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Contents

Foreword

The impact of urban development alternatives on transportation fuel consumption is examined by Wilson and Smith. They demonstrate the feasibility of using simplified travel demand and fuel consumption models to evaluate the transportation fuel requirements of urban development alternatives using the greater Madison, Wisconsin, urban area as a case study. Simplified modal choice of automobile occupancy models are used to test the impacts of transit, ridesharing, and vehicle fuel economy improvements or transportation fuel requirements.

Frederick et al. estimate the costs and benefits of converting the bus fleet of California's South Coast Air Basin to methanol. They conclude that conversion to methanol merits further consideration as an antipollution strategy and propose to extend the analysis to additional potential benefits and costs and to other types of vehicles.

In his paper "Efficiency-Related Changes in Automobiles and Light Trucks," Greene states that an analysis of the sales and characteristics of light duty vehicles since the Corporate Average Fuel Economy standards went into effect in 1978 indicates that technological improvements are responsible for about one-half of the 40 percent increase in automobile fuel economy between 1978 and 1985. Greene further attempts to measure the technical improvements in automotive fuel efficiency by estimating stochastic frontier cost functions for automotive fuel economy in 1978 and 1985.

Shladover reviews the Santa Barbara electric bus project, focusing on the various project phases. Costs are compared with those for more conventional bus technologies, and implications for the future of roadway-powered electric vehicle technology are explored.

Lee-Gosselin and Clinton discuss a project conducted by the Ontario Ministry of Energy to identify and develop research methodologies that could be used before, during, and after an energy shortage to monitor public attitudes and behavior. The study consisted of an information needs assessment, methodology development, and an implementation plan.

Gur et al. analyze monthly fuel purchase logs from a Residential Energy Consumption Survey's Household Transportation Panel to determine the relationship among various household characteristics, purchase frequency, tank inventories, vehicle miles traveled, and fuel expenditures. Results of the survey indicate clear differences in travel and fuel purchase behavior for four distinct groups of vehicle-owning households.

Mintz et al. explore some of the anticipated consequences of low prices for petroleum products and conclude that persistently low oil prices will result in a significant decline in domestic oil production, a moderate increase in petroleum consumption overall and in transportation, and a substantial increase in the nation's import dependence and vulnerability to supply interruptions and price shocks.

Impact of Urban Development Alternatives on Transportation Fuel Consumption

STEPHEN C. WILSON AND ROBERT L. SMITH, JR.

Local officials need information about the transportation fuel consumption impacts of alternative urban development patterns to improve the local land use decision-making process. In this study, the feasibility of using simplified travel demand and fuel consumption models to evaluate the transportation fuel requirements of urban development alternatives is demonstrated. The greater Madison, Wisconsin, urban area is used as a case study to examine the marginal impacts of three alternative residential and two alternative commercial development scenarios for the year 2000. Simplified modal choice and automobile occupancy models are used to test the impacts of transit, ridesharing, and vehicle fuel economy improvements on transportation fuel requirements. To reduce the computing time requirements, the highway network speeds are assumed to be the same for all scenarios. Thus only a single trip distribution (gravity) model is required to evaluate each scenario. The fuel consumption analysis provides support for several regional development plan policies. Average trip length can be reduced by locating population and employment in the same subregion. Concentration of commercial development in the central Madison area will reduce fuel consumption somewhat, primarily because of higher transit use. Development in rural areas should be limited because of high per capita fuel consumption. The reductions in fuel consumption for the most energy efficient development scenarios range from 7 to 15 percent, which are similar to the reductions that were obtained with the transit and ridesharing improvement options. In contrast, reductions of 38 percent are expected from improvements in vehicle fuel economy.

Achievement of the long-term regional goal of minimizing transportation fuel consumption requires implementation of the most energy efficient urban development alternatives. A number of studies have shown clear relationships between transportation fuel requirements and alternative urban development patterns *(1–4)*. Although these studies have provided some general guidelines, local decision makers are more likely to be convinced by studies based on analysis of their own region. The purpose of this study is to demonstrate the feasibility of using simplified travel demand and fuel consumption models to evaluate the transportation fuel requirement of urban development alternatives. Because the travel demand models include simple modal choice and auto occupancy models, the impacts of changes in transit and automobile use can also be evaluated.

RELATED RESEARCH

Schneider and Beck *(5)* studied the impact of the redistribution of population and employment on urban travel requirements. They used an automated search algorithm to find a new distribution of population and employment that would improve the performance of the highway network. Application of the algorithm to a simple 12-node network for the greater Seattle region resulted in reductions in total travel time of 40 to 60 percent. This result was achieved by balancing population and employment at each node but required redistribution of up to 56 percent of the population and 38 percent of the employment.

Edwards and Schofer *(1)* focused specifically on the relationship between transportation energy consumption and urban form. A Lowry model was used to allocate land use subject to constraints on urban form. The Lowry model outputs were merged with a conventional urban travel demand model. Fuel consumption was estimated from the resulting all-or-nothing traffic assignment by using Claffey's curves as a function of link speed *(6)*. A modal choice model was not used. Rather, a range of transit shares was specified for each urban form. Analysis of 37 variations of three basic urban forms (concentric ring, linear, and polynucleated) showed that transportation energy requirements could be reduced by controlling the spread of cities and by channeling development into higher density polynucleated forms.

Peskin and Schofer *(2)* extended Edwards and Schofer's Lowry-based urban development model *(1)* by adding a binary logit modal choice model and a capacity-restrained assignment model. More than 400 experiments were conducted, using concentric ring, one-sided, or polynucleated development together with variations in transit service and pricing, vehicle occupancy, freeway construction, and gasoline pricing. In general, the results showed that polynucleated cities would consume considerably less fuel than concentric ring cities.

Recently, Kim and Schneider *(3)* used Peskin and Schofer's urban development model and Schneider's urban form statistics program to identify relationships between urban form and transportation fuel consumption. Six alternative patterns of basic employment were evaluated for each of three city types—concentrated, dispersed, and polynucleated. The study showed "that higher concentrations of population in the center of the city, better access to the center, and higher population densities can reduce transportation energy consumption." While the polynucleated cities generally required more energy, some

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polynucleated cities were more energy efficient than some concentrated cities because of congestion on central streets. Thus major suburban employment centers surrounded by relatively dense residential development were recommended as a realistic urban development strategy to conserve transportation fuel.

The four studies mentioned *(1–4)* clearly show that urban form and transportation energy consumption are directly related. Although these studies focused on the generation of alternative urban forms, improvements in the methodology used to estimate transportation fuel consumption are also of interest. Janson et al. *(4)* developed a methodology for computing zone-to-zone transportation fuel consumption by mode by using standard transportation planning databases. Highway link speeds were obtained from an equilibrium network assignment, whereas transit fuel consumption per person-trip was based on average loads per transit vehicle mile. Application to Chicago showed the importance of accounting for the relationship between traffic volume and speed. Direct energy consumption per person-kilometer increased for zones closer to the central business district (CBD) because of traffic congestion. The reverse was true for transit because of higher average vehicle loadings and less use of the automobile access mode. One limitation of the methodology was the lack of a fully consistent set of curves for automobile fuel consumption versus speed. Curves developed from field data collected by the General Motors Research Laboratories for arterial streets and freeways from the Characteristics of Urban Transportation Systems (CUTS) manual were selected as the most reliable data available.

An alternative approach to estimating transportation fuel consumption was recently developed by the Dane County Regional Planning Commission *(7)*. The objective of the study was to provide information on the transportation energy impacts of single- versus multiple-family residential development for use by local officials. Annual vehicle trips per dwelling unit (DU) and average vehicle trip length by DU type were estimated for urban zones and rural units of government using available data. Vehicle miles of travel (VMT) per DU were then computed as the product of vehicle trips per DU and average trip length. Finally, fuel consumption per DU per year was estimated by factoring VMT by average vehicle fuel efficiency ratings for the urban and rural areas separately. The study was limited by the lack of travel demand models covering the rural area of the county. Consequently, the impact of changes in employment location on residential travel could not be analyzed.

The research on the relationships between transportation fuel consumption and urban development patterns just reviewed provides a sound basis for evaluating these relationships in a particular urban area. All of the studies except the Seattle *(5)* and the Dane County *(7)* studies used travel demand and supply models to estimate transportation fuel consumption. The complexity and sophistication of the various models, however, varied considerably. Selection of the appropriate set of travel demand and supply models for a particular urban area requires judgments about the level of sophistication required to address the relevant policy issues.

CASE STUDY APPROACH

This study is designed to provide transportation planners with a practical tool for quickly and easily evaluating the impacts of alternative land use policies on transportation fuel consumption. Rather than reallocating population and employment with a Lowry model, a simple proportional allocation of population and employment growth is used to test the marginal impact of highly simplified alternative growth patterns. Available trip generation and trip distribution models are used to estimate the person-trip demand for each development alternative. Transit and vehicle trips are then estimated by assuming that base year transit and automobile occupancy rates will apply in the future.

Estimation of zone-to-zone fuel consumption is simplified by assuming that highway network link speeds are not affected by additional traffic. Thus the minimum time paths required by the gravity trip distribution model can be used to compute fuel consumption from the fuel consumption versus speed curves. Total fuel consumption can then be obtained as the product of fuel consumption and vehicle trip matrices.

CASE STUDY AREA

The area selected for the case study is the Madison, Wisconsin, urban area located in Dane County. The Dane County Regional Planning Commission (DCRPC) is responsible for developing transportation, land use, and other long-range plans for the entire county. The Regional Development Plan includes several policies that could have an impact on transportation fuel consumption: (a) encourage balanced growth of both population and employment opportunities in satellite communities, (b) encourage retail and commercial development in the central Madison area, and (c) preserve agricultural land by limiting development in rural areas.

Evaluation of these policies requires travel demand models that cover the entire county, including the rural areas. Because the available travel demand models only covered the Madison urbanized area, considerable work was required to extend the highway network and travel demand models to the entire county. The years 1980 and 2000 were selected as the base and forecast years, respectively, consistent with the DCRPC regional planning database.

FUEL CONSUMPTION MODEL

Automotive fuel consumption is primarily a function of speed, stops, speed cycle changes, grade, and percent curvature. These relationships vary by vehicle type, but composite curves based on the mix of vehicles in the fleet have been developed. The effects of the vertical and horizontal alignment (grade and percent curvature) are generally insignificant in urban areas and, lacking detailed data, will be ignored for the rural areas as well. On urban streets, the number of stops and speed cycle changes is a function of the level of service and the spacing of signalized intersections. Precise estimation of the level of service on urban networks and the resulting effect on fuel consumption requires use of the macroscopic TRANSYT or the microscopic NETSIM model, but neither of these models is feasible for a regional-scale network. If the level of service is constant or the impact of level of service changes on fuel consumption can be neglected, then the only remaining variable is speed.

The curve for fuel consumption versus speed is U shaped, with higher fuel consumption at low speeds decreasing to a minimum between 30 to 35 mph and then increasing as speed increases. Fuel consumption curves based on a mix of vehicles that represents the late 1970s' automobile fleet are available from a number of sources *(6, 8–10)*. To simplify the analysis in this study, a single composite fuel consumption curve was constructed as shown in Figure 1. Atherton and Suhrbier's *(8)* urban arterial curve is used for the 5- to 40-mph range; above 40 mph it is extrapolated on the basis of the CUTS freeway and Claffey curves. Thus, as a first approximation, fuel consumption is assumed to be a function only of highway network speed.

The fuel consumption curve was developed on the basis of the best information available in 1984 when the study was conducted. Future applications should use the most recent fuel consumption data, such as those reported by McGill *(11)*. Light trucks should also be incorporated in the fuel consumption curve because they now account for about 18 percent of household vehicle miles of travel.

By using the fuel consumption curve, the fuel consumed per trip from Zone i to Zone j for Network k can be computed as

$$FUEL_{ijk} = \sum_{l} f(SPEED_{lk}) \times DIST_{lk} \qquad (1)$$

where

$SPEED_{lk}$ = average speed on the lth link on the minimum time path between Zones i and j for the kth network,
$f(SPEED_{lk})$ = fuel consumed in gallons per mile at the given speed, and
$DIST_{lk}$ = distance in miles in the lth link for the kth network.

The possibility of using multiple networks such as peak and offpeak networks is included because in many urban areas, peak-hour speeds are much lower than offpeak-hour speeds. Total fuel consumption can then be computed by multiplying the fuel consumption matrix, $FUEL_{ijk}$, by the corresponding trip matrix, T_{ijk}, and summing over all ij pairs and networks. The fuel consumption model represented by Equation 1 gives zone-to-zone-based estimates in contrast to the direct link-based estimates that are available from the Urban Transportation Planning System (UTPS) traffic assignment model UROAD *(12)*. The zone-to-zone-based model permits direct estimation of fuel consumption from zone-to-zone trips obtained from a trip distribution (gravity) model as long as the network level of service, and hence link speeds, remain constant over the range of alternatives considered. The assumption of constant link speeds was made in this study to eliminate the need for separate traffic assignments for each of the alternative development patterns considered. This assumption reduces the computational requirements for evaluating the alternatives significantly. The trade-off is that some bias is introduced by neglecting congestion-induced speed changes. The magnitude of the bias, however, should be small even in the year 2000 because the Madison area highway network is not expected to be highly congested. Also, the marginal impacts of changes in population and employment assuming reasonable levels of congestion are of primary interest. The development simply would not occur if the highway network became too congested.

