980.
13. J.G. Metzoff. Magnesium for Automobiles, in Perspective. SAE Paper 800417. Presented at SAE International Congress and Exposition, Detroit, Feb. 1980.
14. R.H. Shackson and H.J. Leach. Maintaining Automotive Mobility: Using Fuel Economy and Synthetic Fuels to Compete with OPEC--Interim Report. The Energy Productivity Center, Mellon Institute, Arlington, Va., 1980.
15. Should We Have a New Engine? An Automobile Power Systems Evaluation--Volume II: Technical Report. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, Calif., 1975.
16. C.L. Hudson, E.S. Putnam, and M.J. Bernard. Vehicle Characterization for the TAPCUT Project: Performance and Cost. Report ANL/EES-TM-171. Argonne National Laboratory, Argonne, Ill., Nov. 1981.
17. M. Chang, L. Evans, R. Herman, and P. Wasielewski. The Influence of Vehicle Characteristics, Driver Behavior, and Ambient Temperature on Gasoline Consumption in Urban Traffic. Report GMR-1950. Traffic Science Department, General Motors Corporation, Warren, Mich., 1976.
18. Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines. Federal Register, Vol. 35 (21y), Nov. 10, 1970, pp. 17288-17313.
19. L.G. O'Connell. Energy Storage Systems for Automobile Propulsion--Final Report. Report UCRL 5353-80. Lawrence Livermore National Laboratory, Livermore, Calif., 1980.

Energy-Conservation Strategies and Their Effects on Travel Demand

DARWIN G. STUART, SARAH J. LaBELLE, MARC P. KAPLAN, and LARRY R. JOHNSON

ABSTRACT

The types of impacts on urban travel demand that might be expected from two broad, multifaceted energy-conservation strategies are described. Based on sketch-planning travel demand modeling conducted for three case study regions and generalized extrapolation of these results to national totals, illustrative travel impact results are presented. Five different types of impact are considered: (a) mode choice by trip purpose (work versus nonwork), (b) variations in transit travel by city type, (c) vehicle miles of automobile travel for work and nonwork purposes, (d) variations in trips per capita and per trip length by purpose, and (e) distributional differences in terms of household (central city, suburban, exurban). The in-place policy, marked by a sharp rise in automobile out-of-pocket costs, had no increase in per capita automobile travel by 2000, although aggregate energy consumption was lowered. The individual travel strategy, which lowered automobile operation cost relative to the in-place policy by improvements to automobile fuel economy, achieved noticeable energy savings with negligible impact on choice of travel mode. The group travel strategy, on the other hand, significantly altered mode choice and saved transportation energy in this way. Significant improvements in transit service and strong automobile travel disincentives yielded dramatic shifts to group travel modes for nonwork travel. Work travel mode choice was affected to a lesser extent, with increases of 30 to 40 percent in transit and shared-ride modal splits.

Meaningful analysis of the many different supply- and demand-oriented strategies for conserving urban transportation energy is a complex undertaking. Not only is the range of available conservation options a wide one, but the applicability of such options within urban areas varies greatly by urban area size and density (1-3). When the potential impact of technology-oriented options (e.g., alternate fuels, engine technology advances, and greater fuel efficiency from the vehicle mix) is considered, another layer of complexity is added (see papers by Hudson and Putnam, and by Saricks, Vyas, and Bunch elsewhere in this Record). Even more complications arise when the analysis tools available for the examination of travel demand impacts are considered, together with the necessary behavioral assumptions that are associated with them (see paper by Kaplan, Gur, and Vyas elsewhere in this Record).

Consequently, because of these complications the analysis results presented in this paper are illustrative only. In order to permit a systematic yet wide-ranging analysis to move forward, a host of reasonable (but still limiting) assumptions has been made. For example, only two scenarios regarding the future socioeconomic characteristics of urban regions [household size, income, energy price, gross national product (GNP)] were considered. Among the many different combinations of energy-conserving actions that could be devised, only two--one emphasizing group travel options (transit and shared ride) and another emphasizing greater efficiency in individual vehicle travel--were investigated (together with in-place policies as a baseline).

The four combinations of scenarios and strategies are intended to represent end-of-range impacts, with the understanding that many other intermediate levels of policy action and impact are possible.

The types of impact on urban travel demand that might be expected from two broad, multifaceted energy-conservation strategies are described. Based on sketch-planning travel demand modeling conducted for three case study regions and generalized extrapolation of these results to national totals, illustrative travel impact results are presented. The method for projecting city-specific responses to the strategies sequentially (1990 and 2000) applied a modified, logit model of travel demand (4, and paper by Kaplan et al. in this Record). Recalibration was performed for each case study city. The model was used directly for each forecast, with revised demographic as well as policy variables. Because of this structure, comparison of results for each year, strategy, and city was consistently achieved.

Five different types of impact are considered: (a) mode choice by trip purpose (work versus nonwork), (b) variations in transit travel by city type, (c) vehicle miles of automobile travel for work and nonwork purposes, (d) variations in trips per capita and per trip length by purpose, and (e) distributional differences in terms of household income levels and location within urban areas (central city, suburban, exurban).

Again, the results presented are not regarded as definitive (and certainly not prescriptive) but as illustrative of the kinds of traveler response that could be expected for organized urban transportation energy-conservation strategies. The modeling tools measured synergistic effects of the strategies and demonstrated differences between cities.

ALTERNATIVE CONSERVATION STRATEGIES

Economic Growth Scenarios

To help bound the analysis of urban transportation energy-conservation potentials, two economic growth scenarios were set forth. These scenarios provide two different economic and social aggregation futures as a backdrop for the analysis of the impacts of conservation policies. The scenarios are distinguished from each other primarily by assumed GNP growth rate, rate of fuel price increase, amount of technology development success, and social organization. Scenario I is generally greater on all these dimensions than scenario III (scenario II was dropped from the analysis). The percentage of the national population living in metropolitan areas is higher in scenario I than in scenario III. Household sizes are slightly smaller and household incomes are significantly higher under scenario I.

Scenario I can consequently be regarded as stronger and more vigorous in economic and technology development terms, whereas scenario III can be regarded as a slower growth, economically conservative, and lower-income economy. Key constrasts between scenarios I and III include (in order) the following items:

1. GNP growth rate--3.6 versus 2.2 percent;
2. Level of social aggregation--strong competition versus disassociation;
3. Research and development activities--high investment versus low investment;
4. Average household size, year 2000--2.37 versus 2.41;
5. Low-income households (less than $13,000 in 1975 constant dollars), year 2000--34 versus 51 percent;
6. High-income households (more than $23,000 in 1975 constant dollars), year 2000--33 versus 23 percent;
7. Total energy consumption, year 2000 (in quads)--114 versus 94; and
8. Oil price per barrel (1975 dollars), year 2000--$46 versus $62.

Case Study Regions for Travel Demand Analysis

Conservation policies were tested in three typical cities, and impacts were analyzed and then expanded to national urban totals. As the testing was done for each city, some variation in policy specification occurred in each according to its features. The typical cities were selected in light of major differences in their transportation-related characteristics; a factor analysis technique was used for grouping cities (see paper by Peterson elsewhere in this Record). The first typical city, Sprawlburg, represents relatively new, spread out, western metropolitan areas. The second city, Megatown, has certain characteristics of the big, densely settled city with satisfactory transit in place. The third typical city, Slowtown, might be best described as a midwestern, industrial, middle-sized metropolitan area.

Cities in the nation are viewed as combinations of the characteristics of these typical cities. The typical cities were selected as extreme or atypical cities along three primary dimensions. Intensive studies of these three cities were used to infer the response of all cities in the country. Because all cities, to some extent, assume the roles of service city, manufacturing center, government center, transport hub, and so forth, the data describing 237 standard metropolitan statistical areas (SMSAs), including 52 socioeconomic and transportation variables from various years (1970 through 1977), were used to define the primary dimensions and the relationships of all cities to those dimensions.

Sprawlburg examples include Phoenix, Nashville, Dallas, Anaheim, and Jacksonville. Megatown examples include Chicago, Philadelphia, Cleveland, Minneapolis, Boston, and San Francisco. Slowtown examples include Flint, Grand Rapids, Lima, Paterson, Norwalk, and York.

Range of Conservation Options

As a baseline for all impact analyses, an in-place policy was established as the extension of all programs and plans in place in 1980 that affect urban transportation. For the three case study cities, these were defined in terms of existing state, regional, and local plans. The two energy-conservation policy packages, so named to reflect the fact that a number of more specific options are contained within each, represent two different approaches to saving energy in urban transportation.

The group travel strategy promotes mass transit and ridesharing with no improvements to automobile technology relative to the in-place policy, whereas the individual travel strategy focuses on automobile technology improvements as the means to decrease transportation energy use while maintaining mobility. In general, the group travel strategy involves large-scale changes in level of service for transit, as measured by service frequency, line-haul travel time, and system coverage in each case study region.

The individual policy actions or measures that were analyzed are given in Table 1. Some 17 different actions are included, falling into four broad groups: land use controls, fuels and vehicles research and development (R&D), economic and regulatory disincentives (automobile travel), and group travel incentives (transit, ridesharing).

Policies varied by the scenario in which they were expected to have the greatest effect; in general, scenario I, with higher GNP and public and private dollars available for research and development, was assumed to be capable of supporting rail transit service expansion. Scenario III, on the other hand, emphasized reduced transit fares and express bus service, including busway construction. Levels of policy change for both 1990 and 2000 are indicated in Table 1, reflecting the years for which demand analyses were conducted.

Figure 1 also summarizes, in a conceptual way, the relative emphasis on selected conservation policies or action areas associated with each strategy. In addition, for the group travel strategy, scenario I relied on capital-intensive light rail systems and some busways, whereas scenario III used more extensive motor bus service in mixed traffic and in exclusive lanes--a low-capital, high operating cost choice.

The level of detail at which transit service changes were specified makes it difficult to simply summarize the changes in Table 1. The measures provided indicate that travel time changes were the same general magnitude in each scenario, but varied by transit mode (bus or rail) and travel corridor. Extent of service was increased substantially over the 20-year period according to the in-place policy; the group travel strategy consequently did not change extent of service as much as the quality of the service provided.

TABLE 1 TAPCUT Conservation Strategies as Tested in Travel Mode Changes from In-Place Policy by Forecast Year

		Group Travel Strategy		Individual Travel Strategy	
Policy Action (measure)	Year	Scenario I	Scenario III	Scenario I	Scenario III
Land use controls (%)					
Live close to work (work trip length)	1990		-6		
	2000		-14		
High density zoning (growth in households relocated near or away from centers)	1990		4.9[a]		4.9[b]
	2000		11.4		5.1
Decentralized work or shop locations (employment growth relocated near or away from centers)	1990		25.8[a]		16.9[b]
	2000		29.3		17.5
Further CBD growth (CBD share of employment)	1990		9.1		-6.8
	2000		18.0		-14.4
Fuels and vehicle R&D (%)					
Vehicle weight R&D (avg fleet car weight)	1990			-3.3	6.7
	2000			-4.3	8.2
Engine, vehicle, and fuels R&D (new car miles per gallon)	1990	2.2	1.8	28.4	-1.4
	2000	2.8	-1.8	23.4	3.6
Economic disincentives for automobiles					
Increase CBD parking cost (daily charge) (%)	1990	200	200		
	2000	200	200		
Impose cost on free parking (in 1975 dollars) ($)	1990	2.00	1.00		
	2000	2.00	1.00		
Increase automobile fuel tax (retail fuel price) (%)	1990	37.2	38.6		
	2000	97.2	42.0		
Group travel incentives (%)					
Carpool promotion (parking costs, walk time to work)	1990	-50	-50		
	2000	-50	-50		
New rail service (track miles built)	1990	235	1		
	2000	215	33		
New rail service[c] (in-vehicle time)					
Express busways built (busway lane miles)	1990	-[d]	164		
	2000	100	111		
Express bus service[e] (in-vehicle time)					
Conventional bus service (routes with improved frequency)	1990	50			
	2000	100			
Conventional bus service (wait time)	1990	-15			
	2000	-15			
Reduce transit fares	1990		-25		
	2000		-25		
Automobile travel behavior, trip linking[f]					

[a]Near.
[b]Away.
[c]Range of 40 to 60 percent for scenarios I and III for group travel strategy.
[d]Same.
[e]On busways and bus lines for scenarios I and III for group travel strategy.
[f]Parametric only; discuss impacts-for scenarios I and III for group travel strategy.

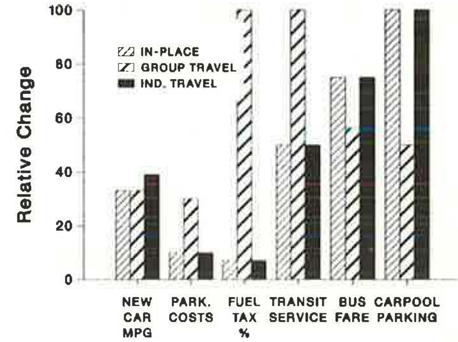

FIGURE 1 Summary of TAPCUT conservation policies in contrast to in-place policies in 2000.

Group Travel Strategy in Scenario I

The policy test of the group travel strategy in scenario I included no changes under land use controls or fuels and vehicles R&D, but there were extensive changes to transit service, including significant development of light rail service and bus frequency improvements, coupled with stringent automobile disincentives in the form of parking costs and fuel taxes. Busways were used in smaller cities, whereas new light rail was built in medium-sized cities. The fuel taxes increased to 50 percent of the retail price in 1990, and to 100 percent by 2000.

Parking costs tripled in central business districts (CBDs), whereas $2 (in 1975 dollars) charges were imposed on free parking under the in-place policy. There were 50 percent reductions in carpool parking costs and in walk times at the work place for both forecast years. Fuel economy changes in new car purchases are reflective of fuel price impacts on automobile purchases and of a minor vehicle design change in the medium-Otto vehicle.

Group Travel Strategy in Scenario III

Significant transit improvements with stiff increases in automobile costs marked the policy test of the group travel strategy in scenario III. Transit improvements focused on increases in express bus service, extensive use of busways in small and medium-sized cities, reduction of fares to 75 percent of in-place policy levels, and a 50 percent reduction in carpool parking costs and walk times was also included. The fuel taxes reached 50 percent of the retail price in 1990 and stayed there to 2000.

Parking taxes ($1 in 1975 dollars) were imposed throughout each metropolitan region, including those suburban lots that were free under the in-place policy. Some land use controls were imposed, which resulted in a net reduction in work trip length, increased residential density, and a damping of the trend under the in-place policy to decrease the CBD share of metropolitan employment. There were essentially no changes in the automobile characteristics defined under the in-place policy for this scenario.

Individual Travel Strategy in Scenario I

In the policy test of the individual travel strategy in scenario I, significant increases in automobile fuel economy were postulated. All other variables were unchanged from the in-place policy. New cars were 23.4 percent more fuel efficient in the year 2000 than their in-place policy counterparts. The stock held by households was nearly 23 percent more efficient than the in-place policy, and 125 percent better than that of 1980.

Fuel-economy gains in newly purchased automobiles are achieved without major weight changes. Engine design improvements in 1990 allow both performance and fuel economy to improve without much reduction in vehicle weight. In 2000 the need for weight change is somewhat greater, whereas the fuel-economy increase over the in-place policy vehicles is not quite as great as for 1990.

Individual Travel Strategy in Scenario III

A modest improvement in automobile fuel economy and an increase in decentralized development are the changes proposed for the policy test of the individual travel strategy in scenario III. The prices of fuel and transit, along with that of parking, are unchanged from the in-place policy. Growth in employment and households tended to locate away from established centers. About 17 percent of employment growth and 5 percent of households growth made these shifts, as compared with the in-place policy. Further, the share of employment in the CBD decreased more rapidly than under in-place policies; it was 14 percent less in 2000.

Automobile fuel economy dips below the in-place policy value in 1990 because of a shift in consumer preference to medium and large cars. With higher performance, technological improvements surpass the effect of the market shift by 2000, however. Market preferences also result in heavier average new car weight in spite of reductions of 3 to 4 percent in small and large cars over the in-place policy.

IMPACTS ON URBAN TRAVEL DEMAND

Both energy savings strategies had significant effects on household travel demand, differing by type of city, intraurban location of households, and household income. In general, the direction of the effects of each policy was the same for each scenario, but results in scenario I were always of a greater magnitude than the same change in scenario III. This is partly attributable to the higher household incomes assumed under scenario I relative to scenario III. Because travel impacts are largest for scenario I, most of the results presented here are drawn from scenario I analyses, except where scenario III results differed from scenario I.

Work Travel Mode Choice

Figures 2 and 3 show the change in year-2000 modal split for work travel under the in-place policy and the group travel strategy. The same number of work trips were assumed under each. Further, origin and destination pairs are also identical because work trips are considered as nondiscretionary trips in the chosen modeling approach. Thus destinations are fixed and only the mode can be chosen. The work trip transit modal share increased for all three city types and at the national average under the group travel strategy. Ridesharing increased significantly in each city, but drive-alone continued as the predominant mode for work travel. The transit share was almost negligible in both Sprawlburg and Slowtown.

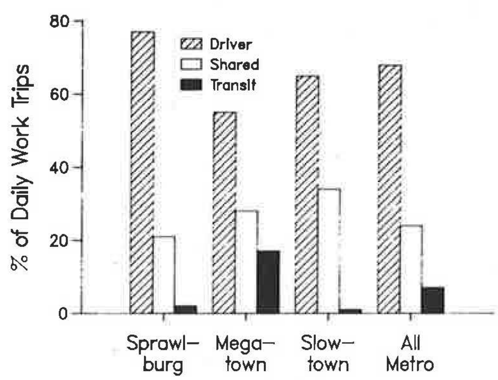

FIGURE 2 Work trip modal shares in scenario I under in-place policy, 2000.