TRAVEL DEMAND MODEL DEVELOPMENT

Expansion of the existing urban area travel demand models to the entire county was hindered by the lack of a county-wide home interview origin-destination (OD) survey. The county-wide 1975 U.S. Census journey-to-work survey provided the primary basis for the expansion. Data from the 1977 Nationwide Personal Transportation Study were also useful *(13)*.

In the rural area, U.S. Census-defined minor civil divisions (MCD) were used as zones so that population and employment data would be readily available. The highway network was developed to provide logical connections between the MCD-based zones. The speeds on the rural highway network were based on location and functional classification. The county was divided into six basic geographic subregions, as shown in Figure 2. The second, third, and fourth subregions form

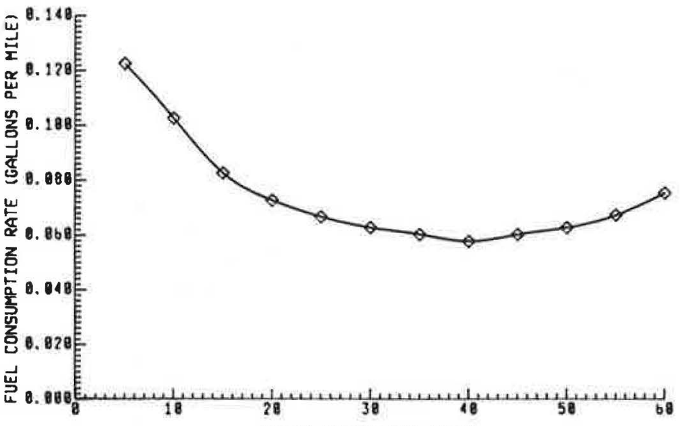

FIGURE 1 Fuel consumption curve.

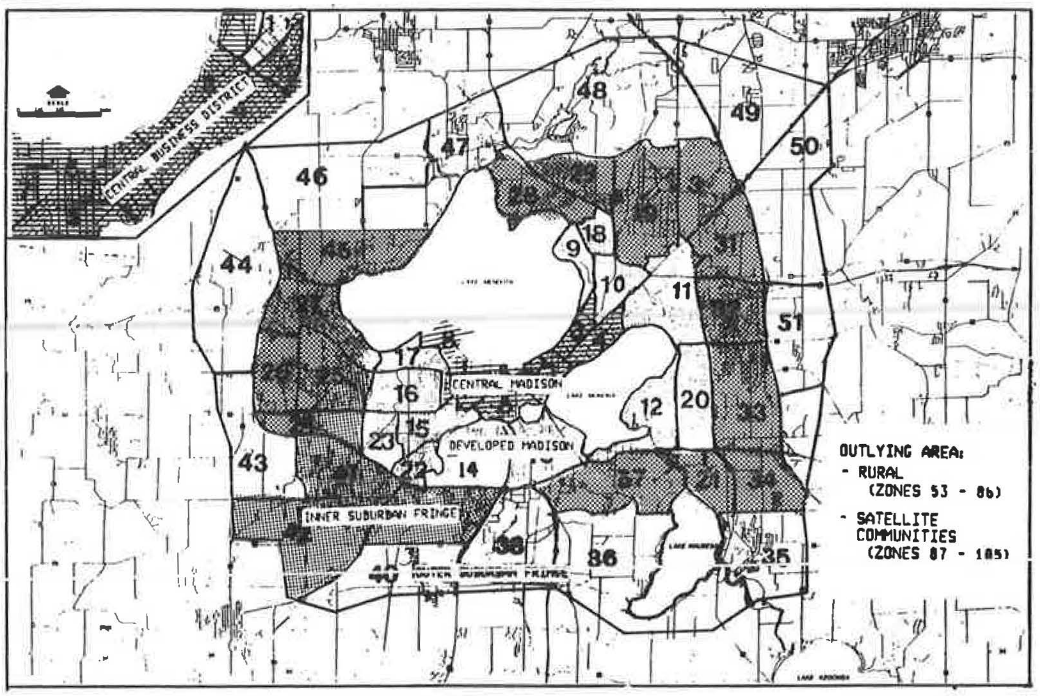

FIGURE 2 Location of subregions in Dane County.

partially complete concentric rings around the central Madison subregion. The "outlying area" is divided into rural and satellite community subregions.

A simple trip rate, trip generation model was developed both for the urban and outlying areas. Only two purposes, home-based work (HBW) and home-based nonwork (HBNW), were used. Non-home-based trips were neglected because of the lack of data on such trips in the outlying area.

The trip production model is shown in Table 1. The trip rates for the outlying area are stratified by rural versus satellite community subregions and single-family versus multifamily DU types. For the outlying area, the HBW rates were obtained from the 1975 Census journey-to-work data. The outlying HBW rates were then factored by the ratios of nonwork to work trips for single-family and multifamily dwelling units obtained from the 1977 Nationwide Personal Transportation Study. For the urban area the trip rates were obtained directly from prior estimates of trip productions.

TABLE 1 AVERAGE DAILY TRIP PRODUCTION RATES PER HOUSEHOLD

Geographic Area	Home-Based Work	Home-Based Nonwork
Central Madison	1.01	4.12
Developed Madison	1.85	5.93
Inner suburban fringe	2.11	6.63
Outer suburban fringe	1.91	7.37
Rural area[a]	2.3	4.98
Single family	2.34	5.43
Multiple family	2.18	4.72
Satellite communities[a]	2.18	4.73
Single family	2.26	5.25
Multiple family	2.12	4.58

[a] Average.

No data were available on trip attraction rates for the outlying area. Consequently, the trip attraction rates suggested in the Quick Response report were used, with trade and service employment substituted for retail employment *(14)*.

The trip distribution (gravity) model was calibrated on the basis of the average trip length standards shown in Table 2 and the HBW trip length frequency distribution from the 1975 Census journey-to-work data. A reasonable fit was obtained for HBW trips both in the urban and outlying areas, but for HBNW trips the gravity model substantially underestimated the desired average trip length in the outlying area. The gravity model estimate in the outlying area however, appears to be more reasonable than the standard because the estimated outlying HBNW trip length is less than the HBW trip length, which follows the urban area pattern.

TABLE 2 GRAVITY MODEL CALIBRATION

Geographic Area and Purpose	Average Trip Length (min) Gravity Model	Standard	Percent Difference
Urban			
Home-based work	11.6	12.0	−3.3
Home-based nonwork	10.1	10.1	0.0
Outlying			
Home-based work	17.3	15.9	8.8
Home-based nonwork	12.4	17.0	−27.1

A simplified modal choice model was developed on the basis of 1980 estimates of transit use within the urban area and 1975 Census journey-to-work data for the outlying area. The resulting model is a 6 × 6 matrix of transit trip percentages for HBW and HBNW trips between the six geographical subregions presented in Table 3. A similar model for automobile

TABLE 3 PERCENTAGE OF TRIPS BY TRANSIT

	DESTINATION SUBREGION					
ORIGIN SUBREGION	(1)	(2)	(3)	(4)	(5)	(6)
Central Madison (1)	44.2[a] (17.5)[b]	12.2 (1.0)	10.9 (0.7)	2.2 (0.5)	0.0 (0.0)	0.0 (0.0)
Developed Madison (2)	21.9 (7.6)	6.8 (0.5)	2.6 (0.2)	1.4 (0.1)	0.0 (0.0)	0.0 (0.0)
Inner Suburban Fringe (3)	12.9 (4.6)	1.7 (0.1)	1.6 (0.2)	1.0 (0.2)	0.0 (0.0)	0.0 (0.0)
Outer Suburban (4)	8.2 (5.0)	0.8 (0.3)	0.7 (0.2)	0.2 (0.4)	0.0 (0.0)	0.0 (0.0)
Rural Area (5)	1.1 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Satellite Communities (6)	3.5 (0.0)	0.8 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

[a] Percent Home Based Work
[b] Percent Home Based Non-Work

occupancy was developed from the same sources. Because fuel consumption can be estimated directly from the vehicle trip tables obtained from application of the modal choice and automobile occupancy models, a trip assignment model was not needed for this study. Elimination of trip assignment significantly reduces the computer time required for the fuel consumption analysis.

SCENARIO DEVELOPMENT

Future levels of transportation fuel consumption will be affected by both residential and commercial development patterns. To highlight potential differences in fuel consumption among development alternatives, highly idealized development patterns were selected that represent the widest possible range of alternatives. Thus, although none of the alternatives may actually occur in pure form, the results will provide a basis for policies to guide growth in a particular direction.

To keep the computer and analysis time to a manageable level, only three residential and two commercial development options were selected, resulting in six development scenarios. The three residential options concentrate all the predicted population growth between 1980 and 2000 into the specified geographic area for that scenario: (a) central Madison, (b) suburban fringe, and (c) satellite communities. In actually allocating the population growth, the population was first converted to dwelling units, using the persons per DU factors presented in Table 4. The additional dwelling units were then allocated to the zones in that geographic area in proportion to the 1980 dwelling units in each zone. Although the three residential growth options have different numbers of dwelling units estimated for 2000, the impact on total person-trips is mitigated by the differences in the trip generation rates (person-trips per DU) among the areas. The net impact on trip generation is given in Table 4 in terms of person-trips per person. The central Madison and satellite communities subregions have about the same trip rate (2.45 and 2.50 person-trips per person, respectively), while the suburban fringe rate is about 25 percent higher. The higher suburban fringe rate is reasonable, considering the lower density, the greater reliance on the automobile, and higher income levels. The two commercial development options concentrate all of the predicted employment growth between 1980 and 2000 into the central Madison and suburban fringe subregions. The increased employment was allocated to each zone in proportion to its 1980 employment. Trade and service employment was estimated by assuming that the 1980 percentage would be maintained.

TRAVEL DEMAND MODEL APPLICATION

The trip generation, trip distribution, modal choice, and automobile occupancy models were applied to determine the vehicle trip table for each scenario. The 1980 highway network and *F* factor curves were used for the gravity model. The fuel consumption for each scenario was then estimated by multiplying the 1980 zone-to-zone fuel consumption per vehicle trip matrix by the vehicle trip matrix for each scenario.

Ideally, the 1980 fuel consumption matrix would have been developed as initially proposed by using zone-to-zone fuel consumption computed as the sum of the fuel consumption per vehicle over all links on the minimum time path between any two zones. Unfortunately, the version of the UROAD computer program used for this study did not permit user-coded subroutines. Consequently, only average zone-to-zone speeds were available to estimate fuel consumption.

Because of the U-shaped relationship between fuel consumption and speed, the use of average zone-to-zone speed, in general, will give biased estimates of fuel consumption. A matrix of correction factors for travel between the urban, suburban-fringe, and outlying areas was developed on the basis of hand calculation of fuel consumption for link-based versus average speeds between zones. The average speed method underestimated zone-to-zone fuel consumption by 3.5 to 14.0

TABLE 4 1980 PERSON-TRIP AND DEMOGRAPHIC DATA BY GEOGRAPHIC SUBREGION

Geographic Sub-region	Total Daily Person Trips	Dwelling Units	Persons per DU	Person Trips per DU	Person Trips per Person
Central Madison	132,400	25,830	2.09	5.13	2.45
Developed Madison	240,700	30,940	2.37	7.78	3.29
Inner Suburban Fringe	268,700	30,700	2.96	8.75	2.96
Outer Suburban Fringe	57,400	6,180	2.70	9.29	3.44
Rural Area	71,600	9,790	3.00	7.32	2.44
Satellite Communities	125,900	18,200	2.77	6.92	2.50
Region	896,800	121,680	2.59	7.37	2.85

percent, with the greatest bias occurring for travel between the outlying area and the urban and suburban fringe areas in which the speed variations are greatest.