The group travel strategy had its strongest effect on ridesharing rather than transit for work trips (5). Nearly all of the diverted drive-alone trips turned to ridesharing in each city. Even though the percentage of work trips is small for transit, the absolute impact on transit systems would nevertheless be large. In Sprawlburg, for example, a change from 1 to 2 percent of all work trips implies that a doubling of ridership occurs during peak hours. Substantial improvement in peak-hour transit service was correspondingly pro-

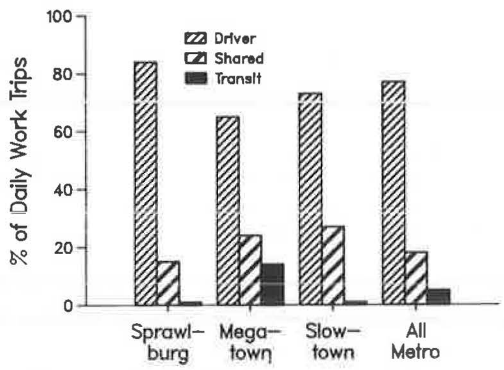

FIGURE 3 Work trip modal shares in scenario I under group travel strategy, 2000.

vided under this policy. Across all metropolitan areas the ridesharing increase of 33 percent [relatively (from 18 to 24 percent of all work trips)] and the transit increase of 40 percent (from 5 to 7 percent) represent significant modal shifts.

Nonwork Travel Mode Choice

To understand analysis results for nonwork travel, it is helpful to examine the average automobile operating costs associated with the policy options. In Figure 4 the rise in operating cost per mile, including fuel costs, is sharpest between 1975 and 1980, slightly moderated between 1980 and 1990, and actually decreases slightly between 1990 and 2000. Costs in 2000 are still higher, however, than costs in 1980.

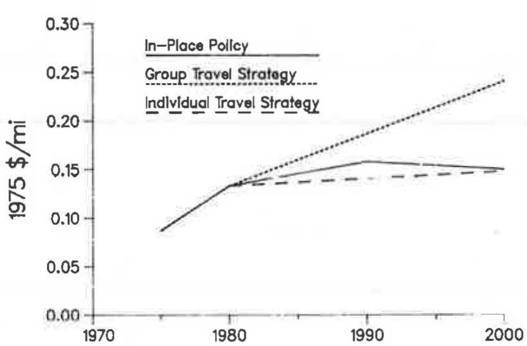

FIGURE 4 Out-of-pocket automobile operating costs in scenario I.

Several factors enter into this representation of automobile operating cost per mile. The retail cost of fuel, average maintenance and repair costs, and the actual fuel efficiency experienced in travel are all included in the analysis. This cost represents out-of-pocket costs associated with vehicle operation and is not equivalent to life-cycle costs. Further, automobile operating costs do not include parking costs, which are assessed per trip. Cost rose most sharply under the group travel strategy. This increase over the in-place policy is due solely to the high fuel tax imposed as part of the group travel strategy. Under the individual travel strategy costs per mile decreased only slightly. This difference was due only to the change in the technologies that were assumed available to households under this policy, because the price of fuel remained the same as under the in-place policy. Although households could have chosen vehicles that lowered operating costs relative to the in-place policy, they instead chose slightly larger automobiles.

In scenario III, not shown in the figure, the difference in per-mile operating costs were less between the in-place policy and the group travel strategy than under scenario I. Oddly, the individual travel strategy results in a slight increase over in-place policy costs. That anomaly was due primarily to the choice of relatively high-performance vehicles by households under that policy set. Operating costs generally were higher under scenario III than under scenario I; further, households are somewhat poorer in scenario III than in scenario I.

Nonwork automobile travel, measured as vehicle miles of travel (VMT) per person, decreased in both scenarios under the in-place policy, whereas nonwork trips per person (by both modes) remained relatively constant. The rise in automobile operating cost and parking costs help explain this phenomenon.

In Figure 5 the nonwork trip modal split for each city and the national metropolitan total is displayed for the year-2000 in-place policy in scenario I. In general, all nonwork travel took place by automobile. The highest transit share was in Megatown at only 4.2 percent of all trips. Figure 6 shows the dramatic impact of the group travel strategy on nonwork travel. The transit modal share over all metropolitan areas increased to 17 percent under this policy. Of greatest interest is the change in Megatown: 40 percent of nonwork trips were taken by transit.

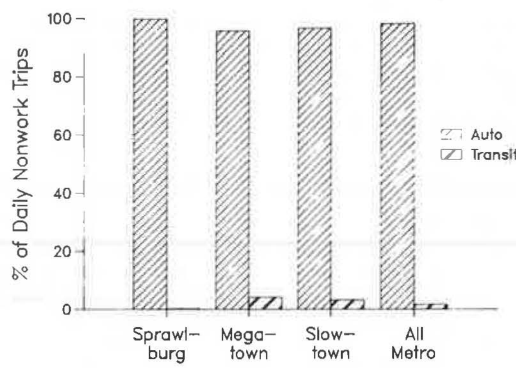

FIGURE 5 Nonwork trip modal split in scenario I under in-place policy, 2000.

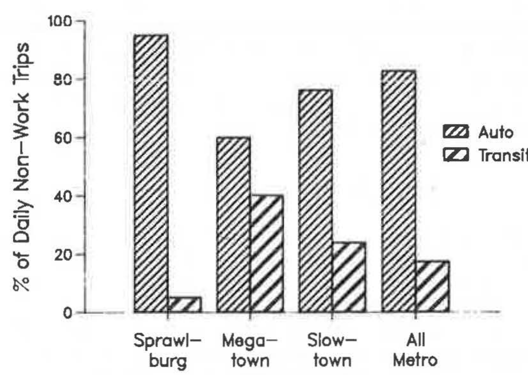

FIGURE 6 Nonwork trip modal split in scenario I under group travel strategy, 2000.

Nonwork travel is modeled as discretionary travel based on cost, household income, and number of attractive destinations. The number of trips per person is a variable result; it is lower under the group travel strategy than under the in-place policy because of the significant increase in automobile operating and parking costs. Nevertheless, the sharp increase in nonwork transit travel, particularly in Megatown, is not simply explained. Many variables were changed under this policy test, and nearly all of them must be examined to search for explanations. Certainly, the logit demand model has been pushed to its limit regarding the standard assumption of constant coefficient values, given the large changes in policy variables that were tested.

The primary explanation of higher transit modal shares for nonwork travel appears to lie with the travel cost and travel time differences of the automobile and transit modes. Discretionary nonwork travel appears highly sensitive to increases in automobile operating costs (including parking costs); as long as a transit option is available that provides significant travel time improvements (especially for out-of-vehicle time) at relatively low fares, a significant proportion of nonwork travel will shift to transit (6,7). Some nonwork trips, as previously noted, will not be made.

Figure 7 tends to support this interpretation. It also depicts the nonwork modal split under the group travel strategy, but for scenario III. Here transit service improvements were the same, except for cross-town corridors, as those hypothesized in scenario I for each city type. Increases in automobile operating costs (by fuel taxes) were less than in scenario I in the year 2000. Automobile operating costs were increased, however, so that nonwork transit ridership increased. (The same increases in group travel parking costs were assumed for CBDs under both scenarios, but scenario I had higher taxes in new areas.) The transit ridership increases were generally only one-third to one-half of those estimated for scenario I, however.

One question to pose is whether the method of calibrating the logit demand model to a new city is actually responsible for most of the difference among the three cities in their response to the group travel strategy, rather than service or population characteristics. The transit service provided in Sprawlburg was at least as satisfactory as that provided in Megatown; the large proportional increase in nonwork transit travel in Sprawlburg represents a huge change for that city, but is far less than the absolute magnitude of change in Megatown.

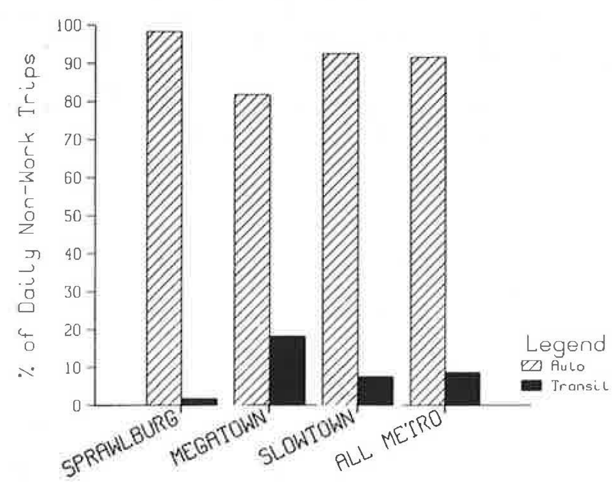

FIGURE 7 Nonwork trip modal split in scenario III under group travel strategy, 2000.

The change in service is apparently at a steep portion of the logit curve for Megatown, but at a flatter part of the curve for Sprawlburg. Slowtown was intermediate between the two in its amount of change; it no longer looks as much like Sprawlburg as it did under the in-place policy. As the calibration process does not change the shape of the choice curve, but rather its horizontal axis, the small absolute change in Sprawlburg may actually be an understated response to large increases in transit service. Because there are no observed data on responses to simultaneous service and cost changes of the magnitude tested here, it is difficult to judge whether the policy variable changes are too large for the model to handle.

Transit Travel by City Type

Primarily because of these increases in nonwork transit travel, all three cities saw parallel increases in overall transit ridership. Figure 8 shows the impact caused by the group travel strategy in each city in scenario I. The increase is expressed as a percentage of the transit trips recorded under the in-place policy in the same year. For example, under the group travel strategy in the year 2000, Sprawlburg had more than 900 percent as many transit trips as it did under the in-place policy. Although the total number of transit trips in Megatown is much larger than the number of transit trips made in Sprawlburg, the amount of increase is far greater in Sprawlburg than in Megatown. Note that there are no 1990 values for Megatown and Slowtown; only the year-2000 values were computed.

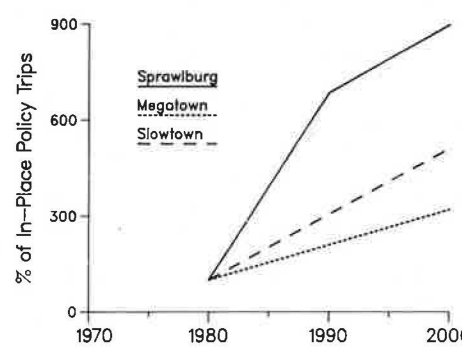

FIGURE 8 Change in transit trips caused by group travel strategy in scenario I by city.

The increase in transit travel in Sprawlburg is displayed under all three policies in Figure 9. These values are expressed as a percentage of the 1980 level of transit trips in that region. Even under the individual travel strategy there was a slight increase in transit ridership. However, the large service increase proposed from 1980 to 2000 under the in-place policy did not increase the absolute number of trips taken on transit. Only the really significant transit service improvements of the group travel strategy, which included an extensive light rail network for Sprawlburg, yielded a significant increase in ridership.

The change in transit travel for Megatown is shown in Figure 10. Again, under the in-place policy, transit trips decrease slightly from 1980 and follow exactly the same trend under the individual travel strategy. It is interesting to note that the improvements in the automobile mode under that policy did not steal from transit travel, but rather added new automobile travel. The group travel

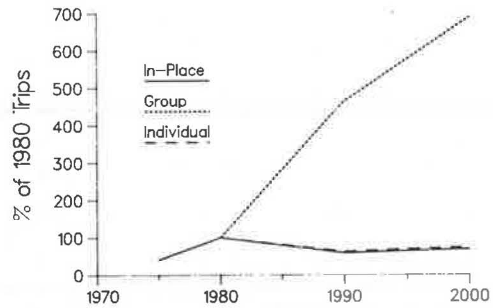

FIGURE 9 Transit trips in Sprawlburg in scenario I by policy.

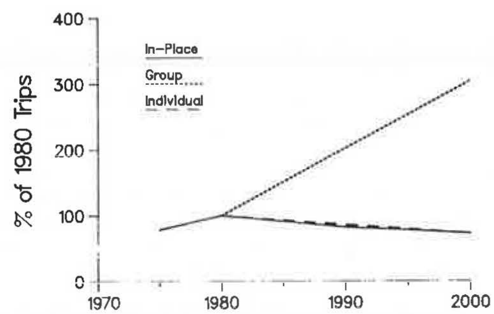

FIGURE 10 Transit trips in Megatown in scenario I by policy.

strategy again had a strong effect on overall transit trips. The increase of more than 300 percent was primarily caused by the increase in nonwork transit trips shown earlier.

The change in transit travel for Slowtown is shown in Figure 11. The in-place policy and the individual travel strategy are exactly the same, such that the line for the individual travel strategy cannot be seen on the graph. The group travel strategy increased transit ridership even more, relatively, than in Sprawlburg. Again, the majority of the increase is caused by the 24 percent transit share for nonwork travel.

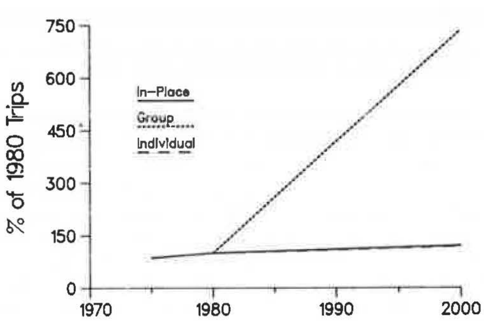

FIGURE 11 Transit trips in Slowtown in scenario I by policy.

Total Person Miles of Travel

In Figure 12 total person miles of travel (PMT) under the in-place policy are displayed, both for households and for individuals across all metropolitan areas. Several observations can be made from these plots. The first is that decreasing household size greatly affects the recording of any results by

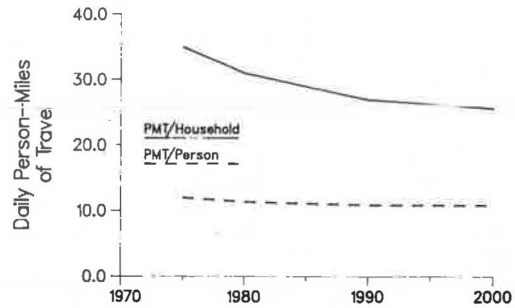

FIGURE 12 Person travel in scenario I under in-place policy.

household. PMT under the in-place policy remains virtually constant on a per capita basis, ranging between 11.98 miles per person in 1975 and 10.88 miles per person in the year 2000. The value for households, however, declined from 35 to 25.7 miles per day per person.

Actual travel per person is virtually unchanged, perhaps an unexpected result given the steady decrease in household size. From an examination of the 1977 Nationwide Personal Transportation Study (NPTS) results, it was expected that there would be a slight increase in per capita PMT: smaller households in that survey exhibited higher per capita, although lower per household daily PMT (8, p. 50). The values shown in Figure 12 represent daily home-based travel on all modes. Linked trips and walk trips are excluded from these values. The increase in automobile operating and parking costs probably explains the damping of growth in PMT per person because of the inability of the travel demand model to capture linked vehicle trips or walk trips.

Work and Nonwork Automobile Travel

Travel by automobile changed differently than total travel. In Figure 13 automobile travel for work trips, expressed as daily VMT per person, is displayed for each city under the in-place policy. The drive-alone and shared-ride modes increased in absolute terms under the in-place policy in each city. The number of work trips per person remained essentially constant, although work trips per household declined in all three cities. The varying patterns of VMT per person reflect the change in residential density in each city over time, as well as the increase in the total amount of work travel being done by automobile. (Only travel by automobile, and not all person travel, is reflected in Figure 13.)

In Sprawlburg and Slowtown VMT per person increases between 1980 and 2000, although it peaks in 1990 for Slowtown. This is primarily because of the

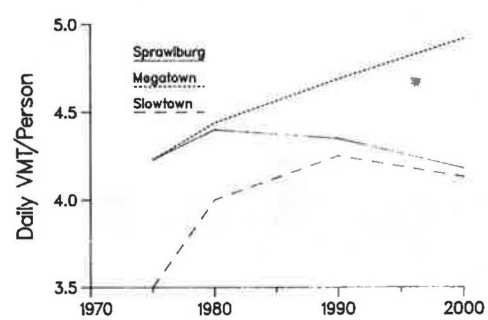

FIGURE 13 Work automobile travel under in-place policy by city in scenario I.

increase in use of the automobile for work trips, rather than the lengthening of average work trips. The anomalous result for Sprawlburg--a decrease in VMT per person after 1980--is primarily because of the infill development that characterized that city's growth in scenario I. Similar results were obtained under the group travel and individual travel strategies, which indicate that the pattern of urban development has more influence on average automobile work trip length than energy conservation policies.

In Figure 14 automobile travel for nonwork purposes is shown for each city for the in-place policy. In all cities automobile travel for nonwork purposes declined from 1980 to 1990 and then increased slightly. The parallel increase and then decrease in operating cost for automobile travel discussed earlier is the major explanation for this pattern.

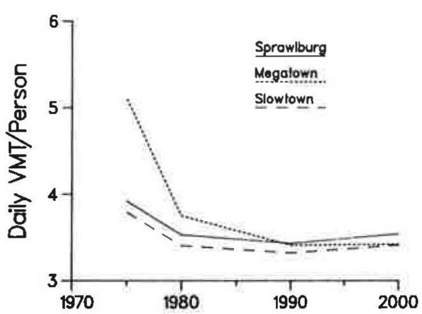

FIGURE 14 Nonwork automobile travel under in-place policy by city in scenario I.

Impacts due to policy actions for nonwork automobile travel are shown in Figure 15. (Again this includes only travel by automobile; not all person travel is reflected.) The group travel strategy sharply decreased per capita mileage for nonwork trips by automobile. The number of nonwork trips declined, which explains some of this decline; however, the length of trips taken also decreased. The individual travel strategy had no effect on nonwork travel, neither increasing nor decreasing automobile travel per person.

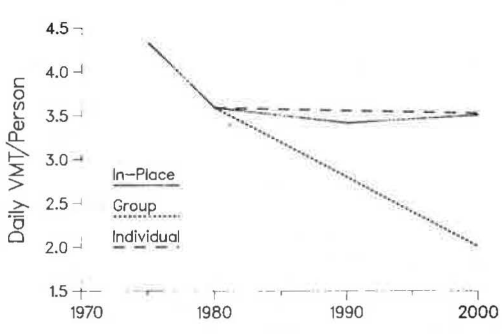

FIGURE 15 Nonwork automobile travel by policy in scenario I.

Trips per Person and Trip Length

Both the number of work trips per person and the average length of each trip are shown in Figure 16 under the in-place policy across all metropolitan areas. These rates do not vary by policy (with one exception--work trip length is reduced in scenario III under the group travel strategy). The number of trips per person is relatively constant, even though it appears to decrease slightly in the graph. It only ranges between 0.66 and 0.63 trips per person per day. Trip length, however, grows somewhat, from just under 8 miles one way to 8.4 miles one way.