MODELING RESULTS

The basic base year 1980 fuel consumption and travel characteristics for the six geographical subregions are presented in Table 5. Three measures of fuel efficiency are included. The fuel consumption per capita measure is the most comprehensive; it includes the impacts of trips per capita, trip length, transit use, and automobile occupancy. Central Madison residents consume the least fuel because they make fewer, shorter trips and use transit to a much greater extent. In contrast, rural residents consume the most fuel, primarily because they make long trips and make almost no use of transit. The gallons-per-person trip measure of fuel efficiency takes into account the variations in trip length, transit use, and automobile occupancy. The rank order of the geographic subregions in terms of gallons per person-trip is the same as for the gallons-per-capita measure, except that the positions of the outer suburban fringe and satellite communities are reversed as the result of the much higher level of trips per capita for the outer suburban fringe. Miles per gallon, the final measure of fuel efficiency, only includes the effect of speed on fuel consumption. The urban area (central and developed Madison) is the least efficient, followed by the suburban area. The rural and satellite communities subregions are the most efficient in terms of direct fuel use per vehicle mile, but the differences are not large.

The overall results for the six scenarios for 2000 are presented in rank order by annual fuel consumed per capita in Table 6. At the regional scenario level, trip length and transit use are the major determinants of the rank order. The central Madison residential scenarios have the shortest trip lengths and the highest transit use. The suburban fringe scenarios have intermediate range trip lengths and moderate to low levels of transit use, whereas the satellite communities scenarios have the longest trip lengths and transit use that is similar to the suburban fringe scenarios.

The impact of commercial development location on the rank order presented in Table 6 is highly consistent. The central Madison commercial scenario is always more fuel efficient than the suburban fringe commercial scenario for the same residential scenario. In this case, transit use is the determining factor because both for the suburban fringe and satellite communities residential scenarios, the trip lengths for the central Madison commercial development scenarios are slightly greater than for the suburban fringe scenarios. Thus, if transit use were equal, the suburban fringe commercial development location would be the most fuel efficient for two of the three residential development scenarios.

The average trip lengths presented in Table 6 are logical. For a given residential development scenario, the trip length should be and is shorter when the new commercial development is located in that same subregion or in the nearest adjacent subregion.

The transit use by scenario presented in Table 6 exhibits a regular pattern. Transit use declines with increasing distance from the central area both for the new residential development and the new commercial development. In contrast, automobile occupancy varies little across the scenarios, with the highest levels occurring for the satellite communities scenarios.

At the subregional scale, average trip lengths for a subregion are primarily affected by the location of the commercial development. As presented in Table 7, average trip length in a subregion is shorter when the commercial development is located in the same or an adjacent subregion. The satellite communities subregion is an exception in which the commercial development that is farthest away produces the shortest average trip length. Apparently, the central Madison commercial development is so far away that the satellite communities are forced to turn inward. The energy efficiency of this development pattern is further reinforced by the higher transit use.

The base year average trip lengths by subregion presented in Table 7 fall in between those for the central Madison and

TABLE 5 BASE YEAR (1980) FUEL CONSUMPTION AND TRAVEL CHARACTERISTICS

	ANNUAL FUEL CONSUMPTION			TRAVEL CHARACTERISTICS			
GEOGRAPHIC SUBREGION	TOTAL[1]	PER HOUSEHOLD (PER CAPITA)	GALL. PER TRIP[2] (MILES PER GALL.)[3]	ANNUAL TRIPS:[4] PER HOUSEHOLD (PER CAPITA)	AVERAGE TRIP LENGTH[5]	PERCENT TRANSIT	VEHICLE OCCUPANCY
Central Madison	4,259	164.9 (78.8)	.107 (14.41)	1,538 (735)	2.66	15.9	1.45
Developed Madison	13,821	446.5 (188.6)	.191 (14.40)	2,333 (986)	4.18	5.1	1.44
Inner Suburban Fringe	18,745	610.3 (206.5)	.233 (14.72)	2,624 (888)	5.02	2.6	1.43
Outer Suburban Fringe	5,273	852.8 (315.5)	.306 (14.73)	2,786 (1,031)	6.70	2.0	1.46
Rural Area	10,913	1115.0 (372.0)	.508 (14.79)	2,196 (733)	11.95	0.1	1.59
Satellite Communities	12,570	690.6 (249.2)	.333 (15.19)	2,075 (749)	7.96	0.4	1.57
REGION	65,581	539.0 (208.5)	.244 (14.73)	2,211 (855)	5.53	4.7	1.47

[1] Thousands of Gallons
[2] Gallons of Fuel per Person Trip
[3] Automotive
[4] Home-Based Person Trips Only
[5] Automobile Trips in Miles

TABLE 6 REGIONAL FUEL CONSUMPTION AND TRAVEL CHARACTERISTICS BY SCENARIO

LOCATION OF	ANNUAL FUEL CONSUMPTION			TRAVEL CHARACTERISTICS			
NEW DEVELOPMENT: RESIDENTIAL [COMMERCIAL]	TOTAL[1]	PER HOUSEHOLD PER CAPITA)	GALL. PER TRIP[2] (MILES PER GALL.)[3]	ANNUAL TRIPS:[4] PER HOUSEHOLD (PER CAPITA)	AVERAGE TRIP LENGTH[5]	PERCENT TRANSIT	VEHICLE OCCUPANCY
Base Year (1980)	65,581	539.0 (208.5)	.244 (14.73)	2,211 (855)	5.53	4.7	1.47
CENTRAL MADISON							
[Central Madison]	69,376	441.2 (178.3)	.214 (14.79)	2,059 (832)	5.06	8.0	1.47
[Suburban Fringe]	75,541	480.4 (194.2)	.233 (14.65)	2,059 (832)	5.29	5.6	1.46
SUBURBAN FRINGE							
[Central Madison]	83,847	569.6 (215.5)	.249 (14.56)	2,287 (865)	5.63	5.5	1.47
[Suburban Fringe]	85,301	579.5 (219.3)	.253 (14.65)	2,287 (865)	5.59	3.4	1.45
SATELLITE COMMUNITIES							
[Central Madison]	85,537	575.9 (219.9)	.263 (14.69)	2,187 (835)	6.13	5.1	1.50
[Suburban Fringe]	88,054	592.8 (226.3)	.271 (14.69)	2,187 (835)	6.10	3.2	1.48

[1] Thousands of Gallons
[2] Gallons of Fuel per Person Trip
[3] Automotive
[4] Home-Based Person Trips Only
[5] Automobile Trips in Miles

TABLE 7 AVERAGE TRIP LENGTH AND PERCENTAGE OF TRANSIT BY COMMERCIAL AND RESIDENTIAL SCENARIO

Geographical Subregion	Central Madison Commerical			Base Year	Suburban Fringe Commercial		
	Central Madison[a]	Suburban Fringe[a]	Satellite Communities[a]		Central Madison[a]	Suburban Fringe[a]	Satellite Communities[a]
Central Madison	1.93[b] (18.6)[c]	2.17 (18.8)	2.14 (18.9)	2.66 (15.9)	3.18 (14.0)	3.15 (13.8)	3.15 (13.8)
Developed Madison	4.34 (6.5)	4.15 (6.8)	4.14 (6.9)	4.18 (5.1)	4.30 (4.0)	4.34 (3.9)	4.31 (4.0)
Inner Suburban Fringe	5.21 (3.4)	5.19 (3.7)	5.20 (3.7)	5.02 (2.6)	4.81 (2.0)	4.81 (2.0)	4.81 (2.0)
Outer Suburban Fringe	7.02 (2.8)	7.01 (2.9)	6.75 (2.9)	6.70 (2.0)	6.54 (1.5)	6.77 (1.5)	6.54 (1.5)
Rural Areas	13.23 (0.2)	12.58 (0.2)	12.51 (0.2)	11.95 (0.1)	12.63 (0.1)	12.60 (0.1)	12.54 (0.1)
Satellite Communities	7.20 (0.5)	8.56 (0.6)	8.57 (0.6)	7.96 (0.4)	8.75 (0.3)	8.82 (0.3)	8.46 (0.3)
Region							

[a] Residential scenario
[b] Average auto trip length in miles
[c] Percent transit

suburban fringe commercial development scenarios, with the exception of the outlying rural and satellite communities subregions. The base year development pattern has a more uniform distribution of commercial development compared with the 2-year 2000 extremes, which logically produces trip lengths in between the two extremes. The pattern of transit use by geographic subregion is entirely consistent; the use declines with increasing distance from central Madison and with increasing distance of the commercial development from the central area.

ADDITIONAL FUEL CONSERVATION OPPORTUNITIES

To assess the importance of urban development options in comparison with other means of reducing transportation fuel consumption, the effects of transit, ridesharing, and vehicle fuel economy improvements were considered both separately and in conjunction with each of the six urban development scenarios. The transit improvements were assumed to generate a 50 percent increase in transit trips for all trip purposes and trip interchanges plus an additional 50 percent increase above the initial increase for suburban fringe work trips and for work trips from the outlying areas. The ridesharing improvements were assumed to increase the work trip automobile occupancy rates by 50 percent. These levels of improvements are not likely to be achieved by the year 2000; rather, they represent upper-bound base lines for comparison with the urban development scenarios.

In contrast with the assumed transit and ridesharing improvements, the assumption of a 62 percent increase in average vehicle fuel economy from 14.7 to 23.8 miles per gallon is much more realistic. This increase is based on the assumption that the congressionally mandated new-car-fleet fuel economy standard of 27.5 miles per gallon is achieved by 1985 and considers the effect of older vehicles on the overall fleet average *(15)*. Although some slippage has occurred in implementing the standard, the projected increase in fuel economy is still achievable by the year 2000.

The impacts of the three additional fuel conservation opportunities are compared with the development alternatives presented in Table 8. The range shown for each alternative and opportunity is based on the range over the six development scenarios. The reductions in fuel consumption that would have occurred in 1980 if the three fuel conservation opportunities had been applied are also presented in Table 8. These 1980 fuel consumption levels form a base line for evaluation of the incremental impact of the development alternatives.

Of the residential development alternatives presented in Table 8, only the central Madison scenarios reduce the fuel consumption per capita from the 1980 base level (a 6.9 to 14.5 percent reduction). If the transit or the ridesharing improvement opportunities had been implemented in 1980, a similar reduction in per capita fuel consumption would have been achieved (of 5.7 and 10.8 percent, respectively), whereas implementing the vehicle fuel economy standards would have had a dramatic impact (38.2 percent reduction). The satellite communities residential scenarios generate the greatest increase in fuel consumption per capita over the 1980 base level, but the increase is not large (5.5 to 8.5 percent). Analysis of the joint impact of the three additional fuel conservation opportunities and the development alternatives for the year 2000 for the marginal reduction in fuel consumption (percent of 1980 per capita fuel consumption) show that the two are not independent (see Table 8). The most energy efficient development scenario

TABLE 8 IMPACT ON ANNUAL FUEL CONSUMPTION OF THE ADDITIONAL FUEL CONSERVATION OPPORTUNITIES COMPARED WITH THE DEVELOPMENT SCENARIOS

Scenario	Range in Fuel Consumption per Capita[a] (gallons per year)	Change as Percent of Base Year
Base Year (1980)	208.5	--
All Development Scenarios	178.3 to 226.3	-14.5 to +8.5
Residential Scenarios		
- Central Madison	178.3 to 194.2	-14.5 to -6.9
- Suburban Fringe	215.5 to 219.3	+ 3.4 to +5.2
- Satellite Comm.	219.9 to 226.3	+ 5.5 to +8.5
Commercial Scenarios		
- Central Madison	178.3 to 219.3	-14.5 to +5.2
- Suburban Fringe	194.2 to 226.3	- 6.9 to +8.5
Transit Improvements		
- 1980	196.6	-5.7
- 2000	163.1 to 219.5	-21.8 to +5.3
(Increment due to Transit)	(-15.2) (-6.8)	(-7.3) (-3.3)
Ridesharing Improvements		
- 1980	185.9	-10.8
- 2000	159.4 to 209.6	-23.6 to +0.5
(Increment due to Ridesharing)	(-18.9) (-16.7)	(-9.1) (-8.0)
Vehicle Fuel Economy Improvements		
- 1980	128.9	-38.2
- 2000	110.2 to 139.9	-47.1 to -32.9
(Increment due to Veh. Fuel Economy)	(-68.1) (-86.4)	(-32.7) (-41.4)

[a] Range over the relevant development scenarios

also improves the energy efficiency of the transit improvement opportunity. That development scenario results in an additional 7.3 percent reduction attributable to transit compared with only a 5.7 percent reduction for the same transit improvements in 1980. Conversely, the least energy efficient development scenario reduces the incremental reduction in fuel consumption from the transit improvement from 5.7 percent (1980) to 3.3 percent (2000). For the ridesharing opportunity, both the most and least energy efficient development scenarios reduce the marginal effectiveness of that option (9.1 and 8.0 percent, respectively, versus a 10.8 percent reduction in 1980). Vehicle fuel economy improvements reverse the pattern of the transit opportunity in that the vehicle fuel economy improvements are least effective for the most energy efficient development scenario and most effective for the least energy efficient scenario. This is logical because transit use is enhanced by high-density compact development, whereas improved vehicle fuel efficiency will have the greatest impact on development patterns that generate the most automobile travel.