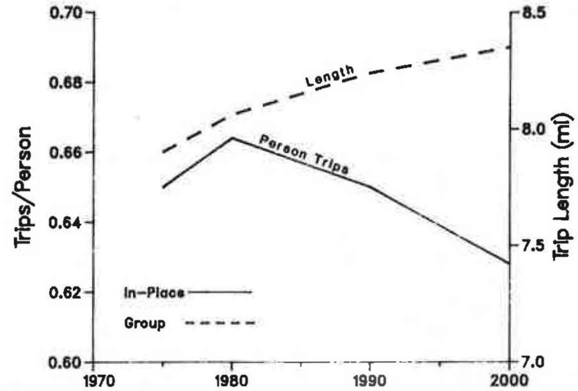

FIGURE 16 Daily work trip and trip length under in-place policy in scenario I.

Figure 17 shows the same information for nonwork trips, including the results of both the in-place policy and the group travel strategy. (Individual travel showed exactly the same pattern of trips per person and trip length as the in-place policy, and it is not marked on the figure.) Under the in-place policy, as the number of nonwork trips per person increased, average trip length correspondingly declined under scenario I. The reverse is shown under the group travel strategy, however. That is, as the number of trips per person declined, the average length of those trips over all modes increased. These results reflect the differing influence of household income gains, which tend to increase nonwork trip rates, and increased automobile operating costs, which tend to reduce them.

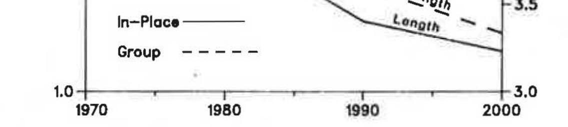

FIGURE 17 Daily nonwork trips and trip length in scenario I.

Work trips per person and trip length by policy in scenario III are shown in Figure 18. As in scenario I, work travel was unchanged across policies in terms of the number of trips per person. However, the length of work trips was shortened under the group travel strategy on input. The average decrease across the nation was about 15 percent by the year

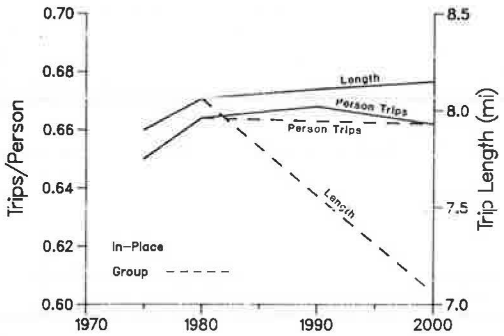

FIGURE 18 Daily work trips and trip lengths in scenario III.

2000, in contrast to the average trip length for the in-place policy. This percentage decrease varied slightly among the cities.

Under the group travel strategy nonwork trips in scenario III decreased further in frequency, while increasing only slightly in length (Figure 19) compared with the in-place policy. This is in the same direction as scenario I impacts, but the magnitude of change is far less.

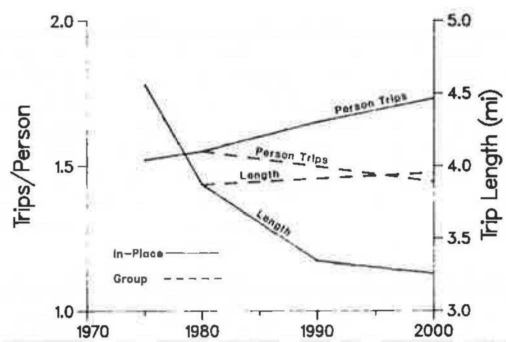

FIGURE 19 Daily nonwork trips and trip length in scenario III.

Differences by Income Group and Household Location

Figures 20 and 21 display further information on nonwork travel in Megatown under the group travel strategy. One reason for the large increase in the number of transit trips for nonwork purposes lies in the increase in the total number of trips that went to the CBD for nonwork purposes (Figure 20). For each income group there is a substantial increase in the share of trips going to the CBD, as opposed to any other destination in the region; further, practically all trips to the CBD were by transit under the group travel policy. This is a big switch from the in-place policy, where one-third to one-half of the trips to the CBD were by automobile. Even with the decrease in the total number of nonwork trips, the increase in the share to the CBD represents a substantial increase in the total number of transit trips--about 60 percent. It is interesting to note that high-income households made the most trips to the CBD, even though high-income households were disproportionately located in the suburban ring.

In Figure 21 all nonwork trips by transit are shown according to the location of the household making the trip. A sharp pattern emerges, in that the greatest proportion of transit trips was taken by urban households, although households in all

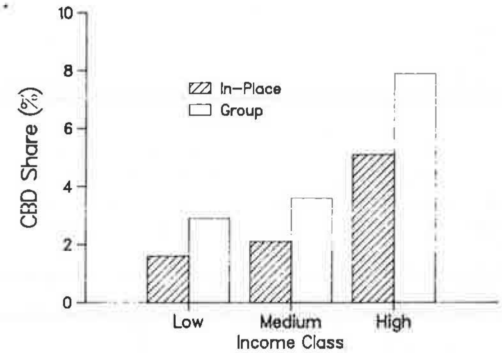

FIGURE 20 Nonwork trips to the CBD in Megatown in scenario I.

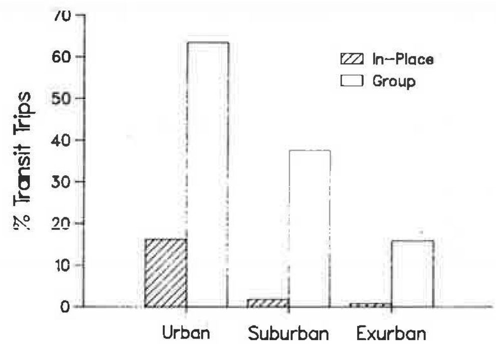

FIGURE 21 Nonwork trips on transit by household location in Megatown in scenario I.

three rings of Megatown experience radical increases in the modal split for transit. In absolute terms the greatest total number of trips is made by suburban households, so that there smaller fraction of trips by transit still represents more than two-thirds of the transit trips made by urban households. Detailed subarea examination of these transit trips indicates that suburban nonwork trips are primarily those taken on a cross-town rail network that was instituted in Megatown under the group travel strategy in scenario I.

CONCLUSIONS

Based on the analyses presented, several broad conclusions can be drawn regarding the potential for well-defined, multiple-action energy-conservation strategies to achieve significant impact on urban travel demand.

In general, it should be remembered that both of the contrasting conservation strategies analyzed in the overall study--group travel and individual travel--have the potential to save noticeable energy over in-place policies (4). The individual travel strategy achieved energy savings through the more efficient use of a significantly changed mix of private automobiles. There consequently was negligible impact on choice of travel mode, as compared to in-place policies. The group travel strategy, on the other hand, promises to significantly alter mode choice for both work and nonwork travel and to achieve transportation energy savings in this way. Group travel impacts on travel demand are consequently more noteworthy; they have been highlighted in this paper.

In-Place Policy

The potential impacts of the group travel strategy in achieving transportation energy conservation must be understood against the trends evidenced by in-place policies.

1. With increasing household incomes and decreasing household size, there is a trend toward more total travel per capita. Although work trips per person are projected to decline slightly, nonwork trips per person are expected to increase significantly.

2. PMT per capita and VMT per capita (for those who travel by automobile) are projected to remain close to constant. This reflects, in part, significant decreases in average trip length for nonwork trips and slight increases in work trip lengths. With steadily increasing automobile fuel economies, a healthy decrease in total (direct and indirect) transportation energy consumption can be expected and is in progress.

3. Even with projected increases in automobile travel cost, essentially constant transit costs, and significantly expanded transit service levels, only modest or no transit ridership increases were projected.

Group Travel Strategy

The various energy-conservation actions included under the group travel strategy, both to promote transit and ridesharing travel and to discourage individual automobile travel, can significantly increase the amount of both work and nonwork travel that is carried by the more energy-efficient group travel modes (9-11).

1. A modest impact on work travel mode choice, ranging between 30 and 40 percent for both transit and ridesharing modes, was estimated across all metropolitan areas. These percentages are applied against the in-place policy transit ridership levels of 5 percent and ridesharing levels of 18 percent.

2. The most dramatic impact of group travel policies potentially lies with nonwork travel. Automobile operating and parking costs were found to have a significant effect on nonwork trip generation, distribution, and mode choice. For this discretionary type of travel, nonwork trip modal splits to transit could increase from a base (across all metropolitan areas) of about 2 percent to as much as 17 percent.

3. Economic disincentives for automobile travel, especially drive-alone automobile travel, must be large to have a significant impact. Automobile fuel taxes of 50 to 100 percent of retail price and CBD parking taxes of 100 to 200 percent of the daily fee were both necessary to achieve the impacts previously discussed. Such disincentives would be particularly difficult to implement, given local political perspectives.

4. Although current transit peak-hour (work travel) ridership levels are modest, in low-ridership regions these group travel impacts could amount to a doubling of required service levels. Such large absolute changes in transit supply will present major challenges to the urban transit industry (12). The significant projected increases in off-peak nonwork transit travel could dramatically alter off-peak service levels, although peak-hour fleet requirements should be adequate for off-peak purposes.

5. Major shifts in nonwork travel patterns could potentially take place. In addition to increases in transit ridership for nonwork purposes, daily VMT per person for automobile travelers who make nonwork trips were projected to decline dramatically. Total nonwork trips per person could decline slightly, but with increases in trip length reflecting the decreasing cost per mile of flat-fare transit dominating the three typical cities' fare structures. Such impacts are especially important because discretionary nonwork travel represents a major arena for voluntary behavioral change, which could profoundly affect transportation energy-consumption patterns.

ACKNOWLEDGMENT

The authors would like to acknowledge the efforts of their colleagues, Bruce Peterson of Oak Ridge National Laboratory and Christopher Saricks of Argonne National Laboratory, in preparing the forecasts for each city and completing the automobile stock model runs. Lynn Ritter of Barton Aschman Associates assisted in specifying the transit level-of-service alternatives, a task that required systematic understanding of both the cities and the demand model. Joseph Schofer of Northwestern University and Martin Bernard of Argonne National Laboratory assisted at various points in the travel demand analysis, as the authors needed their judgments to help them past blockades. David Moses of the U.S. Department of Energy (DOE), the project's sponsor, and Daniel Maxfield, also of DOE, supported the work throughout the last 2 years, allowing the authors the space to carry out this project as they judged necessary for a thorough, professional assessment of the impacts of energy-conservation policies.

REFERENCES

1. R. Bixby et al. Analysis of Actions Appropriate for Transportation Energy Emergencies. Prelim. Res. Report 195. New York State Department of Transportation, Albany, Jan. 1981.
2. F.A. Wagner. Energy Impacts of Urban Transportation Improvements. Institute of Transportation Engineers, Washington, D.C., Aug. 1980.
3. D.G. Stuart and R.J. Hocking. Contingency Transportation Plans for Urban Areas and Their Potential Impacts. In TRB Special Report 191: Considerations in Transportation Energy Contingency Planning, TRB, National Research Council, Washington, D.C., 1980, pp. 145-157.
4. S.J. LaBelle et al. Technology Assessment of Productive Conservation in Urban Transportation--Final Report. Report ANL/ES-130. Argonne National Laboratory, Argonne, Ill., Nov. 1982.
5. M.D. Cheslow. Potential Use of Carpooling During Periods of Energy Shortages. In TRB Special Report 191: Considerations in Transportation Energy Contingency Planning, TRB, National Research Council, Washington, D.C., 1980, pp. 38-43.
6. F.A. Wagner and K. Gilbert. Transportation System Management: An Assessment of Impacts. U.S. Department of Transportation, Nov. 1978.
7. J.F. DiRenzo. Travel and Emissions Impacts of Transportation Control Measures. In Transportation Research Record 714, TRB, National Research Council, Washington, D.C., 1979, pp. 17-24.
8. SG Associates and the Urban Institute. Profile of the 80's. U.S. Department of Transportation, Feb. 1980.
9. J.M. Gross. Forecasting Energy Impacts of TSM Actions: An Overview. Prelim. Res. Report 156. Planning Research Unit, New York State Department of Transportation, Albany, 1979.
10. Transportation Systems Center. Energy Primer: Selected Transportation Topics. Office of

Technology Sharing, U.S. Department of Transportation, 1978.
11. R.H. Pratt and J.N. Copple; Barton-Aschman Associates. Traveler Response to Transportation System Changes, 2nd ed. U.S. Department of Transportation, July 1981.
12. G.F. Taylor. Capacity of Urban Transit Systems to Respond to Energy Constraints. In TRB Special Report 191: Considerations in Transportation Energy Contingency Planning, TRB, National Research Council, Washington, D.C., 1980, pp. 43-48.

Sketch-Planning Model for Urban Transportation Policy Analysis

MARC P. KAPLAN, YEHUDA GUR, and ANANT D. VYAS

ABSTRACT

In this paper the urban transportation policy analysis process (UTPAP) is described. UTPAP was developed as a sketch-planning analysis tool for the study Technology Assessment of Production Conservation in Urban Transportation (TAPCUT). TAPCUT was a comprehensive study of the potential environmental, health, and public safety impacts of various alternative productive urban transportation energy-conservation strategies. Productive conservation strategies encourage energy conservation without disrupting the economy or life-styles. The strategies that were analyzed reflected alternative national investment in infrastructure and technology and regulatory policies. The UTPAP is a sketch-planning model package that incorporates state-of-the-art, household-based, disaggregate travel demand models for mode and destination choice, with detailed specification of automobile technologies. It is useful in analyzing both the short- and long-term implications of city-specific transportation planning policies, and it provides summaries of transportation, fuel-consumption, air quality, public health, and safety impacts. Stratified by both type of household and geographic area of occurrence, these impact measures are valuable in assessing the social equity of transportation policy impacts. Preliminary sensitivity analysis indicated that nonwork travel was more responsive to price and level-of-service (LOS) change than work travel. Transit ridership was most affected by transit LOS improvements, whereas automobile vehicle miles of travel were most affected by fuel price increases. There was also a significant synergistic effect that increased nonwork transit ridership by combining transit LOS improvements with automobile fuel price increases.

In this paper the urban transportation policy analysis process (UTPAP) is described. UTPAP was developed as a sketch-planning analysis tool for the study Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT). TAPCUT was a comprehensive study of the potential environmental, health, and public safety impacts of various alternative productive urban transportation energy-conservation strategies. Productive conservation strategies encourage energy conservation without disrupting the economy or life-styles. The strategies that were analyzed reflected alternative national investment in infrastructure and technology and regulatory policies.

An in-place policy package and two alternative policy packages were defined. Both alternatives were composed of mutually reenforcing conservation strategies. Because there is a high degree of uncertainty about future conditions (exogenous variables), a scenario approach was used to analyze the range of future conditions analyzed through the year 2000. The two scenarios were distinguished by their demographics, macroeconomics, transportation fuels availability and price, and degree of social aggregation. Further details on the study structure are provided by LaBelle et al. (1).

Travel demand, fuel-consumption, and emissions estimates were determined for three prototypical cities. The cities were selected in light of major differences in their transportation-related characteristics by using a factor analysis technique for grouping cities. The first typical city, Sprawlburg, represents a relatively new, spread out, western metropolitan area. The second city, Megatown, has certain characteristics of the big, densely settled city with satisfactory transit in place. The third typical city, Slowtown, might be best described as a midwestern, industrial, middle-sized metropolitan area. Sprawlburg examples include Phoenix, Houston, Dallas, Anaheim, and Tacoma. Megatown examples include Chicago, Cleveland, Philadelphia, Boston, and Baltimore. Slowtown examples include Flint, Grand Rapids, Lima, Paterson, Norwalk, and York. The methods used to select the prototypical cities and expand city estimates to national totals are described by Peterson (2). UTPAP was developed and used to generate these city-specific estimates. The results of the UTPAP estimates were then expanded to national urban totals. The structure of UTPAP, how it was used in the analysis of alternative policies, and some examples of results generated by the process are described.

UTPAP: STRUCTURE OF THE PROCESS

The nature of the TAPCUT study design (multiple scenarios, policies, forecast years, and cities) dictated the need for a quick response, relatively low cost per forecast method of estimating travel demand and impacts. Also, the breadth of strategies required that the travel demand model be responsive to a wide range of alternatives, including new automobile designs, changing fuels mix, transit service improvements, colocation of home and work place, incentives for carpooling, and fuel tax increases. The long range (20-year) focus of TAPCUT required that the forecast reflect the full range of possible travel responses to these varied actions. Changes in trip length, trip generation, distribution, and modal split, as well as changes in automobile occupancy and the number and kind of automobiles owned by households, were all of concern. Land use impacts of the policies were not examined; however, activity patterns that were consistent with both general scenario descriptors and the policy themes were specified as analysis inputs. Also required was a level of output detail sufficient to identify impacts on subpopulations. These impacts included fuel consumption by fuel type, exposure concentrations of pollutants, and accident injuries and fatalities.

These model criteria proved to be quite ambitious. A review of 12 currently available sketch-planning models demonstrated that many satisfied some, some satisfied many, but none satisfied all of the TAPCUT modeling requirements (3). Therefore, a synthesis of existing methods was developed. Where necessary, these methods were modified and in some cases enhanced. The resulting analysis procedure, UTPAP, is shown schematically in Figure 1.

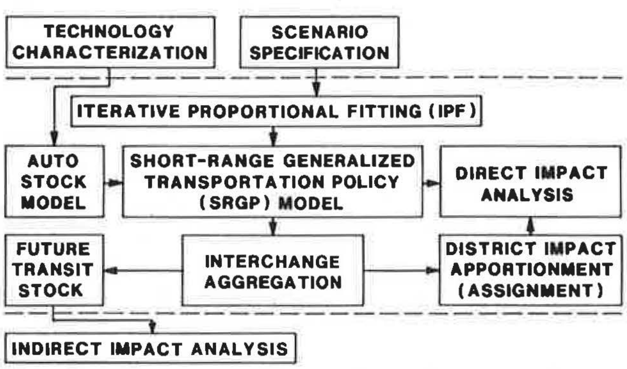

FIGURE 1 Urban transportation policy analysis process.

The central component of UTPAP is XRGP, an extended version of the computerized procedure for short range generalized transportation policy analysis (SRGP) (4,5). XRGP is a sequence of disaggregate travel demand models that estimate aggregate travel demand through a random sample enumeration process. A basic input to XRGP is the household and work trip (HHWORK) file, which contains information on household attributes and the frequency and destination of work trips. These attributes and work trip travel patterns remain constant for a household. Changes in the regionwide distribution of these attributes must be specified outside XRGP and expressed as changes in the expansion weights for the households.