CONCLUSIONS

The primary purpose of this study was achieved. Simplified travel demand and fuel consumption models were developed that produced reasonable estimates of the fuel efficiency of idealized urban development alternatives. The models are simple enough to be understood by many local decision makers. Moreover, the models are relatively easy to calibrate by using U.S. Census and basic travel demand data so that many small- to medium-sized urban areas can undertake similar analyses with minimal effort. The cost and time required to run the models is small because only one gravity model application is required for each development scenario to be evaluated.

Specifically, for the case study area of Dane County, Wisconsin, the fuel consumption analysis of the six development scenarios provides at least indirect support for the three regional development plan policies identified earlier. First, the analysis clearly shows that the average trip length for a subregion is reduced both when population and employment growth are located in that subregion. Thus, the regional plan's policy of encouraging balanced growth both of population and employment in outlying communities should reduce fuel consumption. Second, the analysis gives direct evidence that the policy of encouraging retail and commercial development in the central Madison area will reduce fuel consumption. Compared with suburban fringe commercial development, the central Madison development resulted in lower fuel consumption per capita for all three residential scenarios. Finally, because the rural subregion had the highest fuel consumption per capita by a substantial margin, the policy of limiting development in rural areas will reduce fuel consumption.

The current development trend in the case study area is for both population and employment growth occurring primarily in the suburban fringe subregion. The fuel consumption analysis in part explains the location of this development and why it is likely to continue. Land for residential development is available primarily in the suburban fringe areas. Not surprisingly, the average trip lengths for residents of the suburban fringe areas are less when commercial development is also located in the suburban fringe areas. New businesses and offices are likely to locate where it is most convenient for their customers. The trade-off is that trip lengths for most other residents of the region are increased somewhat. On balance for the year 2000, the overall regional average trip length for the suburban fringe commercial development scenario was just slightly less than for the central Madison scenario.

The primary advantage of the central Madison commercial development scenario is the potential for higher transit use with less fuel consumption. Thus the state of Wisconsin's policy of centralizing state employment in the central Madison area is supported by the projected regional transportation fuel savings. In contrast, the private sector commercial development is likely to locate where their market is growing and where land is available at a lower cost.

Of the three additional fuel conservation opportunities considered, only vehicle fuel economy improvements are likely to have a significant impact on future regional transportation fuel consumption. Even with quite dramatic changes in transit use and ridesharing, the baseline (1980) estimated fuel savings per capita for the transit and ridesharing options were only one-sixth and one-third as large, respectively, as the fuel savings from the currently expected vehicle fuel economy improvements. Additional improvements in vehicle fuel economy would increase those large savings even further. The baseline fuel savings per capita for the transit and ridesharing opportunities were also somewhat less than the maximum fuel savings that could be achieved with the most energy efficient year 2000 development scenario.

The most probable residential development scenario produces an estimated 3 to 5 percent increase in fuel consumption per capita compared with 1980. However, when this scenario is combined with the vehicle fuel economy opportunity, savings of more than 35 percent are possible. In contrast, the transit and ridesharing opportunities produce less than 5 percent savings. The fuel consumption impacts of the urban development alternatives considered in this study appear to be generally consistent with the research based on the Lowry model by Edwards and Schofer *(1)* and Kim and Schneider *(3)*. These two studies found that centralization of population led to reductions in fuel consumption as was found for Dane County in this study. Peskin and Schofer's *(2)* conclusion that polynucleated cities consume less transportation energy than concentric ring cities also is supported by the Dane County analysis if the impact of transit is neglected. Average trip lengths were minimized by locating the population growth in the suburban fringe subregion given that the employment growth was also located in the suburban fringe. If a transit system could be developed to serve the resulting suburban employment centers (polynucleated form) effectively, then such development might be as energy efficient as the highly centralized development scenario.

To reduce the travel demand modeling costs, highway network speeds were assumed to be the same for all scenarios. Thus no traffic assignment model was required. The impact of this assumption on fuel consumption needs to be evaluated. If a traffic assignment model is used, then the potential for substantial overloading on the highway network must be recognized because of the idealized nature of the development scenarios. Consequently, marginal analysis based on incremental additions of population and employment until the network reaches saturation would be appropriate. The sensitivity of the simplified models to less extreme development scenarios should also be evaluated. The impact of a range of residential densities on land that will be available for development could be examined. Potential higher-density suburban development nodes could be identified together with improved transit service to the nodes.

The trip generation models available for the Madison urban area did not explicitly include household size. Analysis of the sensitivity of transportation fuel consumption to the joint effects of household size and household location within the region is needed.

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Converting Transit to Methanol: Costs and Benefits for California's South Coast Air Basin

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Methanol offers much promise as an alternative fuel whose combustion produces no sulfates and fewer nitrogen oxides and particulates than diesel fuel. Another advantage is that large quantities could be manufactured from domestic coal supplies. On the basis of the assumption that an extensive methanol program might well begin with public transit, the costs and benefits of converting the bus fleets of California's South Coast Air Basin to methanol are estimated. Benefits are based on the reduced mortality attributable to lower sulfates and particulates; costs encompass both bus conversion and replacement. When these benefits are compared with costs over a wide range of methanol prices, conversion to methanol is found to merit further consideration as an antipollution strategy. It is proposed that the analysis be extended to additional potential benefits and costs and to other locales and types of vehicles.

Replacing petroleum-based fuels with methanol has been suggested as a promising way to improve air quality and reduce dependence on imported oil. Methanol burns more cleanly and has greater supply flexibility because it can be made from natural gas, coal, or even biomass. Because current technology would allow a fairly easy conversion, the idea has found support among government agencies and environmental groups as well as the energy and transportation industries.

Unlike diesel fuel or gasoline, methanol is an alcohol. Its cooler flame produces fewer nitric oxide emissions and so reduces concentrations of derived pollutants such as nitrogen oxides, nitric acid, ozone, and other oxidants. Particulate emissions, a serious problem with diesel engines, are almost eliminated. Because all sulfur content is removed during manufacture, methanol produces no sulfur dioxide and therefore no sulfuric acid, a principal component of acid rain.

The last decade has witnessed extensive investigation of engine design, emissions content, materials compatibility, and methanol production methods. Test vehicles operate at several sites in California, and additional projects are planned or starting up in Jacksonville, Seattle, and New York. Yet there have been few economic evaluations of methanol conversion, and these few have been contradictory or incomplete. The California Institute of Technology's Jet Propulsion Laboratory *(1)* concludes that methanol's market penetration will proceed very slowly, that it can reduce air pollution levels only slightly, and that methanol prices will rise substantially as demand and reliance on domestic feedstocks increase. Gray and Alson *(2)* are far more optimistic, suggesting that nationwide vehicle usage of methanol made from high-sulfur coal would improve air quality, revive eastern coal-mining areas, and reduce U.S. dependence on foreign oil.

However, none of these studies attempts to quantify the benefits in economic terms. The question of whether the benefits of methanol use outweigh its costs has been left to somewhat subjective judgment. To further the economic evaluation of conversion policies, a simple cost-benefit analysis is therefore developed and presented. To make it as clear as possible, it is restricted to a very limited but promising case: methanol conversion of public transit buses in California's South Coast Air Basin. This allows a demonstration, in the simplest possible way, of the kinds of information and assumptions required to compare benefits and costs. At the same time, a case is chosen that ought to highlight the advantages of methanol and provide a first test of whether analysis of more complex policies is warranted.

The South Coast Air Basin, hereafter referred to as "the Basin," includes the urbanized parts of Los Angeles, Orange, San Bernardino, and Riverside Counties in California. The Basin makes a particularly interesting case study because of its national stature as a pollution center; the reason being that if methanol use could not provide significant benefits in this heavily populated and polluted region, it would be unlikely to provide them elsewhere.

Transit buses provide an ideal technology for a first case study: the vehicles are homogeneous, concentrated at a few public enterprises that keep good records, and fueled and maintained at a few central facilities. These same factors also facilitate the methanol conversion process; in addition, buses are an obvious target because they are highly visible polluters that operate in populous areas and emit exhaust directly at street level. A policy designed to abate air pollution might do well to begin with those vehicles that transgress most in the eyes of the public.

The benefits accruing only from a reduction in the mortality rate are estimated. Air pollution, of course, causes many other kinds of harm: it increases nonfatal illness, burns eyes and lungs, soils and damages materials, blights crops, and reduces visibility. There are two reasons for limiting the benefits considered here. First, in this initial analysis, only the most critical policy issues are addressed. Second, several careful empirical studies have established the pernicious effects of air pollution on health and have provided functional relationships that may be used in benefit-cost analysis.

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In addition, only two pollutants are examined: total suspended particulates (TSP) and sulfur oxides (SO_x). These pollutants can be traced reasonably well from tailpipe to lungs, their health effects are known, and their emissions are virtually eliminated in methanol-fueled engines. Reduction of nitrogen oxides (NO_x) may be an equally important feature of methanol buses, but NO_x health effects occur through a complicated path of photochemical changes in the atmosphere that is more difficult to trace.

For simplicity, the authors analyzed a steady state in which all buses are fueled with methanol, one-twelfth being replaced each year because of normal attrition, and in which population, bus mileage, and value of pollution reduction remain constant. Of course, many things would change over time. Most of these would make methanol conversion more favorable. Increased population and higher incomes would increase the benefits, whereas improved technology will almost certainly reduce the extra costs of equipping buses for methanol use. The authors refrained from speculation on future fuel price differentials. The methodology makes no attempt to address transition problems with methanol conversion or to compare it with alternative ways of reducing emissions either now or in the future.

The analysis, then, chooses a particularly favorable case for methanol but analyzes it conservatively. Because the results show benefits exceeding costs over a significant range of assumptions and fuel costs, conversion of transit buses in Southern California appears to be a promising public policy. Also, analysis of other conversion strategies involving other vehicles and other metropolitan areas is warranted. The methodology presented here provides a sound basis for extending the analysis to such cases and for refining it to include additional types of benefits.

DATA AND METHODOLOGY

Pollution Reduction

The first step in the analysis is to establish the percentage reductions in ambient air TSP and SO_x concentrations attributable to conversion to methanol fuel. This requires knowing the emissions per mile of each type of bus, the total annual miles traveled by transit buses in the Basin, and the total emissions from all sources in the Basin. The results are given in Table 1. Because buses account for only a tiny fraction of emissions in the Basin, conversion would reduce ambient air concentrations by a minuscule 0.43 percent of TSP and 0.226 percent of sulfates.

Mortality Reduction

The second step is to establish the effect on the mortality rate of a unit decrease in the level of each pollutant. The effect of these pollutants has been established by the detailed regression analysis of Lave and Seskin *(3)* and Chappie and Lave *(4)* who used mortality and pollution data from more than 100 U.S. metropolitan areas, and by numerous epidemiological studies, reviewed and extended by Ozkaynak and Spengler *(5)*. The latter authors conclude that as much as 6 percent of the mortality in urban areas can be attributed to particulates and to sulfates, a derivative of sulfur oxides (*5*, p. 54).

TABLE 1 REDUCTIONS IN AMBIENT AIR CONCENTRATIONS OF PARTICULATES AND SULFATES AS A RESULT OF METHANOL USE

Type of Bus	Per-Vehicle Emissions (grams/mi)[a]	Total Annual Emissions (000s kg)[b]	Percent Reduction in Ambient-Air Concentration Compared to Diesel[c]
Particulates			
Diesel	6.275	948.77	
Methanol (M.A.N.)	0.0644	9.74	0.430%
Methanol (GM)	0.6275	94.88	NA[d]
Sulfur Oxides			
Diesel	0.81	122.5	
Methanol (M.A.N.)	0	0	0.226%
Methanol (GM)	0	0	NA

[a] Particulate emissions are from Ullman et al. *(19)*; Grade 2 diesel fuel assumed in diesel engine. SO_x emissions are derived from the sulfur content of the fuel used, which is taken to be 0.05 percent by weight, the maximum now permitted by the state of California for buses in the Basin. Fuel density is 7.163 lb/gal; fuel consumption is 1 gal/4 mi; and sulfur oxide molecules contain 50 percent sulfur by weight, as is the case for SO_2. (Details are presented in an appendix available from the authors.)

[b] Per-vehicle emissions [a] *x* total annual vehicle miles in 1984 [151.2 million *(20)*].

[c] Total annual emissions (diesel buses) minus total annual emissions (methanol buses) result divided by the total annual emissions from all sources in 1983 *(21)*, which is 218.6×10^6 kg for particulates and 54.1×10^6 for sulfur oxides.

[d] GM data are not used in the analysis because of the comparatively poor performance of the GM methanol bus, which is a preliminary prototype. In the testing performed by Ullman et al. *(19)*, the GM's SO_x emissions and a large portion of its particulate emissions were apparently caused by engine oil scavenged into the exhaust.