In UTPAP this HHWORK file is modified by XIPF, an extended version of iterative proportional fitting (IPF), which modifies household expansion weights to reflect future, scenario-specific populations and work trip travel patterns. XRGP has the extended ability to input different vehicle ownership profiles for different household types and account for travel by as many as 10 vehicle types that are fueled by up to seven fuel types. The vehicle-ownership profiles are estimated by the disaggregate vehicle stock allocation model (DVSAM). DVSAM incorporates the Lave-Train new car purchase model (6,7) in an overall model structure to forecast household automobile holdings and purchases. This model estimates the probable automobile-type ownership profiles for 576 household types for input to XRGP.

Zone-to-zone vehicle trip tables by vehicle type are produced by XRGP. These trip tables are aggregated into district-to-district interchanges with standard Urban Transportation Planning System (UTPS) software (UMATRIX and USQUEX) (8). The district-to-district vehicle trip interchange tables are input to a desire-line projection method called CLIP. CLIP provides district level vehicle miles of travel (VMT), emissions, and accident impact measures.

HOUSEHOLD TRAVEL DEMAND MODEL (XRGP)

XRGP estimates residential travel demand in a city. The major input to the model is the household and work trip (HHWORK) file, which includes a sample of about 2,000 to 3,000 households. Each household is described by

1. Location (zone of residence),
2. Socioeconomic attributes, and
3. Attributes of each work trip made by household, which includes destination zone and level of service by all available modes.

In addition, the model needs as input mode-specific interzonal times and costs, a file that provides the distribution of activities that attract nonwork trips, and access and egress service characteristics for each zone. Each household is analyzed by the model separately. The estimated demand by individual households is aggregated (by using input expansion factors) to provide estimated demands for the whole population.

XRGP incorporates all of the capabilities of the original model. It estimates work trip modal split, as well as the generation, distribution, and modal split of nonwork trips. Submodel interactions are shown in Figure 2. Standard model outputs include travel demand, energy, and environmental impacts for the whole city and stratified by area type, income, and automobile ownership levels. Optional outputs include zonal interchange tables.

SRGP was selected as the basis for household travel demand modeling because it emphasized the effects of socioeconomic characteristics of the population on travel demand. This permitted the highlighting of differences among the scenarios, which are distinguished largely by variations in such attributes. The disaggregated demand models within SRGP were likely to be stable over time and scenarios. Limited past tests of model transfer-

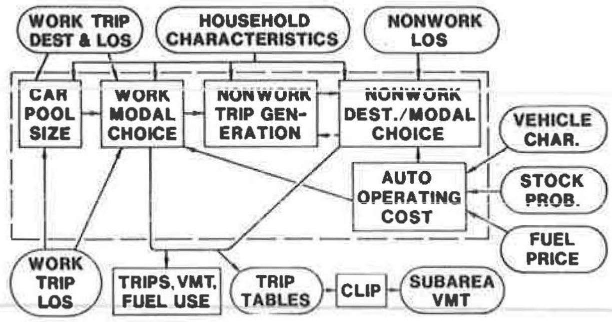

FIGURE 2 XRGP information flow.

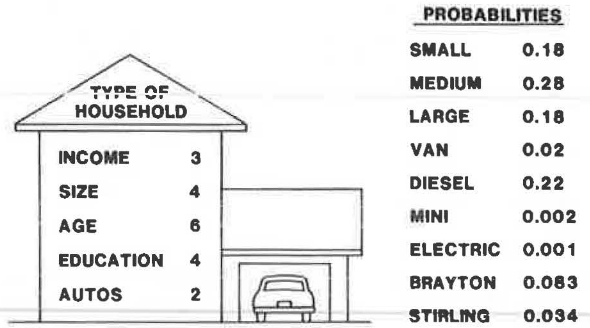

FIGURE 3 Automobile stock probabilities.

ability among cities had been quite encouraging. SRGP provided for the analysis of a wide range of strategies. The level of detail of the model was compatible with the needs of TAPCUT. Network analysis, with the corresponding data needs and analysis costs, was not a necessary part of the process. The model was well documented and had been successfully applied in several diverse cities.

As attractive as SRGP was as a sketch-planning tool, a number of deficiencies were apparent.

1. SRGP was, as its name implies, a short-range model.
2. One average composite vehicle type and fuel consumption versus speed relationship was assumed for all automobile trips, regardless of household or trip characteristics.
3. Geographic reporting of impacts was made by area of residence, not by area of occurrence.

These limitations of SRGP were overcome by providing appropriate links between SRGP and the other components of UTPAP. These links distinguish the XRGP procedure from its predecessor. The long-range forecasting ability of UTPAP is provided by linking XRGP with XIPF. The ability of XIPF to model changes in work travel patterns is described later.

Household Vehicle Disaggregation

XRGP accepts an extended HHWORK file that includes additional household attributes that are important in determining the probable automobile ownership profile of a household. XRGP also provides for the input of a household cross-classified automobile ownership profile table. This table, as generated by DVSAM, contains the probability of owning each of 10 different vehicle types for 576 different household classes. The household classes are distinguished by household size, income, number of automobiles owned, and age and education of the head of household. A detailed description of DVSAM is provided by Saricks et al. (7). A sample of the automobile stock probabilities for the highest-ranked household type in the year 2000 is shown in Figure 3. The method of specifying household automobile holdings permits XRGP to use a disaggregated representation of vehicle fuel-consumption rates.

Fuel-Consumption Calculations

The kinds of vehicles owned by a household have a direct influence on its travel behavior and a profound effect on the amount of fuel used while engaged in travel. Because the fuel economy of passenger cars varies greatly by vehicle type (principally size), the out-of-pocket automobile operating cost experienced by travelers may vary significantly from household to household. With recent rapid increases in fuel prices, out-of-pocket automobile operating cost has become an important factor influencing travel. However, significant increases in vehicle fuel economy (VFE), which occur in the long term, mitigate the price influence on out-of-pocket cost. Both VFE and fuel price were considered in determining out-of-pocket automobile operating cost, which in turn affected travel decisions.

XRGP permits the input of as many as 10 sets of the linear coefficients for the fuel-consumption rate versus speed relationship. Fuel-consumption rate (FCR) by vehicle class is determined as a linear function of the inverse of average trip speed (9):

$$FCR = a + b*(1/S) \qquad (1)$$

Because certain characteristics of future vehicles can be hypothesized for a scenario or strategy, but empirical data on their operation were not available, formulas for relating these characteristics to the values of the FCR versus speed relationship equation coefficients (a and b) were developed (10). According to these formulas:

1. a was evaluated as a function of vehicle curb weight, energy content of the propulsion fuel, system efficiency during acceleration, and system efficiency during cruise; and
2. b was evaluated as a function of drag coefficient, frontal area, fuel-flow rate at idle, fuel-flow rate during braking, and system efficiency during cruise.

Based on these estimates of FCR, trip length, a cold-start adjustment, and the household's vehicle type distribution, the expected out-of-pocket automobile operating cost for each trip is computed uniquely for each household type by XRGP.

Although gasoline is the primary automobile fuel, diesel fuel and gasohol have made notable entries into the market. The introduction of proposed alternative engine technologies offers the prospect of other fuels such as methanol and electricity. Each vehicle type has an expected fuels distribution. These distributions represent the proportion of VMT attributed to each fuel for each vehicle type. For each of the 10 possible types of vehicles, up to seven fuels shares may be specified. For example, it may be expected that in 2000 a Stirling engine vehicle would be propelled 70 percent of its VMT by kerosene, 20 percent by diesel, and 10 percent by methanol. Prices for each of these fuel types are specified.

XRGP Outputs

In addition to considering the effects of alternative vehicle technologies, fuel use, and fuel cost in determining out-of-pocket automobile operating costs, the XRGP program traces all travel by vehicle type and reports trips, VMT, and fuel consumption [in British thermal unit (Btu) x 10,000] by vehicle type. Fuel consumption is also reported by fuel type. As with the original SRGP outputs, these measures are stratified by trip purpose and market segment. XRGP also outputs zonal interchange trip tables by any combination of vehicle types. These specific trip tables by vehicle type are useful for emissions analysis when different vehicle technologies exhibit different emissions characteristics. These trip tables are the link between XRGP and the CLIP method used for district impact apportionment.

EXTENDED ITERATIVE PROPORTIONAL FITTING

Standard Procedure

IPF is an effective and widely used tool in modeling. It has been used to correct survey data for sampling bias (11). The FRATAR trip distribution procedure is a special case of IPF application (12).

The input to the procedure includes a base sample, which consists of a set of observations and target frequency distributions (FDs) of various attributes of the sample. IPF changes the weights of individual observations, so that the modified sample possesses the target FDs. The problem that is solved by IPF can be formulated as an optimization problem with a closed solution. However, for computational efficiency, IPF uses an iterative heuristic.

Many aspects of IPF made it suitable to UTPAP for modifying the base sample file (HHWORK) to represent different scenarios and future years. The target FDs were of a type, complexity, and specificity compatible with procedures for specifying scenarios. The flexibility in the selection of the attributes to be controlled, and in the level of detail of specifying the FDs, made IPF easily adaptable to a wide range of problems. One particular advantage of IPF was that it preserved individual observations and retained important intercorrelations among variables embedded in the observed data.

In adapting IPF to the needs of UTPAP, two major issues were resolved. First was the method of treating work trips. The second problem was the selection of variables for which FDs were to be specified, and in particular, the method for achieving spatial consistency. A description of each issue follows.

Treatment of Work Trips: Extended IPF

The standard IPF procedure operated on only one entity type. Every observation described one such entity, and target FDs were specified for that entity. For example, the basic entity type in the HHWORK file was a household; standard IPF can be applied to modify FDs of household attributes such as the number of persons, number of workers, income level, and so forth. The HHWORK file, however, described also another type of entity--work trips. Each household may produce between zero and nine work trips. The characteristics of work trips in the different scenarios might affect significantly the effectiveness of various strategies. For example, the effectiveness of policies that support transit depend largely on the spatial distribution of work trip destinations (jobs), and in particular the amount of work travel to the central business district (CBD). Moreover, some strategies call specifically for changes in work trip attributes (e.g., residence-job colocation). The procedure for specifying scenarios provided estimate target FDs for major attributes of work trips. A procedure that modified the sample toward those FDs had to be devised. Ignoring this issue would have amounted to leaving the determination of important scenario aspects to the random performance of a mechanical process.

One alternative was to follow the household IPF by another procedure (FRATAR, IPF, or a trip-distribution model) to control the attributes of work trips. This alternative was rejected because it destroyed the internal consistency of the sample file.

The solution involved an enhancement to the IPF procedure. The enhanced procedure--extended IPF (XIPF)--considers simultaneously FDs of the two entity types. The household expansion factors are modified to preserve both FD types. XIPF is also an iterative heuristic, but it is less robust than IPF; it is not difficult to find hypothetical examples of cases where the procedure misperforms. Nevertheless, in numerous actual applications the procedure has proved efficient and reliable.

With the introduction of XIPF, UTPAP became a significantly more powerful tool. It permitted the specification and analysis of inputs of a variety of policies and assumptions on work travel in the various scenarios.

Selection of Controlled Attributes

The second important issue was the various spatial aspects of the problem. The attributes that are controlled by XIPF are given in Table 1. The list covers most of the attributes that are included in the various XRGP demand models. Four FDs address the spatial aspects: district of residence (a household attribute), district of destination, area type of origin, and corridor orientation (work trip attributes).

TABLE 1 XIPF-Controlled Attributes

Attribute	Maximum No. of Classes
Household	
District of residence	100
Household size	20
Annual household income	3
No. of workers in household	20
Age of head of household	20
No. of automobiles	20
No. of work trips	20
Education of head of household	20
Work trip	
Ring of origin	10
District of destination	100
Trip length	10
Corridor orientation	2
Size: number of households	-

Work trip origins were controlled at the more aggregate level of area type (CBD, urban, suburban, exurban) because of the high correlation with residence. The major reason for its inclusion was the need to control the distribution of zero-worker households (primarily retirees). This was in response to scenario statements that in some cases predicted concentration of the elderly in dense areas that are well served by transit, whereas in other cases the scenario predicted more even distribution of such households.

The extent to which work travel is concentrated along corridors is a major determinant of the comparative advantage of fixed guideway transit versus buses. Conversely, it is expected that in the long run the work travel patterns will change to match

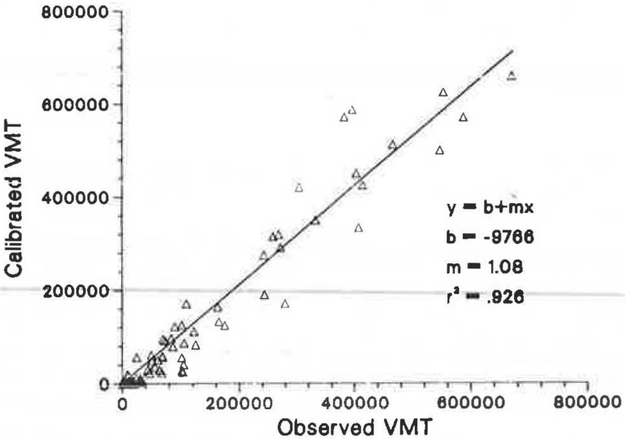

FIGURE 6 Sprawlburg-district VMT comparison.

note that there existed a pronounced synergistic effect between the two types of policies on transit use. Transit increases for shop trips with policy 6 are 50 percent greater than the sum of increases by the component policies 3 and 5. The synergism for social-recreational and work transit travel was 28 and 8 percent, respectively. There was, however, some policy redundancy evident on other travel responses, including total VMT and fuel use.

The results presented in this section reflect short-term responses to postulated fuel price and transit improvement policies. Neither work trip destinations nor household vehicle holding profiles were changed. Also, this brief analysis only examined aggregate measures of travel demand and energy impact. Variable responses by households of different socioeconomic categories or aggregate manifest travel through particular subregions have not been examined. This sensitivity test served, however, as a guide for interpreting the results of

TABLE 3 XRGP Calibration Results

	Sprawlburg		Megatown		Slowtown	
Calibration Criteria	Observed	Calibrated	Observed	Calibrated	Observed	Calibrated
Work trip shares						
Drive alone	84.17	83.95	58.49	58.97	70.53	70.68
Shared ride	15.03	15.02	21.07	21.40	28.26	28.11
Transit	0.80	0.81	20.45	19.63	1.21	1.21
Shop trip shares						
Automobile	99.77	99.76	94.18	94.21	95.53	95.73
Transit	0.23	0.24	5.82	5.79	4.47	4.27
CBD	2.02	2.03	4.7	4.57	7.84	8.14
CBD automobile	-	-	55.97	55.73	-	-
CBD transit	-	-	44.03	44.27	-	-
Social-recreation trip share						
Automobile	99.79	99.76	96.85	96.98	99.75	99.73
Transit	0.21	0.24	3.15	3.02	0.25	0.27
CBD	3.45	3.54	3.68	3.80	7.84	8.14
CBD automobile	-	-	80.53	80.57	-	-
CBD transit	-	-	19.48	19.42	-	-
Nonwork average trip length	3.834	3.847	5.62	5.83	3.47	3.68

TABLE 4 1976 Sprawlburg XRGP Sensitivity Analysis of Percentage Change from Base

	Policy[a]					
Travel Measure	1	2	3	4	5	6
Work travel						
VMT	-0.2	-0.4	-0.8	-0.1	-0.4	-1.3
Fuel	-0.2	-0.4	-0.8	-0.1	-0.4	1.3
Transit	+2.0	+4.3	+9.0	+23.4	92.4	+109.0
Drive alone	-0.3	-0.5	-1.1	-0.1	-0.5	1.6
Shared ride	+1.3	+2.7	+5.5	-0.7	-2.1	3.22
Vehicle trips	-0.2	-0.3	-0.7	-0.1	-0.6	-1.3
Nonwork travel						
Shop person trips	-0.2	-0.3	-0.6	-0.04	+0.06	-0.5
Shop vehicle trips	-0.2	-0.3	-0.7	-1.0	-1.4	-2.3
Shop transit trips	+8.3	+8.2	+20.6	+458	+616	+950
Social-recreation person trips	-1.0	-1.6	-2.6	-0.5	-0.5	-2.5
Social-recreation vehicle trips	-1.0	-1.6	-2.7	-0.9	-1.0	-3.3
Social-recreation transit trips	+8.2	+12.4	+34.7	+172	+232	+341
CBD person trips	-2.1	-3.8	-6.8	+8.9	+11.4	+8.3
CBD vehicle trips	-2.6	-4.7	-8.6	-3.1	-3.7	-12.7
PMT	-2.4	-5.5	-10.3	-0.1	-0.05	-10.2
VMT	-3.1	-6.7	-12.4	-1.0	-1.0	-13.1
Fuel	-2.6	-4.7	-8.6	-0.9	-1.1	-9.5
Total travel						
VMT	-1.9	-3.5	-6.5	-0.5	-0.7	-7.0
Fuel	-1.5	-2.7	-5.0	-0.4	-0.8	-5.6

[a]See text for the definitions of the policies.

the scenario forecasts combined with the TAPCUT policies, where more variables were changed between successive model runs. As the project was particularly concerned with synergistic effects from demographic, land use, and vehicle changes in addition to the transportation energy-conservation policy actions, this sensitivity analysis was essential in understanding the more complex and comprehensive analysis reported in a paper by Stuart, LaBelle, Kaplan, and Johnson elsewhere in this Record.

In summary, the UTPAP is a sketch-planning model package that incorporates state-of-the-art, household-based, disaggregate travel demand models for mode and destination choice, with detailed specification of automobile technologies. It is useful in analyzing both the short- and long-term implications of city-specific transportation planning policies, and it provides summaries of transportation, fuel-consumption, air quality, public health, and safety impacts. Stratified by both type of household and geographic area of occurrence, these measures are valuable in assessing the social equity of transportation policy impacts.

ACKNOWLEDGMENT

The authors wish to express their thanks and acknowledge the numerous contributions made to this effort by the many TAPCUT project participants. Sara LaBelle, the Argonne National Laboratory project manager, David Moses, the U.S. Department of Energy (DOE) project manager, and Daniel Maxfield, also of DOE, were a continued source of support and guidance. Darwin Stuart and William Davidson of Barton-Aschman Associates provided valued assistance in model selection and in overcoming a multitude of obstacles. Frank Koppelman of Northwestern University contributed invaluable advice regarding model calibration. Bruce Peterson of Oak Ridge National Laboratory dedicated a tremendous effort in the often thankless job of data collection and preparation. His efforts and the cooperation that he received from the planning agencies in the three prototypical cities are greatly appreciated.

REFERENCES

1. S.J. LaBelle et al. Technology Assessment of Productive Conservation in Urban Transportation, Final Report. Report ANL/ES-130. Argonne National Laboratory, Argonne, Ill., Nov. 1982.
2. B.E. Peterson. City Decomposition and Expansion. Report ORNL/TM-8502. Oak Ridge National Laboratory, Oak Ridge, Tenn., Sept. 1982.
3. M.P. Kaplan and D.G. Stuart. Selection of Travel Demand Models for the TAPCUT Project. Report ANL/EES-TM-180. Argonne National Laboratory, Argonne, Ill., Feb. 1982.
4. Cambridge Systematics, Inc. Urban Transportation Energy Conservation: SRGP Operating Instructions and Program Documentation, Volume V. Report DOE/PE/9628-1. U.S. Department of Energy, Oct. 1979.
5. R.E. Nestle; Cambridge Systematics, Inc. SRGP Operating Instructions and Program Documentation, Version May 9, 1979. Draft Document. North Central Texas Council of Governments, Dallas, May 10, 1979.
6. C.A. Lave and K. Train. A Disaggregate Model of Automobile Choice. Transportation Research, Vol. 13a, 1979.
7. C.L. Saricks et al. Personal Vehicles Preferred by Urban Americans: Household Automobile Holdings and New Car Purchases Projected to the Year 2000. Report ANL/EES-TM-170. Argonne National Laboratory, Argonne, Ill., Jan. 1982.
8. UTPS Reference Manual. Planning Methodology and Technical Support Division, UMTA, U.S. Department of Transportation, April 2, 1979.
9. M. Chang et al. The Influence of Vehicle Characteristics, Driver Behavior, and Ambient Temperature on Gasoline Consumption in Urban Traffic. Report GMR-950. Traffic Science Department, General Motors Corp., Warren, Mich., 1976.
10. C.L. Hudson et al. Vehicle Characterization for the TAPCUT Project: Performance and Cost. Report ANL/EES-TM-171. Argonne National Laboratory, Argonne, Ill., Nov. 1981.
11. L.T. Ollmann, S.M. Howe, K.W. Kloeber, and G.S. Cohen. Marginal Weighting of Transportation Survey Data. In Transportation Research Record 677, TRB, National Research Council, Washington, D.C., 1978, pp. 73-76.
12. Urban Transportation Planning, General Information, and Introduction to System 360. FHWA, U.S. Department of Transportation, June 1970.
13. H.S. Schleifer, S.L. Zimmerman, and D.S. Gendell. The Community Aggregate Planning Model. In Transportation Research Record 582, TRB, National Research Council, Washington, D.C., 1976, pp. 14-27.
14. User's Guide to MOBILE2. Office of Mobile Source Air Pollution, U.S. Environmental Protection Agency, Ann Arbor, Mich., 1980.

Technology Assessment of Productive Conservation in Urban Transportation: An Overview

DAVID O. MOSES, SARAH J. LaBELLE, and MARTIN J. BERNARD

ABSTRACT

Travel within urban areas accounted for about one-third of all the person miles of travel and about 5 quads of energy in 1975. Two energy-saving strategies were designed for this sector that were aimed at minimal disruption to life-styles and the economy while achieving the reductions in aggregate energy, especially petroleum, consumption. These productive conservation strategies

were tested in three typical cities; results were expanded to national urban totals and compared with results under a reference forecast of in-place policies. One strategy stressed group travel, whereas the other promoted individual travel. A scenario approach was used for projection of economic and social variables. Both strategies saved energy. Trips per person declined under the group travel strategy, which suggests that its greater energy savings were at the expense of some decrease in mobility. The impacts of environmental degradation and traffic fatalities were significantly different under the group travel strategy and were better than impacts under either the individual travel strategy or the in-place policy.

The transportation sector directly consumes one-quarter of the energy used in this country, with automobile passenger travel accounting for half of the energy supply for the transportation sector. Because of rising fuel prices and intermittent supply shortages, federal, state, and local governments have begun to introduce various strategies (combinations of policies and technologies) designed to conserve urban transportation energy while maintaining a productive economy.

The environmental consequences of many of the conservation strategies have not been adequately assessed. As a result, a technology assessment project sponsored by the U.S. Department of Energy (DOE) was initiated in late 1979. The goals of the project were to provide a description of several alternative strategies that promote energy conservation in the urban passenger transportation sector, a better understanding of the environmental impacts of such strategies, and an identification of the constraints to the implementation of such strategies.

The study is the Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT). The background, structure, and preliminary results of TAPCUT are presented in this paper.

BACKGROUND

The transportation sector is almost entirely dependent on petroleum (1-3). For the past 30 years transportation has accounted for more than one-half of the petroleum used or one-fourth of total energy consumed in the United States. Passenger cars alone account for half of the energy in the transportation sector.

Intraurban travel (i.e., travel that occurs within an urban area) corresponds to about one-third of all person miles of travel (PMT). In the absence of transportation controls [which to date have been strategies of reducing vehicle miles of travel (VMT) that were developed for air quality control plans], urban travel was expected to increase in proportion to changes in population.

Most forecasts assume that the automobile will continue to be the dominant urban travel mode, because average income is projected to rise faster than the costs of owning and operating a car. Transit ridership, which has steadily declined since World War II, has leveled off and has even shown slight increases since the oil embargo of 1973. Nevertheless, under current policies transit patronage, which accounts for about 2 percent of urban travel in most regions, is expected to achieve little if any growth.

To date the single most effective force in improving urban travel efficiency has been the corporate average fuel economy (CAFE) legislation in 1975. By 1985 total automobile fuel consumption should be less than that in 1975 because of improved vehicle efficiency. However, the continued increases in travel will eventually overcome this advantage, so that by the year 2000 energy consumption is predicted to surpass 1975 levels.

Figure 1 illustrates both the range of projected increases in travel as well as selected forecasts of automobile energy use. This figure shows the consistency of the view that vehicle fuel-efficiency improvements would have only a temporary effect on energy, and especially gasoline, consumption.

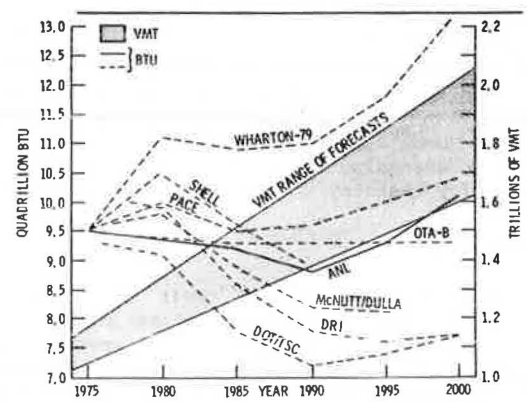

FIGURE 1 Selected projections of automobile energy.

With the real cost of gasoline declining since the 1950s, except for 1973 and 1980 in which it rose slightly in real terms, there have not been any clear signals to the American motorist that conservation was either a desirable or necessary behavior. Intermittent interruptions in gasoline supplies and price increases have served as sharp reminders to the public of the vulnerability of the current transportation system. The response has been a rapid increased demand for fuel-efficient vehicles and at least a short-term reduction in travel.

As indicated by changes in automobile purchase behavior and transit ridership, individuals are looking for solutions to the problem of remaining mobile while not greatly changing the amount of time and money devoted to travel. Declining domestic petroleum production coupled with the current expectation of no major market penetrations of alternative fuels and vehicles before the year 2000 (even the cumulative effect of electric vehicles, which may be introduced by 1985, are not expected to be major before 2000) leads directly to the heart of the problem: What can be done in the interim and what would be the effects of those actions?

Within DOE one responsibility is the conduct of technology assessments that identify the environmental consequences of various energy policies. Technology assessment is a form of policy study that systematically defines, explores, and evaluates both the direct and indirect economic, social, environmental, and institutional consequences of the introduction or expansion of new technologies or policies in society. The need for a technology assessment in the transportation sector was apparent in mid-1979, and a literature analysis was initiated to identify what was known about the problem.

PROBLEM REFINEMENT

An extensive literature analysis of transportation studies produced in recent years yielded data sources and identified issues where either the analysis was incomplete, of questionable quality, or the study had little effect on policy (4). The information gained from the literature analysis, when synthesized with current major issues in the transportation sector, provided an initial list of candidate technology assessment studies. To narrow this list three major bounding decisions, as illustrated in Figure 2, were applied:

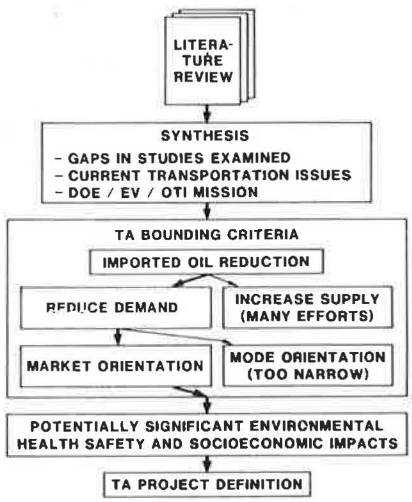

FIGURE 2 Problem refinement process.

1. The study had to be within DOE's purview of reducing dependency on foreign petroleum,
2. The study would emphasize demand-reducing rather than supply-increasing strategies, and
3. The study would take the more comprehensive market or transportation demand approach (as opposed to a single mode orientation); this approach groups travel modes according to use, which requires consideration of modal shifts and relative modal advantages.

The candidate studies were then examined to determine if significant environmental impacts were anticipated to warrant the technology assessment.

At the conclusion of the problem refinement process, a technology assessment project was defined that would

1. Cover the urban passenger transportation market,
2. Emphasize conservation (reduction of foreign petroleum demand) strategies,
3. Span the present-to-2000 time period within two bounding futures,
4. Consider both policy and technology alternatives, and
5. Focus on environmental (broadly defined) impacts.

From this definition the specific objectives of the technology assessment project were developed.

PROJECT OBJECTIVES

The technology assessment described in this paper was designed to investigate the potential environmental, health, and safety impacts of two alternative productive conservation strategies. Productive conservation strategies are defined as being neither disruptive of the economy nor of the American lifestyle but instead encourage conservation in various sectors, including transportation (5).

Because by this definition productive conservation promotes energy savings in a manner that is neither economically nor socially disruptive, special attention was paid to the unanticipated diffuse impacts of the strategies, a task well suited to the technology assessment format.

This technology assessment was designed to meet several broad objectives:

1. An identification of internally consistent (mutually reinforcing policy or technology elements following a specific theme) productive conservation strategies that will aid in the reduction of the United States' dependence on petroleum in urban transportation,
2. A comparative analysis of the energy savings and environmental impacts of the various productive conservation strategies, and
3. An analysis of the issues and the barriers that may constrain these productive conservation strategies from becoming effective.

A broader discussion of each objective follows.

Identification of Potential for Energy Conservation

The concept of productive conservation as applied to urban passenger travel can be partly defined as reducing energy consumption, especially consumption of petroleum-based fuels, while maintaining social interaction. The potential for this is substantial simply because energy has never been an important factor in financing and operating urban transportation systems.

These urban automobile-oriented systems are energy intensive as currently operated. The single-occupant vehicles operated within these systems were most often designed for comfort and speed in an era of cheap energy. That many proposals to reduce this energy intensity have been developed argues that reduction is possible even within the constraints of productive conservation. The matching of alternative strategies comprised of policy and technology elements to the distinct types of in-place systems (which can physically change only gradually during the time frame of the study) in three city classes promises to increase the potential for finding significant energy savings.

Comparison of Environmental, Health, and Safety Impacts

The transportation energy-conservation policies that were studied were for the most part similar to those measures necessary to improve environmental quality. That is, there were trade-offs between impacts on different environmental subsystems and, in some cases where energy-conservation strategies had negative environmental impacts, the design of mitigation strategies or redesign of the initial conservation strategy is required.

TAPCUT included a broad environmental impact analysis for each strategy and is now using the results of impact analyses to indicate where further mitigation of impacts might be required.

Analysis of Barriers to Implementation

A study of the impacts of any proposed new policy or technology element must include some consideration of its feasibility. This study was concerned with the feasibility of implementation, but it did not undertake any assessment of commercialization or a detailed barrier analysis. Instead these issues and concerns were incorporated in two places: development of the strategies and the environmental impact analysis. Cost and management or administrative barriers were considered in choosing policy elements for the productive conservation strategies.

The study's definition of environmental impact assessment covers many of the issues often included in barrier analysis: resource use and institutional, social, and economic impacts. Questions of equity in tax-based policies, of the impacts of labor unions, of safety on roads with smaller automobiles and large trucks, and of fuel economy and engine emissions trade-offs were considered.

The state-of-society assumptions associated with the socioeconomic impact analysis also provided a framework for evaluating the societal change that accompanied the implementation of the technological developments. These assumptions characterized the future society's economic and social systems, demographic make-up, institutional structure, as well as attitudes and values.

PROJECT STRUCTURE

The overall flow of the project is shown in Figure 3. Travel demand analysis was performed for each of three typical cities under policies now in place and forecast to continue. Environmental impact analysis of the forecast travel was also city specific. The two productive conservation strategies--group travel and individual travel--were defined, and the travel and environmental impacts were then estimated. The final step is the overall comparison of policy-driven results in contrast to the results under in-place policies.

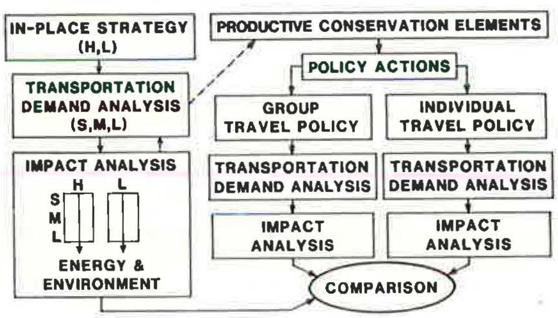

FIGURE 3 TAPCUT project flow.

The task structure designed to meet the project goals is shown in Figure 4. The other papers presented in this Record on TAPCUT relate to this structure. Hudson and Putnam discuss the design of the technologies; Saricks, Vyas, and Bunch present the forecasts of the supply of transportation; the city selection and expansion to national totals are covered by Peterson; Kaplan, Gur, and Vyas address the method for household travel demand forecasting; and Stuart, LaBelle, Kaplan, and Johnson highlight the changes in travel demand that result from the policies. The scenarios used as background in the analysis and the energy-conservation policies are briefly presented in this paper, as well as the method and preliminary results for the environmental impact analysis. Further detail is presented in the project final report (6).

Scenarios

Selected features of the two scenarios defined for this project are shown in Figure 5. These variables were considered scenario variables because they are out of the realm of direct control of the decision

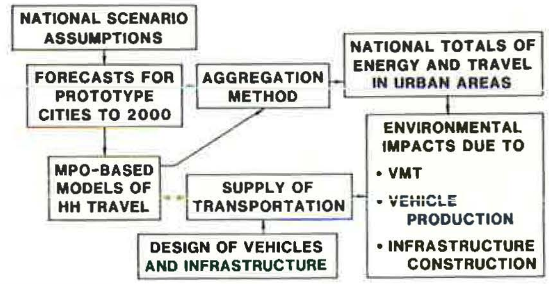

FIGURE 4 TAPCUT project structure.

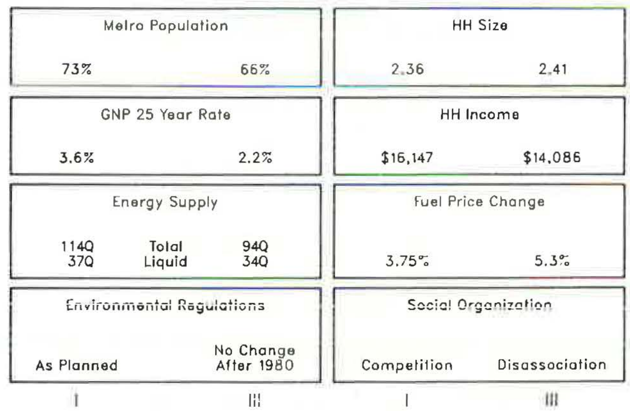

FIGURE 5 Scenario summary.

makers of interest in this project. Clearly, some of these variables will be affected indirectly by decisions made regarding energy conservation in transportation; however, these interactions are not of the first order and are not modeled directly in this project. The two scenarios can be briefly distinguished as scenario I (wealthy scenario with high technology success) and scenario III (relatively poor scenario with low technology success). The major differences between the scenarios that affect travel demand were in the forecast retail fuel price and the average income (in 1975 dollars). The range of difference in other variables was not sufficiently large to account for significant differences in the travel forecasts.

The rate of change in fuel price as shown is an average annual value from 1990 to 2000. The rate of change from 1980 to 1990 was higher than the 20-year rate in both scenarios. The rate of change in gross national product (GNP) is given as an average for the years 1975 to 2000. A 5-year cycle was built in to the annual GNP level.

Metropolitan population represented the percentage of national population residing in standard metropolitan statistical areas (SMSAs) in 2000 in each scenario, against the same national total. The Census Series II forecast of 260.378 million persons in 2000 was the national base.

Energy supply was forecast but was not directly used for the demand analysis. The demand for energy in urban local travel can be compared against demand by consuming sectors and against various supply forecasts. The scenario assumption on environmental regulation, by contrast, influenced which set of automotive emission standards was used in the air quality impact analysis; for scenario III the changes scheduled to take effect in 1983 and beyond were cancelled. The social aggregation assumptions influenced land use forms primarily, which led to higher employment densities in scenario I than in scenario III.