The precise relationship between emissions and ambient concentrations of particulates and sulfates is not one to one (though it is far more straightforward than for nitrogen oxides and ozone, which is one reason for omission of the latter here). In the case of particulates, recent evidence suggests that it is mainly fine particles that cause health damage *(5)*, whereas the data used by Lave and Seskin do not distinguish by particle size. Because a high proportion of the particulates emitted by diesels are fine, their harmful effects are probably underestimated by ignoring that feature. This belief is supported by a replication of the Lave and Seskin work for a more recent year, which shows that where fine particles are a smaller proportion of all particulates, a weaker relationship exists between particulates and mortality.

In the case of sulfur oxides, most of these emissions are transformed into sulfates through atmospheric reactions. The common assumption is that atmospheric sulfate concentrations are proportional to sulfur oxide emissions. This assumption has some support from atmospheric simulation models, at least in the case of the clear weather that characterizes Southern California *(6)*. Note that even though sulfates are a component of particulates, they can be treated separately without double counting because they are also treated as separate pollutants in Chappie and Lave's statistical work.

The most comprehensive estimates of the quantitative relationship are those by Chappie and Lave *(4)*. Their work remains the most careful and complete study of the effects of air pollution on mortality in actual urban populations and includes data from 1960, 1969, and 1974.

For each pollutant, the three estimated elasticities of mortality with respect to concentration were averaged, one for each of the three years (*4*, p. 349). This average was then adjusted downward by 0.0303 (sulfate elasticity) and 0.0234 (particulate elasticity) on the basis of the difference, in the 1974 results, caused by adding a socioeconomic variable that was unavailable in the earlier years' data (*4*, p. 352). The assumption is that including that variable in the earlier years would have made the same difference in the results for those years. (Further details are provided in an appendix available from the authors.) This procedure is conservative in that without this adjustment, the sulfate and particulate elasticities would be 61 and 197 percent higher, respectively. Alternatively, if the best regression estimates from the 1974 data were used, ignoring the earlier years, the sulfate elasticity would be about twice as high, and the particulate elasticity would vanish, with a slight overall increase in the benefits estimated in the next sections.

The resulting changes in mortality rates and total mortality are given in Table 2.

TABLE 2 REDUCTION IN MORTALITY DUE TO METHANOL CONVERSION

Pollutant	Elasticity of Mortality with Respect to Ambient Air Concentrations[a]	Reduction in Total Mortality Rate (annual deaths per million)[b]	Reduction in Annual Deaths in Los Angeles Basin[c]
Particulates	0.0119	0.41	4.36
Sulfates	0.0500	0.91	9.63
Total	0	1.32	13.99

[a] Percentage change in total mortality rate, divided by percentage change in ambient air pollutant concentration (see text for sources).

[b] Elasticity times pollutant reduction from Table 1, times total mortality rate in South Coast Air Basin (8,025 per million, computed from data provided by the Departments of Public Health of Los Angeles, Orange, San Bernardino, and Riverside counties).

[c] Reduction in total mortality rate times population of Los Angeles Basin (10.62 million).

Value of Mortality Reduction

The third step is to express in dollars the benefits from reducing the mortality rate. This requires multiplying the reduced mortality rate by a dollar value assigned to the reduction in risk of death. The assignment of this explicit value is crucial because it allows the quantification of benefits; hence it is necessary to digress to present the conceptual basis with some care.

Many studies have stumbled on the apparent paradoxes inherent in placing a dollar value on policies that save lives. Discounted value of lifetime earnings has often been used, despite the obvious defects that most earnings are for the person's own consumption and that this measure places no value on the lives of retired people.

Here the now widely accepted concept of willingness to pay is followed: How much do people pay to reduce hazards, or how much extra compensation do they demand for working under hazardous conditions (*7–9*)? Rather than ask the value of saving an identifiable person's life, we ask the value of reducing the ongoing risk of fatality that everyone faces. This is more consonant with the way in which policies actually affect people because most policies, including those concerned with air pollution control, make very small changes in the mortality risk facing large numbers of people.

For example, suppose that a clean air policy reduced everyone's annual risk of dying from 1 in 100 to 0.99 in 100. How much would the average person be willing to pay for such a change? This is an answerable question, because people can be observed making choices involving risk changes of this magnitude, such as purchasing safety equipment or choosing among jobs involving various degrees of hazard. [In fact, changing jobs from one of average occupational risk to one of no occupational risk involves a reduction of about this amount (.01 in 100).] If such observed behavior indicates that people are willing to pay $800 per year for this reduction (or to forego wages of that amount), then the willingness to pay for a reduction in risk from 0.0100 to 0.0099 is $800.

In a community of 10,000 people, such a risk-reduction policy lowers the expected annual death rate from 100 to 99. It could be stated, somewhat loosely, that it saves one life per year. Because in the aggregate these people are willing to pay 10,000 × $800 = $8 million/year for the risk reduction, it could be said that the "value of life is $8 million." This is just shorthand, however, for the more precise earlier statement. It does not mean that Sara Jones's life is worth $8 million; it means that 10,000 people are willing to pay $800 each for a reduction in risk that, in aggregate, will probably save one life.

Kahn (*10*) discusses the methodological weaknesses and strengths of some of the best-known attempts to estimate people's willingness to pay for risk reduction. She presents a strong case for relying on the estimates derived from labor market analyses. For example, estimates based on markets for safety equipment have ignored the inconvenience associated with installation, maintenance, and use of the safety devices.

Kahn also presents a comprehensive analysis of sources of bias in the labor market studies and thereby offers a convincing basis for choosing estimates by Olson (*11*) and Viscusi (*12, 13*) that are among the highest of the various studies. Kahn in particular advocates using the "value of life" obtained by Olson for a combined sample of union and nonunion workers, which is $8 million in 1984 dollars. The subsequent and widely cited work by Viscusi (*14*) also results in estimates of comparable magnitude. Nevertheless, current practice in government analyses of safety practices uses much lower values, typically $0.5 to $1.5 million, resulting from the earlier studies and from the method of present discounted value of lifetime earnings. In this analysis both figures, $1.5 and $8 million, are used to test the sensitivity of the results. At the higher of these figures, the mortality reduction given in Table 2 is valued at $113 million annually, of which 69 percent results from reduced sulfates and the remainder from reduced particulates.

Implicit in this calculation is a value per kilogram of emissions removed for each pollutant, obtained by valuing the reduced deaths given in Table 2 (last column) at this value and dividing by the corresponding emissions reductions given in Table 1 (middle column). At the higher value of mortality reduction, each kilogram of particulates or sulfur oxides emitted costs society $37 or $629, respectively—startling figures considering that a typical diesel bus emits a kilogram of sulfur oxides in about 2 weeks (1,370 mi) and of particulates in less than 2 days (159 mi).

Costs

The fourth step is to calculate the costs of the methanol strategy. There are two main costs: a capital expenditure for conversion and an operating expenditure for fuel.

Building methanol buses is relatively expensive because they are manufactured in small quantities. For example, Seattle Transit paid $175,000 each for 10 methanol buses while paying only $126,000 each for new diesels. General Motors, however, in testimony to Congress in 1984, indicated that annual production of 250 to 300 methanol buses could bring the cost differential down to between $6,000 and $7,000 (*2*, p. 125). This appears to be a more pertinent estimate for this study. This estimate is also more consistent with the evidence from Florida's retrofitting experiment in which the Florida Department of Transportation estimated the actual cost of converting an existing bus, once substantial scale is attained, at $7,500 to $10,000 (*15*, p. 73). However, to accommodate both possibilities and to remain conservative, a range of $6,500 to $49,000 is adopted here as the additional cost of replacing a diesel with a methanol bus. In estimating the average life of a transit bus at 12 years, it is assumed that one-twelfth of the vehicles in the Basin fleet will be replaced annually. Multiplying this number (369) by $6,500 to $49,000 gives a range of the annual additional capital cost of purchasing methanol rather than diesel buses (Table 3).

TABLE 3 REPLACING DIESEL WITH METHANOL BUSES: ANNUAL ADDITIONAL COST

Additional Cost per Bus Replaced ($)	Average Bus Lifetime (years)	Total Annual Additional Cost[a] ($millions)
6,500[b]	12[c]	2.40
49,000[d]	12	18.08

[a] Additional cost per bus multiplied by total number of transit buses in the South Coast Air Basin (4,432), result divided by average life of transit bus.
[b] Gray and Alson (2, p. 125).
[c] Wachs and Levine *(20)*.
[d] Based on actual prices paid by Metro Transit, Seattle, Washington, in 1986.

The instability of the world oil market implies instability in the price of diesel fuel, increasing or diminishing its present price advantage over methanol. The current price of methanol reflects a worldwide oversupply, but a substantial increase in demand could drive the price up. In light of these uncertainties, the results of this analysis are presented as a function of price differentials between diesel and methanol fuels.

It is convenient and common to state fuel prices on the basis of equivalent energy content rather than equivalent volume. A gallon of methanol contains fewer Btu (57,000) than a gallon of diesel (128,000), and so the price per gallon of methanol is multiplied by 128,000/57,000 to obtain a price per 128,000 Btu of fuel. No further adjustment is required because the fuel efficiencies of methanol and diesel engines are comparable *(16)*. The total annual fuel cost differential is found by multiplying the price differential computed in this way by the annual number of gallons of diesel fuel currently burned by all of the transit buses in the Basin (37.8 million).

It should be noted that some costs are neglected in the analysis. Because methanol is toxic, burns with an invisible flame, and produces harmful vapors, there may be an additional cost to handle it safely. In addition, because of the discrepancy in energy content, buses will require twice as many gallons of methanol as diesel, which will increase the costs of refueling and storage (costs of larger fuel tanks on the buses themselves are already taken into account). However, these and similar costs appear to be relatively small.

RESULTS

The results of the analysis are shown in Figure 1 as functions of the excess of methanol price over diesel price. There are two alternative assumptions on value of life ($8 million and $1.5 million), leading to two alternative estimates of benefits, shown as horizontal lines. There are two alternative assumptions on differential bus acquisition cost ($6,500 and $49,000), leading to two alternative estimates of costs, shown as sloped lines. Costs, of course, rise as the methanol price increases relative to the diesel price.

It is clear that the alternative assumptions shown make a great deal of difference to the conclusion. The authors have argued that the higher value-of-life estimate ($8 million) and the lower capital cost estimate ($6,500) are the more accurate ones. If that is true, benefits exceed costs even when methanol prices (per energy content of a gallon of diesel) are as much as $2.93 higher than diesel. Over the past year, the average price differential has been $1.00, at which point benefits exceed costs by a ratio of three to one.

On the other hand, comparison at the lower estimate of value of life is not as favorable. Only if the price difference drops to $0.50 do benefits outweigh costs, assuming General Motors' estimate of $6,500 as the extra cost of building a methanol-fueled bus. Many possible benefits of methanol have been omitted; for example, methanol use in buses would reduce NO_x emissions as well as weaken the impact of direct street-level exhaust. Also omitted are the advantages of improved visibility and lessened morbidity, soiling, and materials and crop damage. All these benefits must be taken into account in deciding whether a policy of methanol conversion would still be worthwhile, given the less favorable assumptions on the value of mortality reduction.

CONCLUSION

This first try at a cost-benefit analysis of a methanol conversion strategy leads to several tentative conclusions. On the substantive side, there is real promise for a policy of converting transit buses in the Los Angeles basin. Given recent evidence about

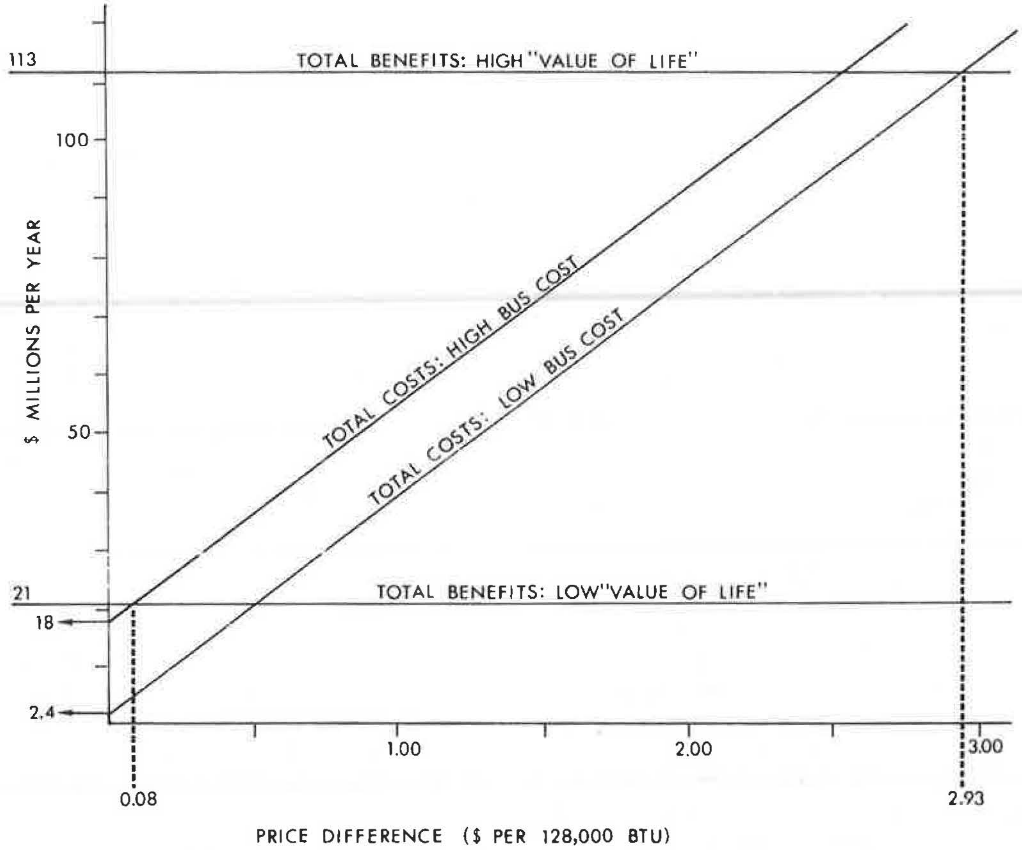

FIGURE 1 Benefit-cost analysis in terms of methanol-diesel price difference.

people's willingness to pay for lower mortality risk, the policy is justified over a wide range of methanol prices. When the older estimates of value of life are used, the case is not as clear cut. Both evaluations are quite conservative, however, because the analysis was limited to the negative effects of only two pollutants—sulfates and particulates—and examined only one positive effect—the change in mortality.

In terms of a research agenda, three sources of uncertainty need further work. One is the effect of methanol use on other pollutants, particularly photochemical oxidants. These are compounds often believed to cause the worst problem in the South Coast Air Basin; therefore, a careful analysis of the potential for reducing them through lessened nitric oxide emissions might show considerable benefits. The second is the possible existence of important benefits from reduced sickness, reduced materials and crop damage, and improved visibility. The third is the question of whether the same benefits can be attained in other ways such as by using diesel fuel with less sulfur and aromatic hydrocarbons or by fitting buses with particulate traps and catalytic converters.

The work of Weaver and his colleagues *(17, 18)* suggests that starting with diesel fuel typical of that used in the United States and adopting a low-sulfur and low-aromatic fuel (similar to that taken as the baseline in this analysis and already required in the Los Angeles basin) is the most cost-effective means of reducing particulate emissions. They also suggest that in terms of the incremental cost of making further particulate reductions, particulate traps compare favorably with methanol. An extension of the methodology described here could provide further evidence on the comparative merits of these strategies, taking into account more pollutants than did Weaver.

A deeper policy question underlying this analysis of transit buses is the benefits that might be achieved from a wider methanol conversion strategy, including cars, trucks, and perhaps stationary sources as well. The answer cannot be confidently predicted. Whether the favorable case for methanol extends to other types of vehicles or other locations is likely to depend critically on extensions of the research methodology.

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Advances in Automobile Technology and the Market for Fuel Efficiency, 1978–1985

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The Corporate Average Fuel Economy standards for automobiles and light trucks were intended to improve energy efficiency primarily through technological improvements. While it is not clear how much of the impetus for manufacturers to improve fuel economy should be attributed to the Corporate Average Fuel Economy, analysis of light-duty vehicle sales and characteristics since the Corporate Average Fuel Economy went into effect in 1978 does indicate that technological improvements are responsible for about one-half of the 40 percent increase in automobile fuel economy between 1978 and 1985. Size class shifts are responsible for only 10 percent of the total gain. The 1978–1985 market for automotive efficiency reflects interactions of demand shifts, regulation, and technological change. An attempt is made to measure the technical improvements in automotive fuel efficiency by estimating stochastic frontier cost functions for automotive fuel economy in 1978 and 1985.

The Corporate Average Fuel Economy (CAFE) standards for automobiles and light trucks (Energy Policy and Conservation Act of 1975) were based on the assumption that cost-effective technology for nearly doubling automotive fuel economy without significantly affecting consumer satisfaction existed, and should be used. This assumption is reflected in the fact that when National Highway Transportation and Safety Administration (NHTSA) established the fuel economy standards in its final rule, it assumed that no sales shifts would be required to reach 27.5 mpg in 1985 *(1)*. Some critics of the standards have assumed that technology would not advance and that the standards would have to be met by forcing producers and consumers to settle for less desirable combinations of fuel efficiency and other attributes *(2–4)*. Examined in this paper are the trends in automobile sales and characteristics from the first year of the CAFE standards to the present (1978–1986). The purpose of this paper is to contribute to the theoretical and factual bases for consideration of the appropriateness of the standards as currently formulated. This review indicates that technological improvements, rather than merely a move to smaller or less desirable but more efficient vehicle designs, have been a major factor in the 40 percent increase in automotive efficiency since 1978. Trends in market demand have also been important, however, and there is also evidence that the range of choices available to consumers has been reduced. A reconsideration of CAFE standards should begin with an understanding of the interdependence of these factors and the role that they have played in past mpg improvements.

First, a brief discussion of the economics of the market for vehicle attributes is required to provide a context for the facts and figures. This discussion is followed by an exploration of the changes in vehicle characteristics (weight, engine size, vehicle size) that are directly or indirectly important to consumers, that most directly affect mpg, and whose effect is mediated by the technology that manufacturers incorporate in the vehicles they produce. (Throughout this paper, technology is used in the economist's sense to represent the production capabilities of firms. An advance in technology therefore does not necessarily imply an advance in scientific or engineering knowledge but could instead result from the application of existing knowledge.) Stochastic frontier production functions that quantify technological change are estimated. Finally, changes in light-duty vehicle fuel economy from 1978–1986 are decomposed into a variety of sales shift and vehicle engineering categories. The categories do not correspond exactly to the technology versus demand shifts dichotomy that is desired but do help to understand the relative magnitudes of these components.

ECONOMICS OF VEHICLE ATTRIBUTES

It is useful to consider the automobile market to be a market for vehicle characteristics rather than for uniform vehicle units. This characterization of the market for attributes of commodities is referred to in the economics literature as "hedonic demand analysis" *(5–7)*. Each vehicle is a bundle of characteristics that includes fuel efficiency, carrying capacity, luxury, and other numerous and often vague attributes. It is assumed that consumers possess "bid functions" that express their willingness to pay for each attribute at given levels of all others. A consumer's bid function for the ith attribute, B_i, depends on the prices of all attributes, p, and other characteristics of the consumer, c (e.g., his income, age, tastes). Producers, on the other hand, possess "offer functions," O_i, which express their ability to supply attributes given the prices of all inputs to production, w, the technology available to them, T, and regulatory constraints, R. The market can be described by sets of different bid functions for different consumers (j) and offer functions for producers (k).

$$O_{ik}(w, T, R) = B_{ij}(p, C) \qquad (1)$$

The reason it is so difficult to ascribe changes observed in the market to any particular cause is that these functions are

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numerous and interdependent. Bid functions generally are unobservable. Only the intersections of bid and offer functions can be observed. Intersection points (actual vehicle characteristics bundles) may shift when consumers' bid functions shift in response to higher fuel prices, demographic changes, or changes in tastes. Figure 1 shows the trade-off between vehicle weight and fuel efficiency in gallons per mile. Higher fuel prices cause the bid function (demand curve) to shift downward, resulting in lighter, more efficient cars. Attribute bundles offered may shift in response to higher factor prices, regulation, or technological change, which cause producers' offer functions to shift. The same shift caused by higher fuel prices could be achieved via regulation by restricting the supply curve to the dashed portion. This forces consumers to accept something other than their preferred attribute bundle, resulting in a loss in economic efficiency. An improvement in technology is shown in Figure 1 by a shift in the offer function (supply curve) to the left. Without any change in demand, this results in heavier and more efficient cars. Shifts in both supply and demand could result in both lighter and more efficient cars.

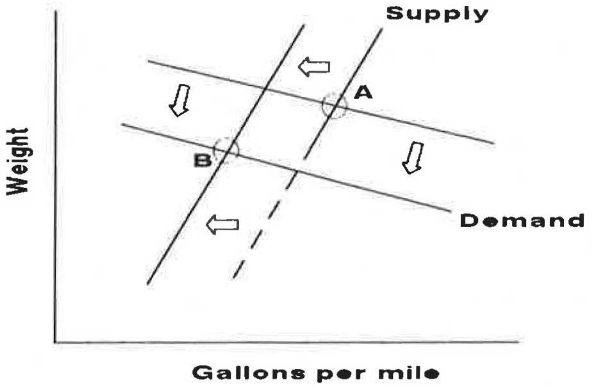

FIGURE 1 Trade-off between vehicle weight and fuel efficiency in gallons per mile.

Regulation, such as CAFE, is an attempt to alter the course of change. If it can be assumed that the market is functioning as a classical competitive market and technology is held constant (or assumed to respond correctly to market signals), then regulatory intervention can be justified only if it promotes a noneconomic societal goal (e.g., national defense). If the market is operating properly, consumers are getting the bundles of attributes they want most for the lowest possible price. Regulations that force producers to offer more fuel economy, either at a higher price or with less of some other desired attribute, also force consumers to accept vehicles with less of some other desirable attributes. Economic analyses of CAFE that have begun from these premises have inevitably concluded that the regulation would be *(2, 3)* or has been *(4)* harmful to the economy. However, the intent of CAFE was to stimulate or accelerate technological improvement, not to force consumers to accept vehicles with less desirable attributes. To shed light on this issue, the role of technological change in the market for fuel efficiency must first be understood. The technology of production can be viewed as a production function describing the quantity of output that can be produced for given levels of inputs. In this case, the outputs and inputs are multidimensional. The production function translates a vector of inputs, x_j ($j = 1$ to n), into a vector of vehicle attributes, y_i ($i = 1$ to m),

$$y = F(x) \tag{2}$$

For the cost-minimizing firm, there exists a cost function, C, for every production function, which gives the minimum cost, c, for producing a given level of output and given input prices *(8)*,

$$c = C(y, w) \tag{3}$$

Assume that one of the y_i's (let it be y_1) is fuel economy and that it is a function of some subset of the remaining y_i's, which is assumed to be $(y_2, y_3, \ldots, y_k)$. By the implicit function theorem *(8)* y_1 can be expressed as a function of y_2 through y_k.

$$c = C[y_1 (y_2, \ldots, y_k), y_2, \ldots, y_m] \tag{4}$$

The importance of this is that fuel economy can be expressed as a function of other vehicle attributes, and this function will represent the state of technology for producing fuel economy at a given time. This result can be used to construct production frontiers for 1978 and 1985 and determine whether or not the frontier (technology of production) has advanced.

CHANGING ATTRIBUTES AND THE TECHNOLOGY FRONTIER

Many attributes may be indirectly related to fuel economy. From an engineering point of view, however, there are only a few attributes that have both a major influence on fuel economy (an influence large enough to have contributed significantly to the more than 40 percent increase in automobile fuel economy from 1978 to 1986) and important implications for consumer satisfaction. The attributes used here are vehicle weight, engine size (or size to weight ratio), projected frontal area (width times height), and price. An attribute such as interior space may be assumed to influence fuel economy, but its influence may be entirely a function of its effect on weight, engine size, and frontal area. Thus, if the latter three variables are included in the implicit function for fuel economy, interior space need not be included. To be sure, numerous other factors affect fuel economy, for example, internal engine friction, but these factors are unimportant to consumer satisfaction.

From the viewpoint of this analysis, reduction of internal engine friction represents a technological improvement. In the discussion that follows, assume that fuel efficiency can be expressed as a function of curb weight, engine displacement divided by curb weight, projected frontal area (width times height), and a measure of luxury accessories.

If each automobile sold in any year was represented by a point in a six-dimensional (weight, power, frontal area, fuel economy, price, luxury) space, the envelope or outer surface of that space would represent the technology frontier—the highest level of fuel economy achievable for a given weight, power, area, and cost, given the input prices and technology of that year. An improvement in technology is then defined as a movement of the frontier toward better fuel efficiency, other things equal.

The data for the analyses that follow come from the "Oak Ridge National Laboratory MPG and Market Share Data System" *(9, 10)*, which contains sales statistics at the nameplate level (e.g., Chevrolet Cavalier) and shares of production by engine and transmission type, together with Environmental Protection Agency (EPA) estimated fuel economies and selected vehicle specifications.