City Forecasts

Starting from a data base for 237 metropolitan areas, three typical metropolitan areas were identified for study in this project. A method was developed to select the cities based on characteristics relevant to transportation energy consumption, such as average daily travel, household income, and population density. Three cities were selected that constituted extreme examples along the three dimensions defined from city characteristics that influenced transportation energy use. One dimension identified large cities with satisfactory transit systems; this was called Megatown. The second dimension, called Sprawlburg, involved new, fast-growing sprawl cities. The third dimension identified midwestern, industrial towns that were smaller in population than the other two; it was termed Slowtown. All metropolitan areas in the nation were related to these three dimensions. A linear expansion method was also developed, which allowed national urban forecasts to be made by using the detailed forecast of the three typical cities.

The TAPCUT forecasting effort focused on the details of the three cities by using actual travel and land use data files from the cities as the base and by using the cities' forecast as a reference for all scenario-specific forecasts. Forecasts of employment activity by type and residential location were made for each city under the conditions of each scenario, with some modification for policy impacts. The forecast independent variables for TAPCUT for typical cities (by scenario and year) are as follows:

1. Residential location--total households, household size, earners per household, average income, and household location: central business district (CBD), center city, suburban, or exurban; and
2. Employment activity--total employment, location of employment, development density, and type of employment: manufacturing, retail, service, or other.

Travel Demand Forecasts

The city-specific forecasts previously described were organized for input to the travel demand modeling package. Household characteristics from the base year in each city's travel survey [supplied by the metropolitan planning organization (MPO)] formed the basis of the travel demand forecasting approach. The forecast citywide distributions were translated into model inputs to determine their effects on household travel behavior by using an iterative proportional fitting method.

Modified household records combined with the transportation level-of-service (LOS) forecasts for the horizon year drove the travel demand model. Transportation LOS parameters included detailed specification of transit service and of automobile characteristics, including speed, operating costs, and emission rates. Both work and nonwork travel were separately forecast and reported for households in three income classes and three locations within the urban area (center city, suburban, and exurban).

The urban transportation policy analysis package (UTPAP) was used for case study city travel demand forecasts (Figure 6). It included an extended version, called XRGP, of the short range generalized transportation planning (SRGP) model at its core. That model used a logit formulation, both for work trip mode and for destination and mode choice for nonwork trips. The changes in VMT for each class of household (the major output of UTPAP) provided the starting point for much of the environmental impact analysis.

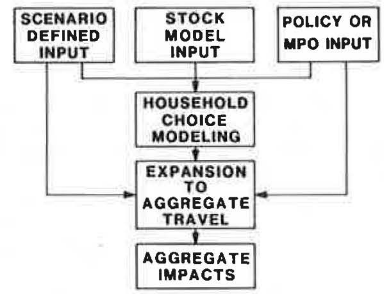

FIGURE 6 TAPCUT travel demand modeling (macro view).

Technology Characteristics

The characteristics of vehicles used by household were specified in great detail. Three different sets of new vehicles were designed for the policy tests. Initial price, operating cost, power/weight ratio, passenger capacity, fuel economy, and pollutant emissions were specified for each vehicle. Many of the characteristics were used to determine the cost of travel for the modal-choice models. Other characteristics, such as power/weight ratio, were used only in the vehicle stock model. That model determines which kind of automobile will be purchased by urban households and the distribution of vehicles held by household in forecast years.

The design of the automobiles reflected both policy and scenario considerations. In the in-place policy both scenarios were supplied with the same initial set of vehicles; there were slight differences in the vehicle mix chosen by households in each scenario. Under the individual travel strategy new car fuel economy was increased as a policy action. The increase was modest in scenario III (4 percent over the in-place policy) and fairly large in scenario I (23 percent). In scenario I the average new car fuel economy reached 40 miles per gallon in 2000. Specific vehicles, of course, reached higher fuel economies; this fuel-economy value includes the effects of consumer choice among the vehicles offered for sale.

New car weight declined in all size classes in each technology set, averaging about a 25 percent decrease from 1980 new cars. The individual travel strategy technology sets had a decrease in average new car weight of 10 percent from the in-place policy in scenario I and only 3 percent in scenario III. In scenario III consumers chose some automobiles in 2000 that had actually increased their weight. In general, weight decreases were constrained by the standards for reasonable performance (power/weight ratio) in all TAPCUT vehicles.

Environmental Impacts

The major focus of this study was to determine the environmental impacts associated with energy-conservation strategies. Consequently, environmental impact analysis was quite detailed. Air quality and water quality impacts from vehicle production and VMT were addressed, as well as the associated health effects. Traffic safety and workers safety were both estimated. Impacts on all resources, both energy and minerals, have been estimated. Further, socioeconomic effects from the changes in travel, in production of vehicles, and in the transportation infrastructure were also addressed, focusing on the transportation industries, subpopulations in urban areas, and interest groups.

Transportation Energy-Conservation Strategies

The first task of the study was to prepare reference forecasts, that is, to build a baseline against which to compare the energy-conservation strategies. The in-place policies were defined as those current policies directly bearing on transportation and energy consumed in transportation by urban households. Key aspects of in-place policies are summarized in Figure 7. Generally, policies were interpreted as what was on the books in 1980 plus any scheduled changes beyond that time. For example, the CAFE requirement for 27.5 miles per gallon in new cars by 1985 was now scheduled, but no increases beyond that are scheduled. Other important policies include the constant dollar value of gasoline taxes; this implies an increase in inflated dollars, but not in real dollars.

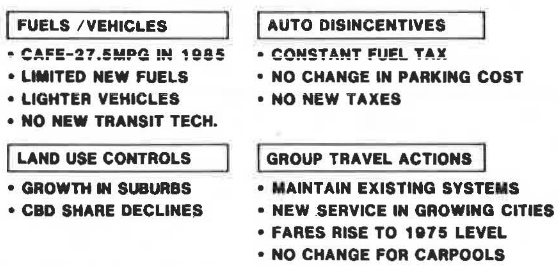

FIGURE 7 In-place policy in transportation energy.

Although automobile technology is expected to improve considerably over the 20-year horizon simply from forces now in place, transit technology is not expected to change much at all by 2000. No exotic transit technologies were selected for use in any of the typical cities in their own plans, that is, the in-place policy for this project. Only slight improvements to current technologies, such as light rail, diesel bus, and rapid rail, were tested. The policies regarding elderly and handicapped users of transportation were presumed to moderate from their 1980 versions in such a way as to allow transit systems to continue operating, although certain resources would be devoted to the provision of special services for those groups. (The expected changes in those policies have since occurred.)

The in-place policy was translated into variables that could be changed in the modeling package selected for the project. These variables are referred to as policy levers. It was essential to define any policy of interest in terms of these levers. As shown in Figure 7 the five major classes of policy levers are fuels and vehicles, economic disincentives for automobile travel, group travel actions, and land use controls. Other categories of policy levers were examined and then excluded from the analysis when either no reasonable policy could be defined in terms of these levers or there was no sufficient theoretical work done to define the relationship between a policy action and a response to the action. An example of the first case is extensive land use controls that would result in major changes in the length of the work trip. An example of the second is the relation between telecommunications and transportation.

Two strategies were developed, and both were aimed at reducing energy consumption in urban travel. The group travel strategy focused on reduction in energy use through increased use of efficient group travel modes. The individual travel strategy was aimed at that same goal, but achieved it through significant improvements in automobile technology. As shown in Figure 8, many more levers were adjusted for the group travel strategy than for the individual travel strategy. The arrows indicate the direction, not the magnitude, of the change.

The group travel strategy changed the tax on automotive fuels and the tax on parking, in one instance lowered transit fares, extensively improved transit systems, and induced land use changes supportive of transit system use. No changes were made in automotive technology with respect to the in-place policy.

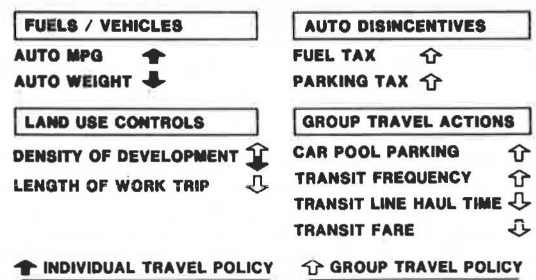

FIGURE 8 TAPCUT policy levers.

The individual travel strategy required only an improvement in automobile fuel economy achieved through new design for automobiles. In scenario III small land use changes that were supportive of automobile use were instituted.

TAPCUT Fuel Price

The fuel price in TAPCUT was the result of both scenario assumptions and policy changes. The base price without taxes was a scenario-specified variable. Taxes on that price were a policy variable, however. In Figure 9 the net resulting price to the consumer is plotted in 1975 dollars for each scenario and policy from 1975 until 2000. The price in scenario III ($2.55 in 2000) was considerably higher than the price in scenario I ($1.89). However, the tax on fuel under the group travel strategy for scenario I was double the rate of the tax for scenario III under that policy. As a result the price in the year 2000 was nearly the same in each scenario under the group travel strategy.

For scenario III, the higher rate of price increase was tied to the limited success in finding new domestic sources of oil and the unsatisfactory international position of the United States in purchasing imports. The technological success in scenario I was the main reason behind the lower price of the primarily domestically produced fuels.

As all liquid fuels were competing for the same market, it was presumed that there would be relatively small variation among fuel prices, just as now. Thus even if a fuel costs more to produce than the average liquid fuel, it would be priced close to the predominant fuel in the market. This is reasonable, given the assumption that a few large suppliers would provide all the different kinds of fuels, such that the cost of one could be balanced out by the profits from another cheaper-to-produce fuel.

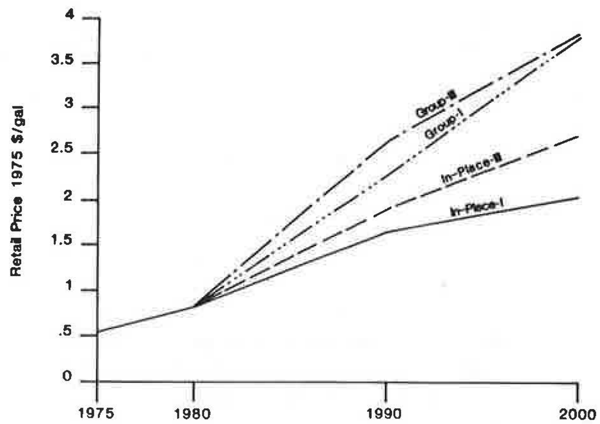

FIGURE 9 TAPCUT fuel prices.

SELECTED ANALYSIS RESULTS

Aggregate Measures of Travel

VMT and PMT from urban households in scenario III are plotted in Figure 10. These are annual figures and include an estimate of non-home-based travel. Under the in-place policy PMT in the aggregate did not change much, although VMT increased slightly. The forecast metropolitan population change was only 6 percent from 1980 to 2000 in scenario III, so that large growth in travel would not be expected. Nevertheless, these plots are nearly flat (0.1 percent change in PMT, 3.5 percent change in VMT), primarily as a result of increase in the price of travel.

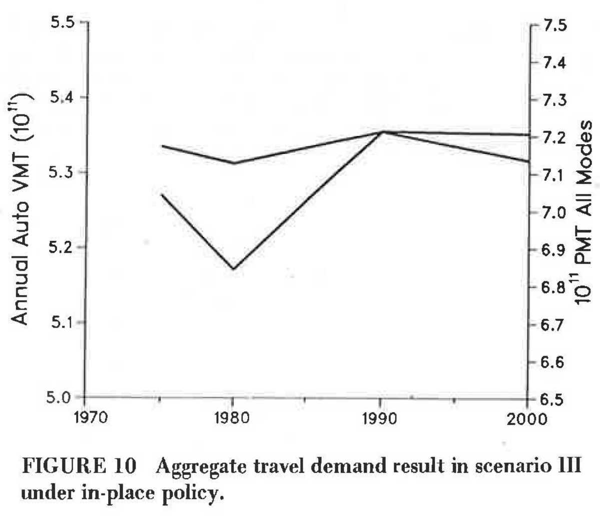

FIGURE 10 Aggregate travel demand result in scenario III under in-place policy.

In scenario I, where metropolitan population grows 17 percent and households are wealthier, person travel increases 7.6 percent over 20 years and vehicle travel increases 17 percent.

The strategies affected aggregate travel measures differently. The group travel strategy resulted in a 23 percent decrease in VMT with respect to the in-place policy in both scenarios; but PMT increased in scenario I by 0.6 percent, yet decreased nearly 10 percent in scenario III. This difference in the scenario results under the same strategy suggests that the households located in the denser land patterns of scenario I can satisfy travel needs more easily on satisfactory transit. Some of this difference is explained by the policy action in scenario III that only resulted in a 14 percent decrease in average work trip length. In scenario I, however, changes in PMT occurred only in nonwork (discretionary) travel, as work trip length and frequency were unchanged by the policy action.

The individual travel strategy had virtually no effect on the aggregate travel measures of VMT and PMT. The fuel-economy increases, although notable, did not affect out-of-pocket expenses sufficiently to increase travel demand. Households chose slightly larger automobiles that had satisfactory fuel economy, but not the best fuel economy available; the net effect was no change in out-of-pocket expenses relative to those under the in-place policies.

Examination of costs of the strategies and the tax and fare revenues generated indicated that costs were 80 percent, whereas revenues fell 40 percent, under the in-place policies. This situation was worse under the individual travel strategy but reversed under the group travel strategy. In the latter strategy transit fares covered operating costs and gasoline tax revenues covered projected capital expenditures (6).

Energy Consumption

Figures 11 and 12 show the total direct energy consumption under all three policies in each scenario. Even under the in-place policy energy use for urban transportation declined significantly--about 40 percent from 1980 to 2000. Further, under each policy energy consumption declined still more. The lowered energy use per trip, which resulted from fuel-efficient vehicles, explains much of this reduction in total use. The increase in the price of automobile travel without large increases in transit service also figures in the decline in energy use under the in-place policy (7).

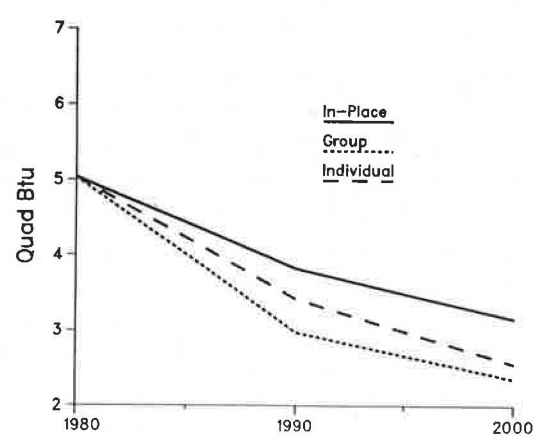

FIGURE 11 Direct energy consumption by urban households for local travel in scenario I.

Under the group travel strategy direct energy consumption was reduced 25 percent compared to the in-place policy in 2000 in scenario I. The decrease was 18 percent in scenario III (see Table 1). Direct energy savings were less under the individual travel strategy, but still significant--19 percent in scenario I and 7 percent in scenario III. However, when direct and indirect energy consumption are both included, the energy savings from the individual travel strategy diminishes considerably--9 percent in scenario I and only 1 percent in scenario III. The group travel strategy decreases remain the same.

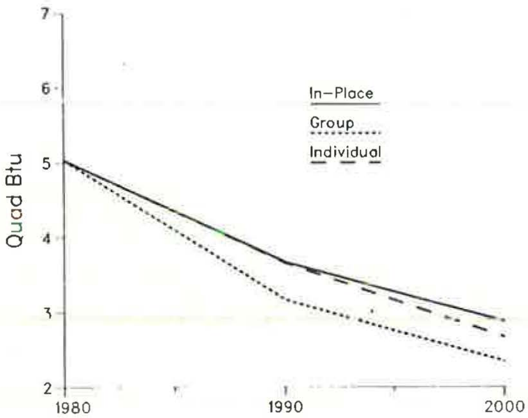

FIGURE 12 Direct energy consumption by urban households for local travel in scenario III.

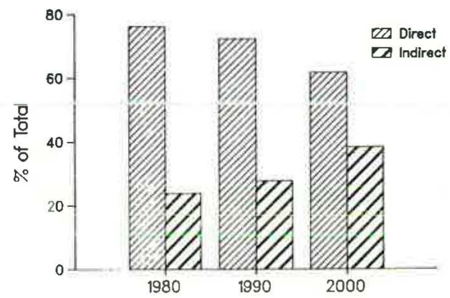

FIGURE 13 Comparison between direct and indirect energy use for urban travel in scenario III under individual travel policy.

TABLE 1 Selected TAPCUT Results: Changes in Aggregate Travel and Energy for National Metropolitan Travel

		Percentage Change in				
Policies and Years Compared	Scenario	VMT	PMT	Direct Energy	Indirect Energy	Total Energy
In-place policy 1980 to in-place policy 2000	I	+17	+8	-37	+53	-16
	III	+4	+0.1	-43	-4	-34
In-place policy 2000 to group travel policy 2000	I	-23	+0.6	-25	-22	-25
	III	-23	-9.7	-18	-17	-18
In-place policy 2000 to individual travel policy 2000	I	+0.1	+0.2	-19	+4	-9
	III	-1	-0.6	-7	+10	-1

Note: The total metropolitan population differs in each scenario.

On a passenger mile basis (rather than lane mile) automobiles and highways are more energy intensive to produce than buses and light rail systems, the dominant TAPCUT transit modes.

The relationship between direct energy consumption (i.e., for vehicle operation) and indirect energy consumption (i.e., for manufacture of vehicles, fuels, and roadways) changed over time (Figure 13). Indirect energy accounted for nearly 40 percent of the total energy expended for urban transportation under the individual travel strategy. Under scenario I use of synthetic fuel increased the indirect energy total. Further, the more fuel-efficient vehicles were more energy intensive to produce. Increased use of transit under the group travel strategy did not change the relationship between indirect and direct energy as significantly. Even the more energy-intensive forms of transit are less energy intensive than automobile manufacture. Petroleum savings are greatest under the group travel strategy in scenario I. Energy savings are greatest, however, in scenario III. Petroleum savings achieved through fuel substitution (as in scenario I) exact a price in the form of higher consumption of other fuels (8). These last three figures taken together indicate that energy savings can be achieved in many different ways, but the costs of achieving the savings vary significantly.

The relationship between energy use and total trips per person is shown in Figure 14 for scenario I. There it can be seen that trips increased under the individual travel strategy, even though energy use was decreasing significantly. This is a contrast to the group travel strategy, where both trips and energy use declined, the latter even more dramatically than under the individual travel strategy. Trips per person can be interpreted as a measure of mobility, although not a complete measure, which indicates that the greater energy savings of the group travel strategy was at the expense of slight decreases in mobility. Only transit and automobile trips by household members (and not pedestrian travel) are included in this figure.