Changes in the technology frontier from 1978 to 1986 are illustrated in two-dimensional plots of each attribute versus efficiency (Figures 2 through 5, prices are list prices in 1985 dollars). Not only has the technology frontier advanced, but points have also shifted relative to the frontier. Whereas in 1978 the best 2,500 lb automobiles achieved 25 mpg (0.04 gal/mi), the best in 1985 were getting 33 mpg (0.03 gal/mi). On the other hand, automobiles weighing more than 4,000 lb were virtually eliminated, which suggests a restriction of choice. In comparison with 1978, automobiles in 1985 are clustered closer to the frontier, suggesting that models have generally moved closer to the state of the art. The technology frontier for projected frontal area shows a similar advance (Figure 3), suggesting significant improvements in aerodynamic design.

Displacement to weight evidences no outward migration of points (Figure 4). There is a tendency for points to cluster closer to the frontier and a pronounced elimination of the highest engine size-to-weight ratios. A more direct measure of power (i.e., horsepower) would have shown different results, but such data were not available in the ORNL data base *(9)*. From 1978 to 1986, average horsepower per liter increased from 28.0 to 40.3 for domestic automobiles and from 46.0 to 56.5 for imports, according to *Automotive Industries* magazine *(11)*. This conclusion is supported by a linear regression of horsepower against engine displacement (cu in.) for domestic versus imported cars for 1978 versus 1985 using specifications published in *Automotive News'* annual edition. Turbocharged and diesel engines were excluded. The results (Table 1) indicate that a typical 150 cubic inch displacement (cid) domestic automobile would have 78.7 hp in 1978 but 100.0 hp in 1985. A 100 cid import would have 76.4 hp in 1978 and 82.0 hp in 1985. Thus no movement of the cid/weight frontier implies considerable improvement in the hp/weight frontier.

These snapshots of the technology frontier indicate advances on all four fronts. There is evidence, however, that the range of choices has been reduced. The heaviest automobiles and largest engine size-to-weight ratios of 1978 have disappeared. It also appears that on all fronts, points have moved closer to the frontier. This should reflect improved efficiency of production; that is, everyone is now closer to the state of the art.

STOCHASTIC FRONTIER COST FUNCTIONS

Although two-dimensional snapshots of the technology frontier are useful for illustration, they are inconclusive and possibly misleading because they fail to account for trade-offs among more than two attributes. What appears to be an advance in the gallons-per-mile versus frontal area frontier could actually be a reflection of the fact that automobiles with the same frontal area were lighter in 1985. To capture such effects, the cost function must be observed in all five dimensions.

Econometric techniques have recently been developed for estimating such technology frontiers by using models in which the error term is a convolution of truncated and untruncated normal distributions *(12)*. Recall that the cost function can be expressed with gallons per mile (gpm) as the dependent variable being a function of other vehicle attributes (a vector Y),

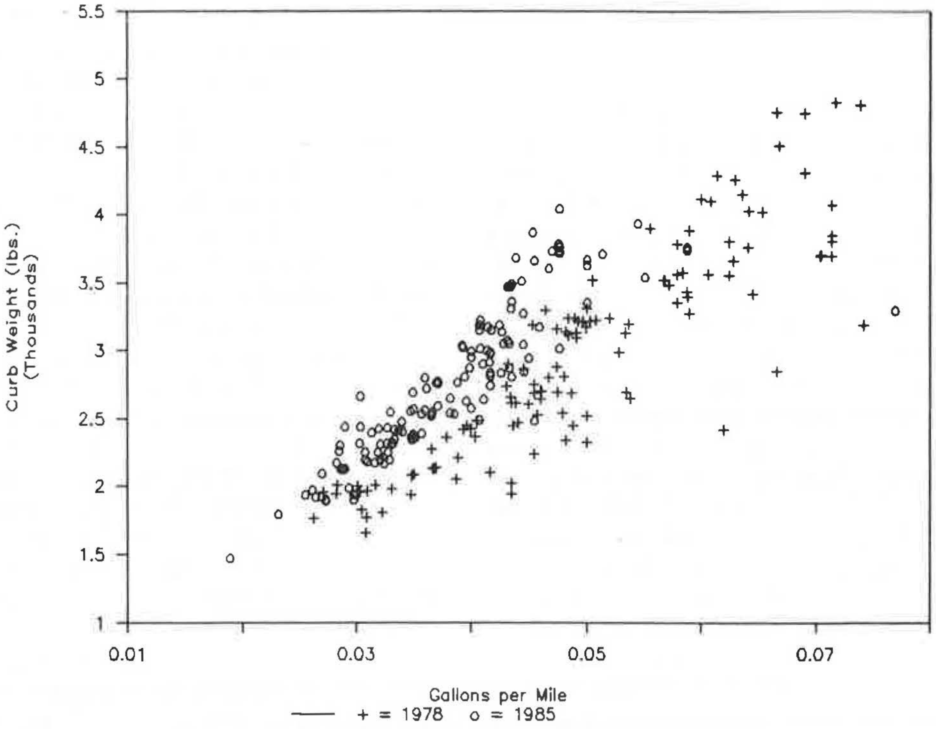

FIGURE 2 Weight versus efficiency, 1978 and 1985 automobiles.

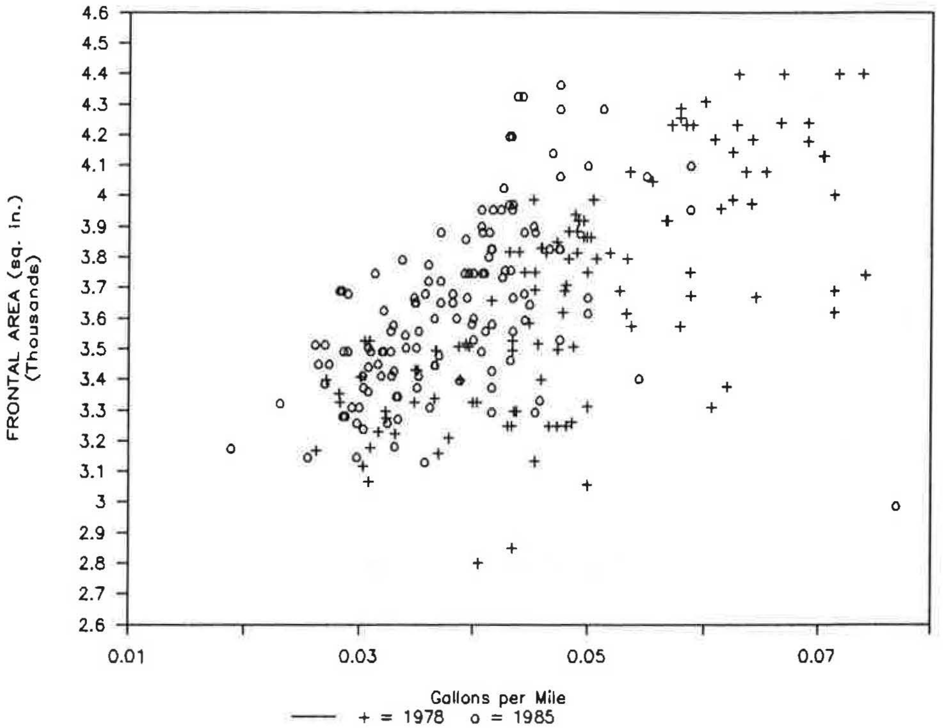

FIGURE 3 Frontal area versus efficiency, 1978 and 1985 automobiles.

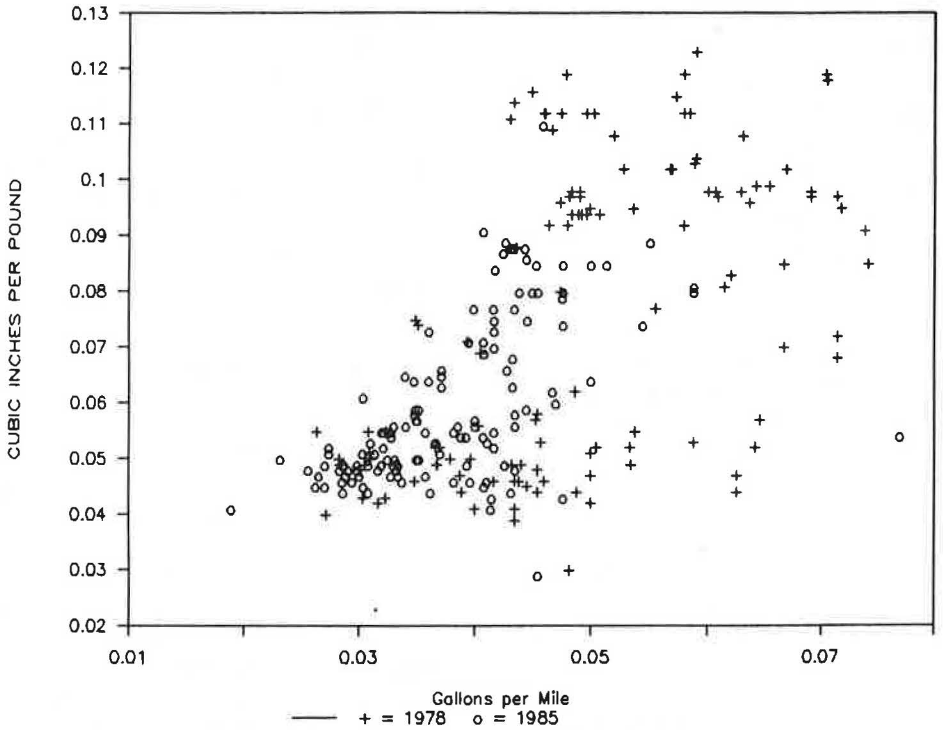

FIGURE 4 Displacement/weight versus efficiency, 1978 and 1985 automobiles.

and a vector of parameters to be estimated, which is indicated by *b*,

$$gpm = f(y, b) + \varepsilon \qquad (5)$$

The usual assumption made in regression analysis is that ε is normal with mean = 0 and variance σ^2. The stochastic frontier model proposed by Aigner et al. *(13)* decomposes ε into two components,

$$\varepsilon = u + v \qquad (6)$$

where *u* has the usual normal distribution and *v* is a half-normal distribution ($v > = 0$).

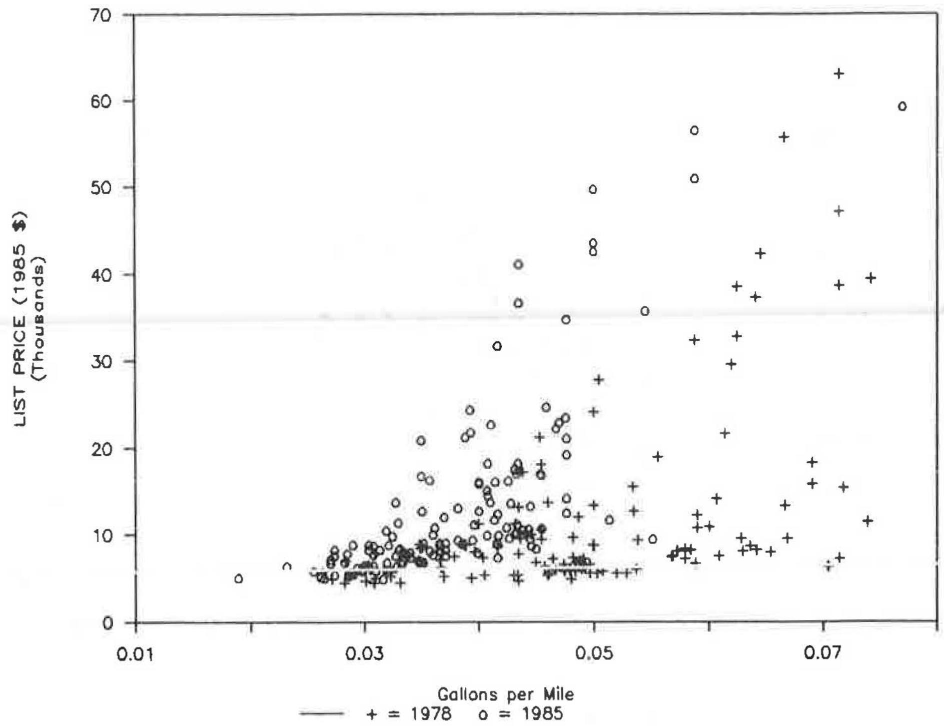

FIGURE 5 List price versus efficiency, 1978 and 1985 automobiles.

TABLE 1 LINEAR REGRESSION OF HORSEPOWER ON DISPLACEMENT

	Intercept	Slope	R^2
Domestic automobiles			
1978	19.52	0.3946	0.89
1985	43.89	0.3741	0.74
Imported automobiles			
1978	7.05	0.6929	0.95
1985	7.41	0.7457	0.91

NOTE: Measured in cubic inches.