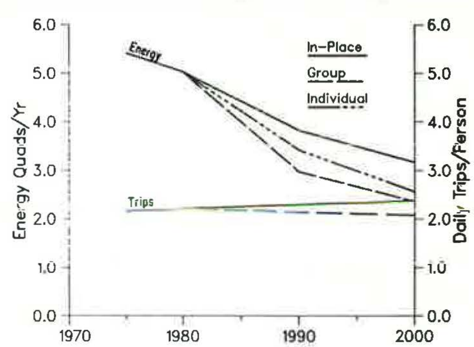

FIGURE 14 Change in trips and direct energy for travel in scenario I.

Health Effects: Air Quality

The health effects from vehicle operation have been estimated on a city-specific basis. The health effects were related to pollutant emissions from the vehicles, including carbon monoxide, ozone, nitrogen oxides, particulates, and hydrocarbons. Health effects were measured in terms of excess deaths, hours of discomfort, and morbidity. These changes were estimated for various groups in the population, including groups more sensitive to each of the pollutants. Health effects caused by carbon monoxide were given considerable attention; both ambient exposure for the region and specific periods of exposure from travel in each portion of an urban region were included (9).

The bulk of the CO emission reductions from automobiles went into effect in the 1980 model year, with the 7.0 g/mile standard for automobiles. That reduction has the largest single beneficial impact on health effects of all variables considered. If that reduction is maintained, differences in strategy effects are fairly small at the national level. However, if either the vehicle emissions return to pre-1980 levels or significant VMT increases beyond the TAPCUT forecast occur (e.g., because of lower fuel prices), the forecast reductions in deleterious health effects are unlikely to occur. City differences were evident here; Sprawlburg CO emissions begin to rise in 2000 in scenario III. In that scenario population growth was highest for Sprawlburg, and CO emission standards were not made more stringent after 1980. Discomfort from CO emissions was projected to rise from 1990 to 2000, thus approaching 1980 levels. Megatown and Slowtown had no such increases in any forecast.

Traffic Safety

Figure 15 shows the effect of the changing automobile fleet on traffic safety. Specifically, fatalities per million population caused by vehicles in urban areas are plotted alongside the amount of VMT in small vehicles for the in-place policy. These values are for one of the typical cities that is most similar to national trends. The graph demonstrates the strong relationship between small car VMT and the fatality rate. Unless there is a decrease in the rate per million vehicle miles of fatalities in small cars with respect to the other size vehicles, then the forecast switch to small-sized vehicles will bring with it an increase in overall fatality rates. Speculation about changes in severity and frequency of accidents when there are more small cars in the fleet suggests that the rates may go down; however, there is currently no empirical basis for making these conclusions (10).

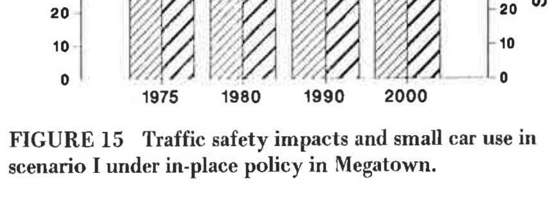

FIGURE 15 Traffic safety impacts and small car use in scenario I under in-place policy in Megatown.

Economic Impacts

The economic analysis addressed the question of whether the conservation policies were really productive. The result was that they were productive at the scale of national economic activity. No impacts on industries outside transportation were projected. Within transportation industries, such as highway construction and bus manufacture, growth was expected to correspond to the strategy. Changes to the balance of trade were estimated and were found to be small relative to the other factors that influence the balance of trade.

One caution is that only changes from metropolitan area travel and vehicle production were forecast. Metropolitan households hold three-quarters of the automobile stock, so automobile production impacts are probably dominated by the market studied. However, nonmetropolitan household automobile travel, all intercity travel, and all goods movement are excluded from consideration in TAPCUT. Impacts from decreases in vacation travel, for example, that might occur with TAPCUT's high fuel prices, are excluded from the analysis, thereby limiting the conclusion about the productivity of the strategies. Because of interactions among the four travel markets, of which one was studied, it is difficult to draw conclusions about the net effects on all travel. Goods movement might increase as delivery trucks are substituted for personal cars in shopping, whereas intercity automobile travel might decrease.

Physical Environment Impacts

Overall, the group travel strategy is significantly less harmful to the environment than either the in-place policy or the individual travel strategy. Analysis of the impacts of air quality, water quality, and toxic pollutants at a city level support this conclusion. The reduction in VMT is the strongest explanation for the dominance of the group travel strategy, coupled with the absence of any new pollution problems under that strategy. The forecasts of impact are sensitive to the VMT forecast; in Sprawlburg cities, where VMT and population are growing rapidly, air quality begins to deteriorate after 1990.

CONCLUSIONS

The TAPCUT project began with three goals: a description of several alternative strategies that promote energy conservation in the urban passenger transportation sector, a better understanding of the environmental impacts of such strategies, and an identification of the constraints to the implementation of such strategies. The conclusions are stated in terms of these goals.

1. Two distinct approaches to saving energy in urban passenger transportation have been defined in realistic terms. Both approaches resulted in energy savings beyond policies currently in effect. In terms of national economic activity, both are productive conservation policies. However, the total vehicular trips by households was decreased under the strategy (group travel) that saved the most energy. The reduction in trips could be construed as nonproductive because of life-style changes imposed on some households. A further productivity consideration is that the group travel strategy raised enough revenues to pay for the capital and operating costs incurred for roads and transit, whereas the individual travel strategy worsened the deficits projected under the in-place policies.

2. The policy that focused on group travel was more benign than the others tested on environmental grounds. That is, however, the same strategy that lowered trips per person with respect to the in-place policy. It is clear that the assumed motor vehicle emission standards played an important part

in this conclusion, however. Improvements in fuel economy were decoupled from emissions rates in TAPCUT technologies within the selected performance specifications for personal automobiles. Failure to meet the currently mandated emission standards could significantly worsen the environmental impacts of the individual travel strategy, where fuel economy was raised to its highest value.

3. Some barriers to implementation of energy-saving policies have been identified. The individual travel strategy requires a healthy automobile industry that is able to systematically improve new cars over a 20-year period and anticipate some shifts in consumer preference for vehicle size and propulsion system. The strong, government-supported research and development element tested under this strategy increased industry vitality. The current abrupt shifts in government policy toward industry may add to the many barriers internal to the industry, especially in the area of long-term research and development. The group travel strategy requires cooperation by various levels of government, as the service improvements were financed from fuel tax revenues. The organizational structure of service providers may have to change to a more competitive system to be sufficiently flexible to serve new markets.

The land use controls hypothesized, although modest in their net effect, constitute a significant directed change in growth patterns. Tools to implement the changes proposed under both policies have been suggested, but further examination of them is warranted, given the importance of activity patterns in using the group travel modes effectively.

Imposition of the gasoline and parking taxes listed under group travel, although they were effective in the simulation, would be unpopular with several groups. These taxes did demonstrate the magnitude of change in the transportation taxing structure necessary to produce significant changes in travel behavior. Previous limited experience with economic disincentives (taxes) for automobile travel as transportation control measures has elicited a strong reluctance on the part of local governments to implement them.

ACKNOWLEDGMENT

In this paper selected results of research carried out by a large team of environmental analysts and transportation planners for a project funded by the Office of Environmental Analyses, DOE, are summarized. Their work is separately documented in the technical memoranda indicated in the references. Summaries of the physical environmental impacts were taken from analyses by John Croom, Management of Resources and the Environment. Several staff members of the Futures Group firm assisted in the scenario definition and economic impact analysis. Additional support was provided by Larry Hill, Lewis University, on economic and resource impacts, and by Alan Schnaiberg, Northwestern University, on demographic forecasts.

REFERENCES

1. Transportation Energy Conservation Data Book, 3rd ed. Report ORNL 5493. Oak Ridge National Laboratory, Oak Ridge, Tenn., Feb. 1979.
2. National Transportation Policies Through the Year 2000. Final Report. National Transportation Policy Study Commission, Washington, D.C., June 1979.
3. R.E. Knorr and M. Millar. Projections of Direct Energy Consumption by Mode: 1975-2000 Baseline. Report ANL/CNSV-4. Argonne National Laboratory, Argonne, Ill., Aug. 1979.
4. S.J. LaBelle. Technology Assessment in Transportation: Survey of Recent Literature. Report ANL/CNSV-TM-44. Argonne National Laboratory, Argonne, Ill., March 1980.
5. R. Stobaugh and D. Yergin, eds. Energy Futures: Report of the Energy Project at Harvard Business School. Harvard University, Cambridge, Mass., 1979.
6. S.J. LaBelle et al. Technology Assessment of Productive Conservation in Urban Transportation, Final Report. Report ANL/ES-130. Argonne National Laboratory, Argonne, Ill., Nov. 1982.
7. M.K. Singh. Energy Consumption due to Local Travel by Urban Households Under Three Alternative Policies, 1980-2000. Report ANL/EES-TM-172. Argonne National Laboratory, Argonne, Ill., Nov. 1981.
8. M.K. Singh and S.J. LaBelle. Analysis of Total Energy Use of Urban Transportation Energy Conservation Strategies. In Transportation Research Record 935, TRB, National Research Council, Washington, D.C., 1983, pp. 19-26.
9. M.D. Rowe and M.A. Crowther. Health Impacts of Productive Conservation in Urban Transportation. Report BNL 51575. Brookhaven National Laboratory, Upton, Long Island, N.Y., Jan. 1982.
10. J.R. Gasper and S.W. Rosenberg. Public Safety Impacts of Policies Developed for Productive Energy Conservation in Urban Transportation. Report ANL/EES-TM-186. Argonne National Laboratory, Argonne, Ill., May 1982.

Errors in this paper are solely the responsibility of the authors.

Selection of Case Study Cities and Expansion to National Urban Totals

BRUCE E. PETERSON

ABSTRACT

A decomposition technique based on the response of a small sample is presented to forecast the responses of all cities in the nation to transportation-related policies. The responses of interest are changes in travel, energy use, and environmental quality. This technique was used in the Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT) study to select a sample of three cities for analysis and then to expand their results to all urban areas. By hypothesizing the existence of a linear-response function estimated from the sample, it is possible to express each city's response as a linear combination of the sample responses. By using selection criteria suggested by the method, Phoenix, Chicago, and Flint were used as sample cities, and the national per capita urban response was estimated to be 0.6 times that of Phoenix plus 0.3 times that of Chicago plus 0.1 times that of Flint.

The Technology Assessment of Productive Conservation in Urban Transportation (TAPCUT) study is an attempt to forecast the responses of all U.S. cities to different sets of transportation-related policies. However, the travel demand models used to forecast these responses are specific to individual cities because they depend on detailed knowledge of the nature and setting of a particular city. The magnitude of the data-collection problem and the expense of running these models make it impossible to apply them to each city individually; instead researchers are limited to three case study cities that can be examined in detail. In consequence, it must determined both how to best select the case studies and how to expand the results of the analyses into forecasts for the entire nation.

Fortunately, a great deal of information, mostly from the Bureau of the Census, is already available about the socioeconomic characteristics of individual cities. These characteristics are certain to be related to a city's response, even though the form of the relationship may not be known in advance. This information is the only basis available for constructing an expansion procedure and can be used to select the best sample with respect to the expansion technique.

For this study the known information was contained in a data base characterizing the 237 standard metropolitan statistical areas (SMSAs) (1), augmented with data on transit systems. Fifty-two variables deemed most appropriate for a transportation study were selected, and a standard R-factor analysis was conducted on these variables to obtain eight uncorrelated factors. Cities were subsequently characterized by their factor scores, that is, their locations in the variable space formed by the eight factors. This was done because subsequent steps in the analysis require uncorrelated variables with similar scales and also for the simplicity of a city's representation. Figure 1 is a schematic of variable space, with the circles representing cities.

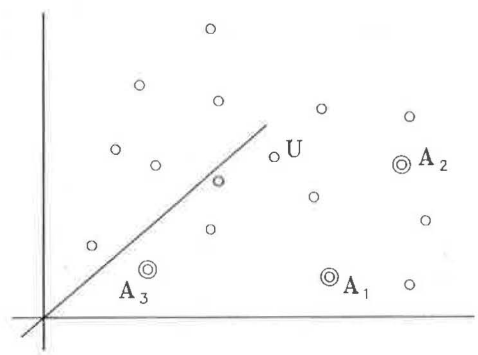

FIGURE 1 Variable space.

The methods used to transform this information on city characteristics into a quantitative technique for expanding the results of TAPCUT's analyses to all U.S. cities are described. First, the existence of a response function, a simple impact model for all cities that can be calibrated from analyses conducted on a sample, is proposed. Second, the types of error in this impact model are enumerated to develop criteria to evaluate possible choices for a sample. Third, available selection schemes are examined for their suitability, and a sample of three cities is determined. Finally, by applying the expansion method, the national response is estimated in terms of this sample.

RESPONSE FUNCTION

In order to estimate a national response, the responses of all cities must be implicitly estimated and the responses to national totals must be aggregated. Response here means any scalar-valued impact of interest that is related to policies that may be tested, such as vehicle miles of travel per person or pollutant concentrations. The basic assumption made is that a particular city's response to a given set of policies applied systematically to all cities is determined, except for a stochastic error term, by its location in variable space. For instance, cities with similar characteristics will have similar locations and presumably will have similar responses to a common policy change. This is formalized by hypothesizing a scalar-valued response function f defined on the domain of variable space. Naturally, for each impact of interest, f will be a different function. If f can be estimated from the response of the sample cities, then any city's response can be estimated by finding the value of f at that city's location.

Although the response function may have an involved form, it is not known, in general, what that form is. In the absence of this knowledge, the response function is approximated by a linear function, $\hat{f}$. The three case study cities define a two-dimensional plane, a subspace of variable space. In that plane a linear function can be defined unambiguously from its values at the three points; consequently, this plane is referred to as known space. Because the response of the case study cities can be determined through the use of detailed travel demand models, values of $\hat{f}$ can be estimated for every location in known space.

Most cities, of course, are outside the plane, where a linear function cannot be specified from the sample. Consequently, an arbitrary city (U) is represented by its projection in the plane U_p, the point in known space closest to U, and it is assumed that the response of U is close to that of U_p (Figure 2). The degree of confidence held for this rep-

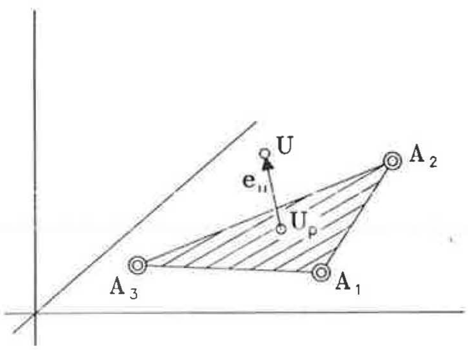

FIGURE 2 Known space.

resentation is indicated by the length of the error vector (e_u), the distance of U from known space. The point U_p is a linear combination of the locations of the sample cities A_i:

$$U_p = \sum_{i=1}^{3} \alpha_i A_i \quad (1)$$

where $\Sigma\, \alpha_i = 1$. Consequently, the estimated response of U_p, and also that of U, is the same linear combination of the sample responses:

$$\hat{f}(U) = \Sigma\, \alpha_i \hat{f}(A_i) \quad (2)$$

Effectively every U.S. city has been decomposed into a sum of components because of the three sample cities.

It may be valuable to compare this decomposition approach to a discrete classification, which otherwise would have been necessary. In a classification, variable space would be divided into three regions that cover the space. Within each region a representative city would be chosen where the response would be measured. That response would then be imputed to every city located in the region. In other words, the response function is approximated by a step function of constant value within each region. Because an arbitrary function can typically be better approximated by a linear rather than by a step function with the same number of points, a modest improvement in the accuracy of estimates can be expected from this decomposition.

SOURCES OF ERROR

There are a number of sources of possible error in the estimates of response, and examining them can help in the selection of a sample that will minimize the error.

Characterization Error

The variables used to characterize the cities cannot be expected to completely determine a city's response. There are certain to be other determinants of response, some completely idiosyncratic to individual cities (such as historical accidents of development) and others systematic that were not included in the original data set (such as climate and topography). Therefore, a city's actual response can be expected to vary from the value of the true response function by an error term ε. Effectively, the response function f indicates an ideal response that ignores other factors not included in the analysis. In the hope that these other factors do not introduce a systematic bias into the national forecasts, the individual characterization errors ε are assumed to be identically distributed random variables with variance σ^2, to be uncorrelated, and to have an expectation of 0. In forecasting a particular city's response, nothing can be done about this error, but its expected effect is 0.

An important consequence of this type of error is that measured responses for the sample cities, even if the forecasting models are perfect, will not correspond to the ideal responses that the researcher would like to obtain. An explained in the following subsections, this can have a fundamental impact on the confidence that can be placed on national expansions when using different samples.

Representation Error

Because a city's actual location differs from its projection where the response function is evaluated, these differences undoubtedly contribute to a mischaracterization of its response. The sum of these errors [$\Sigma \parallel e_u \parallel$ or $\Sigma \parallel e_u \parallel^2$] is highly dependent on the choice of the sample and the particular plane they form.

Specification Error

Specification error is the difference between the true response function and the linear approximation used to estimate it. The situation shown in Figures 3 and 4 assumes two case study cities; therefore, known space is one dimensional. (In Figure 3 cities A and B are the case studies, whereas C and D are the case studies in Figure 4.) Given the case studies A_i and the true response function f, there is a true linear approximation to f, $\hat{f}$. For an arbitrary city U with representation U_p in known space,

$$f(U) = f(U_p) = f(\Sigma\alpha_i A_i) = \Sigma\, \alpha_i f(A_i) = \Sigma\, \alpha_i \hat{f}(A_i) \quad (3)$$

because the true linear approximation and the true response functions are equal at the sample points. But, in general, $\hat{f}(U_p)$ will differ from $f(U_p)$. Without knowledge of f, it is impossible to specify the magnitude of this error.

Nevertheless, the measured responses of the case studies are themselves displaced from the ideal responses by their characterization errors, for $\hat{f}$ is also not accessible. Thus $\hat{f}$ must in turn be approximated by $\tilde{f}$, the linear function determined by the measured responses:

$$\tilde{f}(U_p) = \Sigma\, \alpha_i \tilde{f}(A_i) \quad (4)$$

Under these assumptions about characterization error,

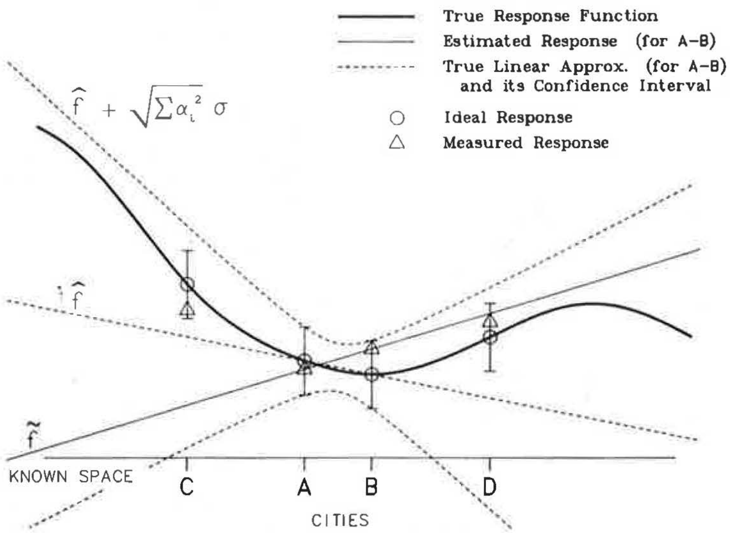

FIGURE 3 Variance estimates using adjacent sample cities.

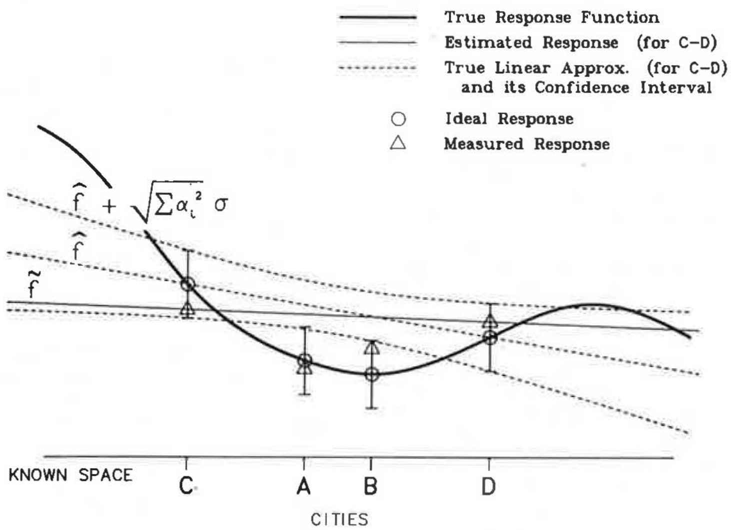

FIGURE 4 Variance estimates using extreme sample cities.

$$\tilde{f}(U_p) = \Sigma\, \alpha_i [f(A_i) + \epsilon_i] \tag{5}$$

Then

$$E[\tilde{f}(U_p)] = \sum_i \alpha_i f(A_i) = \hat{f}(U) \tag{6}$$

and

$$Var[\tilde{f}(U_p)] = \sum_i \sum_j \alpha_i \alpha_j \, Cov(\epsilon_i,\epsilon_j) = \left(\sum_i \alpha_i^2\right) \sigma^2 \tag{7}$$

Recall that $\Sigma\, \alpha_i = 1$. The variance of $\tilde{f}$ is minimized when all the α's are equal and grows rapidly when any of the α's exceeds 1 or is negative. This happens outside the interior of the region surrounded by the case studies.

Thus there are two components of specification error. The first component is the difference between the measured and true linear approximations to f, $|\tilde{f} - \hat{f}|$, which is indicated by the variance of $\tilde{f}$. Minimizing this difference makes widely separated samples desirable. The second component is the difference between the true response function and its true linear approximation, $|\hat{f} - f|$. Provided f is reasonably behaved, this error is minimized in the neighborhood of the samples, which makes samples located close to the preponderance of other cities desirable. For instance, if the preponderance of cities is located close to A and B (Figures 3 and 4), choosing C and D to be case studies would introduce large specification errors because of this source. This argues against choosing a sample at the extremes of the region occupied by the population of cities.

Selection Error

The possibility exists that the selected sample will have a uniform or nearly uniform response. This will happen if known space is parallel to planes of equal response, so that all the variation in response is contained in cities' error vectors rather than their projections. This would make it difficult to state anything with assurance about national response. If instead known space is perpendicular to equal response planes, the effect of the error of representing a city by its projection is minimized. For this reason it is desirable to select, on subjective grounds, a sample that is likely to have widely varying responses.

Measurement Error

In addition to the characterization error ε in forecasting the sample responses, there will be additional errors included because the models used for forecasting responses cannot be expected to operate perfectly. Some of the problems are caused by imperfections in the models themselves; these cannot be helped, except by developing superior models. Others, however, are caused by imperfect data used in their calibration and operation. This problem can be reduced by choosing samples where satisfactory data exist.

SAMPLE SELECTION

There are a number of strategies available for selecting a sample. In many cases these strategies are part of a general classification scheme. However, the decomposition approach can be used with any choice of sample cities; unlike most discrete classification schemes, the logic of the expansion method does not prescribe the sample choice. Any selection scheme can be evaluated for the appropriateness of its choices in the accuracy of estimates of response.

Standard classification schemes use clustering or grouping algorithms to divide a population into a set number of groups from which a single sample can be selected for each. The important characteristic is that groups are defined first; sample points then follow as those most representative of single groups. In clustering, neighboring individuals are joined iteratively into groups that become progressively larger in size and smaller in number until the desired number of groups is formed.

Clustering is an effective strategy when clearly identifiable groups exist in the population. It is difficult to find such groups in this population of cities; instead, the distribution appears to be somewhat globular, with the preponderance of cities located fairly close to each other and gradual attenuation toward the edges. Invariably, clustering algorithms applied to this population produced a single large group with two small outlying groups. This is not an unusual problem when a small number of groups must be selected (1); however, it is clearly not a desirable sample by any of the error criteria discussed previously. Clustering schemes to control this tendency are available (2), but their arbitrary nature mitigates their desirability. In addition, the logic of the decomposition procedure does not require the existence of relatively homogeneous groups the objective clustering is designed to achieve. Indeed, it was developed precisely to overcome problems of lack of homogeneity.

Grouping algorithms also form discrete groups. In general, groups are not built iteratively; rather, perturbation procedures are used on a specified existing group structure to optimize some objective, generally minimizing the ratio of variance within groups to variance between groups. Grouping procedures operate on the mean location of individual group members for measures of variance. Again, homogeneity within groups is the desired objective.

Location-allocation algorithms are similar to grouping in their objective; the difference is that a sample choice is made first, and groups are then formed around the sample individuals according to which sample point is closest. Successively superior samples are then chosen with the objective of minimizing the sum of distances between each city and the sample point that represents it (3). Distances can be weighted by the size of the city, or a function of distance can be used. For instance, using the square of distance will minimize the number of cities that are at extreme distances in variable space from a sample point.

The advantage of using any classification-based selection procedure is that the sample points are sure to be in reasonable proximity to several other individuals, which minimizes the second type of specification error, $|\hat{f} - f|$. Unfortunately, other types of error are not addressed. In fact, the most significant shortcoming of all of these methods is that they do not provide a range of reasonable choices to subjectively evaluate trade-offs in the other types of error, some of which are subjective. Instead they indicate only a single choice of three, which is optimal for the specific objective used by the algorithm. Their basic structure as integer programs defeats any attempt to capture and analyze the continuous variation in city characteristics.

A fourth method, Q-factor analysis, has the advantage of offering insights into the structure of the cities' distribution in variable space in order to evaluate the relative advantages of any possible choice (4,5). Q-factor analysis examines relationships among individuals according to their relative scores on the variables that characterize them, analogous to the way standard R-factor analysis examines relationships among variables. It does this by establishing a new basis for the space of cities and thus identifies dimensions along which cities change. Each individual city can then be expressed by its loadings on each of the dimensions. It is hoped that each dimension can be associated with a particular type of city, so that every city can be thought of as being composed to varying degrees of different ideal city types.

Figure 5 shows three of the seven dimensions that emerged from the Q-factor analysis, with the loadings of selected cities indicated. A line is drawn from each city to the axis it is closest to. Although the axes are pictured as perpendicular, an oblique rotation was actually done. In most cases there was little difficulty interpreting the factors. For instance, factor A showed relatively new and expansive western cities at one extreme, with older New England cities at the other. Factor B was clearly related to size and transit use, whereas factor C was related to the importance of manufacturing. For example, Detroit had relatively high loadings on the dimensions of both size and manufacturing.

Insofar as the Q-factors can identify the important types of cities, they may also identify the important different types of responses to policies. Clearly, factor B of city size is an important determinant of response, and Chicago, having the highest loading on this factor, was included in the sample. Phoenix and Flint, which are near extreme points on their respective factors, were also selected for the sample. The choice was made mostly on the subjective grounds that their natures, and therefore probable responses, were likely to be different. However, this sample also had the advantage of satisfactory data availability, which reduced measurement error. In addition, there are a number of other cities with high loadings of the same sign on their respective axes, which makes it likely that there are a number of other cities with similar positions in variable space. This reduces, though it does not minimize, the second type of specification error.

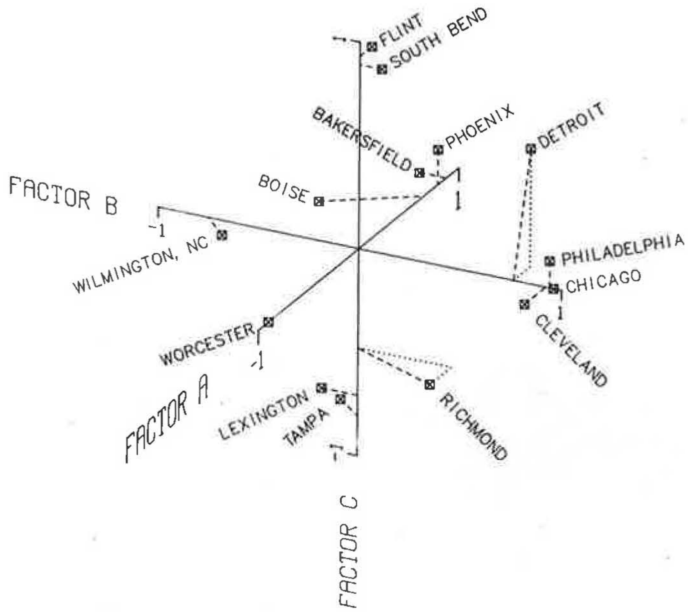

FIGURE 5 Q-factor loadings.

Figure 6 is a diagram of known space using this sample, with the projections of all cities indicated on it. The axes' locations and orientation are completely arbitrary; for convenience in calculation, Flint was chosen as the origin, with the first basis pointing toward Chicago. However, the metric is the same as that of the original eight-dimensional variable space. Figure 7 is the same projection, except that the length of representation error vectors is also indicated. With all cities weighted by population, the mean locations for all U.S. cities in 1980 and 2000 are indicated by arrows in Figure 6. (Projections of year-2000 urban populations are made by assuming all cities in the same geographic region grow at the same rate.) Implicitly, forecasting impacts that assume a national average city located at this point with the nation's entire urban population is exactly the same as forecasting a response for each city individually and aggregating them to a national total. It is concluded that the best estimate of a national urban response is approximately 0.6 times the response of Phoenix plus 0.3 times the response of Chicago plus 0.1 times the response of Flint.

In subsequent analyses these three cities lose many of their individual characteristics. Most important, any effect of the planning processes used in these cities on their development is disregarded,

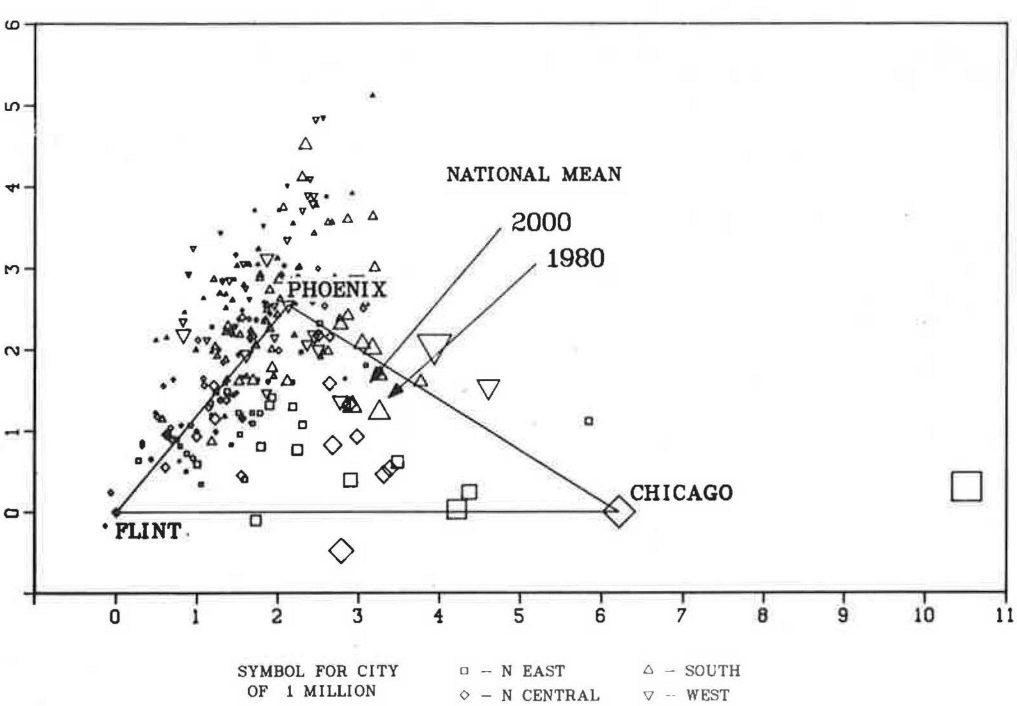

FIGURE 6 City projections in known space.

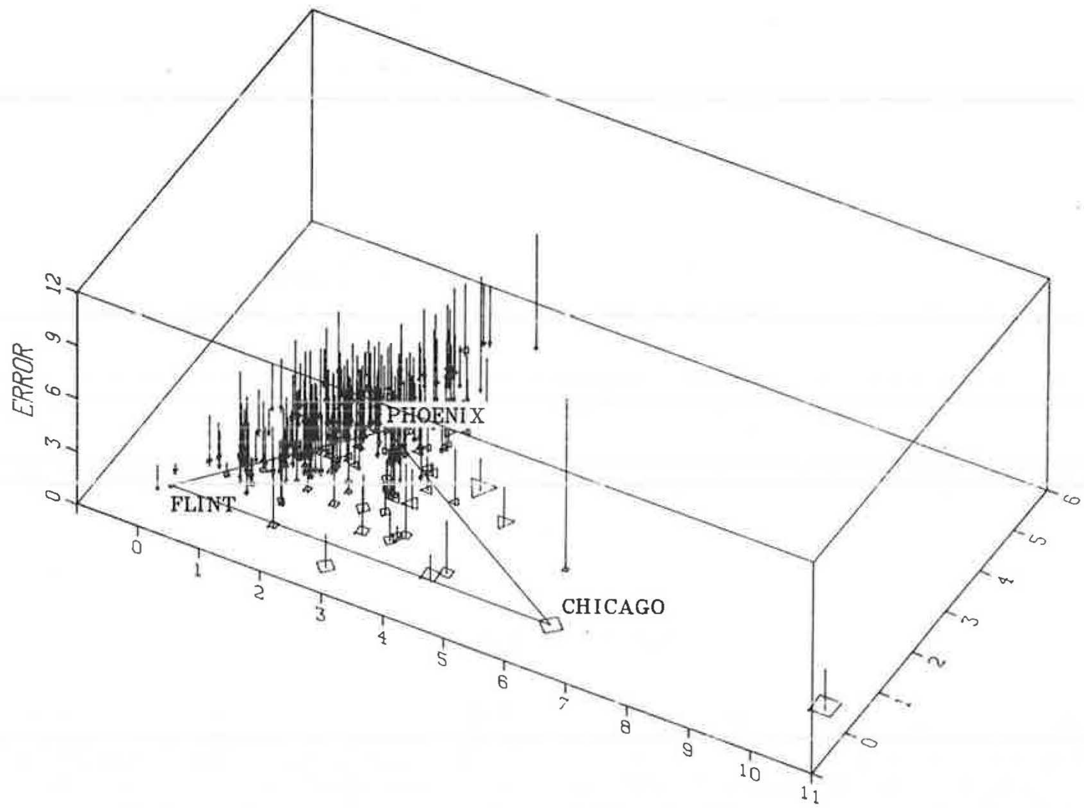

FIGURE 7 Representation errors.

substituting instead general development and growth patterns that express the policies being tested, assumptions about national economic and social trends, and the cities' status as representatives of a large number of other cities. As representatives, the three case studies become more hypothetical or ideal than real; thus they are subsequently referred to as Sprawlburg, Megatown, and Slowtown. These names were selected to express the important characteristics of the dimensions of city development they represent, characteristics that are present to some degree, either positively or negatively, in all U.S. cities.

ACKNOWLEDGMENT

This research was sponsored by the Office of Environmental Analysis, Assistant Secretary of Environmental Protection, Safety, and Emergency Preparedness, U.S. Department of Energy, under contract with Martin Marietta Energy Systems, Inc.

REFERENCES

1. E. Lake et al.; Urban Systems Research and Engineering Inc. Classification of American Cities for Case Study Analysis. U.S. Environmental Protection Agency, 1976.
2. P.M. Lankford. Regionalization: Theory and Alternative Algorithms. Geographical Analysis, Vol. 1, 1969, pp. 196-212.
3. A.J. Scott. Combination Programming, Spatial Analysis, and Planning. Methuen, London, England, 1971.
4. L.J. King and D. Jeffrey. City Classification by Oblique-Factor Analysis of Time-Series Data. In City Classification Handbook (B.J.L. Berry, ed.), Wiley-Interscience, New York, 1972.
5. R.J. Rummel. Applied Factor Analysis. Northwestern University Press, Evanston, Ill., 1970.