The one-sided error term v is interpreted as deviations from the production frontier due to inefficiencies. Because the frontier represents the best technology, all points should lie on or above it (inefficiencies will result in greater than optimal gpm). The u term represents the usual random factors (e.g., measurement error, unobserved variables). Aigner et al. suggest using σ_v/σ_u as a measure of average inefficiency, because it expresses the deviations from the frontier due to inefficiency relative to those due to unobserved factors. The same authors note, however, that the separation of the residual variance into its two components cannot generally be satisfactorily accomplished, even for sample sizes as large as 100. Likewise, the estimates of σ_u and σ_v were found to be very sensitive to a few extreme data points. Gallons-per-mile frontiers were estimated with the 1978 and 1985 data illustrated earlier, using the LIMDEP *(14)* econometric software package. Figures 1–5 suggest that a simple linear frontier function will describe the data adequately. Four variables remained in the final equations, in addition to an intercept: (a) curb weight, in pounds; (b) price, in 1985 dollars; (c) engine size (in cubic inches) to weight ratio, a measure of performance; and (d) price to interior volume (in cubic feet) ratio, a measure of luxury. Frontal area was tested and found to be not statistically significant. The final parameter estimates are given in Table 2.

The pattern of signs on coefficients in Table 2 implies that fuel consumption will increase with increasing weight, power, and luxury. Thus, to obtain lower fuel use, consumers would have to give up some amount of each, if technology is constant. In contrast, fuel consumption decreases with increasing vehicle price; that is, for the same level of weight, power, and luxury, greater efficiency can be bought at a price. The trade-off rates can be computed by taking derivatives of each variable with respect to

$$dX/dmpg = (1/C_x)\,(mpg_t)^{-2} \qquad (7)$$

where C_x is the estimated coefficient for the variable X and mpg is indexed by t to indicate that the trade-off rate is dependent on the level of mpg. Estimated average trade-off rates for 1978 and 1985, using the gpm predicted by the appropriate frontier function at the mean values of right-hand-side variables in the respective year, are given in Table 3. The mpg-weight trade-off rate is about the same in both years: 150 lb/mpg. The luxury trade-off rates are also close: about $35/ft^3 per mpg (1985 dollars). The dollar cost of mpg appears to have gone up considerably, however, $4,867 per mpg in 1985 versus $2,987 in 1978 (again, both are 1985 dollars). The power (engine size-to-weight ratio) cost of mpg appears to have decreased (0.0106 in.^{3}/lb/mpg in 1985 versus 0.0287 in 1978). This result is consistent with the increased level of horsepower available per cubic inch in 1985, as illustrated in Table 1.

The 1985 frontier is considerably lower than that of 1978, reflecting a significant advance in technology. To illustrate, two-dimensional graphs were drawn of the partial relationships between gpm and each variable, holding other variables constant at their 1978 average levels (Figures 6–9). In all cases, the

TABLE 2 STOCHASTIC GPM FRONTIER ESTIMATES

Variable	Coefficient	Std. error	Mean of var.	Elasticity
n=112		1978		
Intercept	1.338 E-04	2.430 E-03	1.0000	
Weight	1.291 E-05	8.212 E-07	3.036 E+03	7.867 E-01
Power	7.094 E-02	2.892 E-02	7.644 E-02	1.088 E-01
Price	-6.824 E-07	1.526 E-07	1.672 E+04	-2.289 E-01
Luxury	5.943 E-05	1.278 E-05	1.985 E+02	2.368 E-01
σ_v/σ_u	1.578 E 00	7.345 E-01		
$\sigma_v^2+\sigma_u^2$	6.863 E-03	1.031 E-03		
n=144		1985		
Intercept	3.217 E-03	2.011 E-03	1.0000	
Weight	8.260 E-06	7.743 E-06	2.794 E+03	4.632 E-01
Power	1.144 E-01	2.173 E-02	5.934 E-02	1.362 E-01
Price	-2.492 E-07	8.323 E-08	1.419 E+04	-7.098 E-02
Luxury	3.132 E-05	5.401 E-06	1.685 E+02	1.059 E-01
σ_v/σ_u	1.545 E-00	5.366 E-01		
$\sigma_v^2+\sigma_u^2$	5.116 E-03	5.179 E-04		

TABLE 3 ESTIMATED TRADE-OFF RATES BETWEEN MPG AND OTHER AUTOMOBILE CHARACTERISTICS

Characteristic	1978 Frontier	1985 Frontier
Weight (lb/mpg)	−157.8	−146.9
Price ($/mpg)	2986.9	4867.4
Power (cid/lb/mpg)	−0.0287	−0.0106
Luxury ($\$/\mathrm{ft}^3/\mathrm{mpg}$)	−34.3	−38.7

1985 partial frontiers lie well below the 1978 partial frontiers. This means that the 1985 vehicles offer better fuel efficiency at the same price, weight, power, and luxury.

Although the frontier has advanced broadly, the slope of the frontier is generally less steep (the power versus gpm curve is the only exception, and the possible effect of the changing horsepower–engine size relationship has been noted previously). This means that while the technology of producing gpm has generally advanced, the ability to trade off vehicle attributes for improved fuel economy has become more difficult. In other words, the constant technology price of efficiency (reduced gpm) is higher in 1985.

These results show a definite improvement in the technology of automotive efficiency. In the following section, the size of this improvement is measured and compared with other attempts to break down automotive mpg gains into technological and other components.

EFFECTS OF SALES SHIFTS AND ENGINEERING CHANGES ON MPG

How do fuel economy improvements since CAFE break down into technological improvements, demand-induced sales shifts, and regulatory restriction of supply? So far, no one has been able to achieve such a breakdown. Attempts have been made to break down mpg changes into various components by means of engineering analysis or the analysis of sales and mpg data. Although these studies do not allow a clear distinction to be drawn between technological advances and regulation-induced restriction of choice, they do provide a substantial amount of information about how mpg improvements have come about, which may contribute to making informed judgments on this point. To these studies can now be added a decomposition into pure technological change (an advance of the frontier) versus all other factors, based on the 1978 and 1985 frontiers estimated earlier. Heavenrich et al. *(15)* grouped the estimated 77.8 percent mpg improvement of passenger automobiles from 1975 to 1985 into four categories: (a) powertrain optimization, (b) transmission type, (c) engine displacement and combustion type, and (d) vehicle weight (Table 4). For domestic and imported vehicles the majority of mpg improvement was allocated to powertrain optimization, which includes changes in engine design and calibration, emission control systems, transmission design details, axle ratio, and optimization with respect to the test procedure. Only domestic automobiles achieved significant mpg improvement by reducing weight. If it can be assumed that consumers are more or less neutral to powertrain optimization changes, then this analysis would allocate two-thirds or more of the 1975–1985 mpg gain to technological change (if costs were equal).

Another source of fuel economy changes broken down by engineering components is NHTSA's sixth annual report to Congress *(16)*. This report, the last by NHTSA to attempt such an analysis, allocates 4.35 mpg of the total 5.3 mpg change for passenger automobiles between 1978 and 1981. More than one-half of the total (2.35 mpg) was allocated to weight reduction, a sharp contrast to Heavenrich et al. estimates for 1975–1985. Aerodynamic drag improvements were allocated 0.37 mpg, lock-up torque converters 0.27 mpg, increased use of diesel engines 0.25, increased manual transmissions 0.14, increased use of five-speed manuals 0.09, and four-speed automatics and reductions in vehicle performance (hp/iw) 0.08 mpg. If weight and performance reductions or manual transmissions (diesels might arguably be omitted) are not counted, this leaves about 40 percent for technology improvements.

A method of decomposing year-to-year changes in mpg into sales shift and engineering design components was developed by Greene et al. *(17)*. By using sales figures and EPA combined

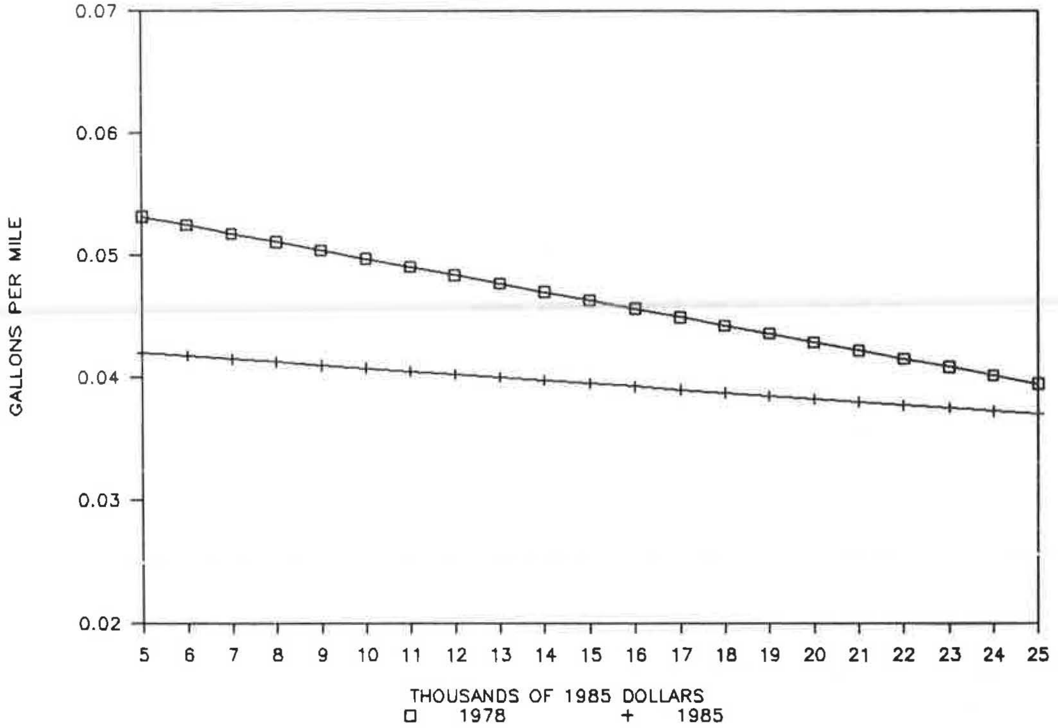

FIGURE 6 **Price versus efficiency frontiers, 1978 and 1985 automobiles.**

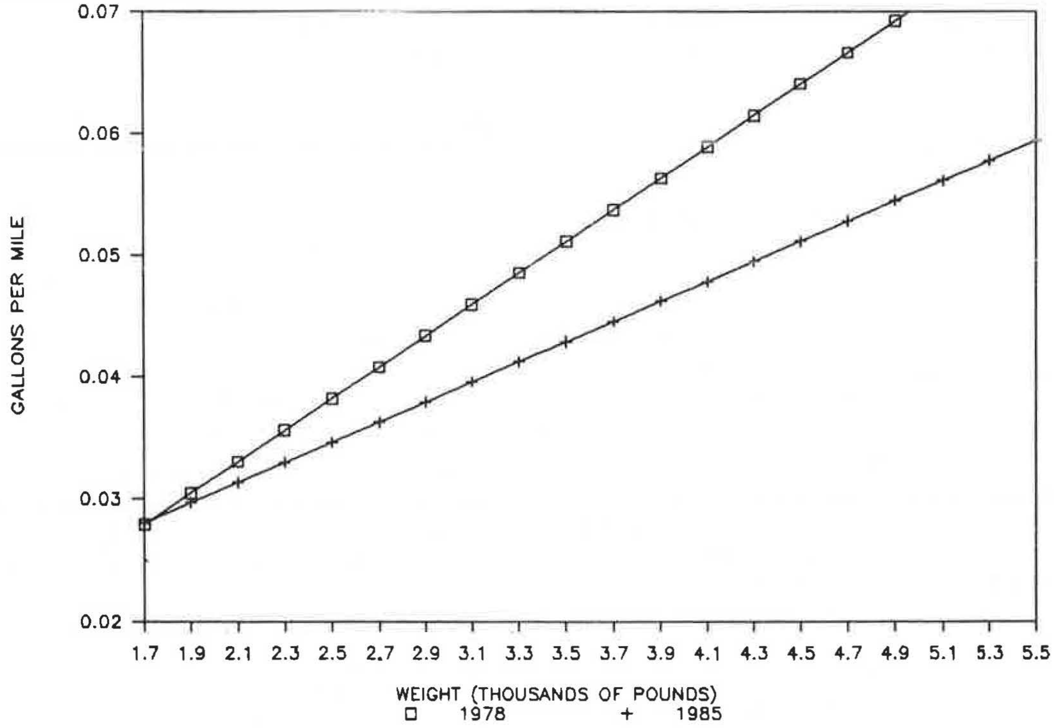

FIGURE 7 **Weight versus efficiency frontiers, 1978 and 1985 automobiles.**

city-highway fuel economy estimates, the method breaks out mpg changes into the following components:

1. Size class sales shifts,
2. Nameplate sales shifts,
3. Configuration sales shifts,
4. Continued configuration mpg improvements,
5. Nameplate introductions,
6. Configuration introductions,
7. Nameplate discontinuations, and
8. Configuration discontinuations.

The first three components capture sales shifts among makes, models, and configurations present in successive years.

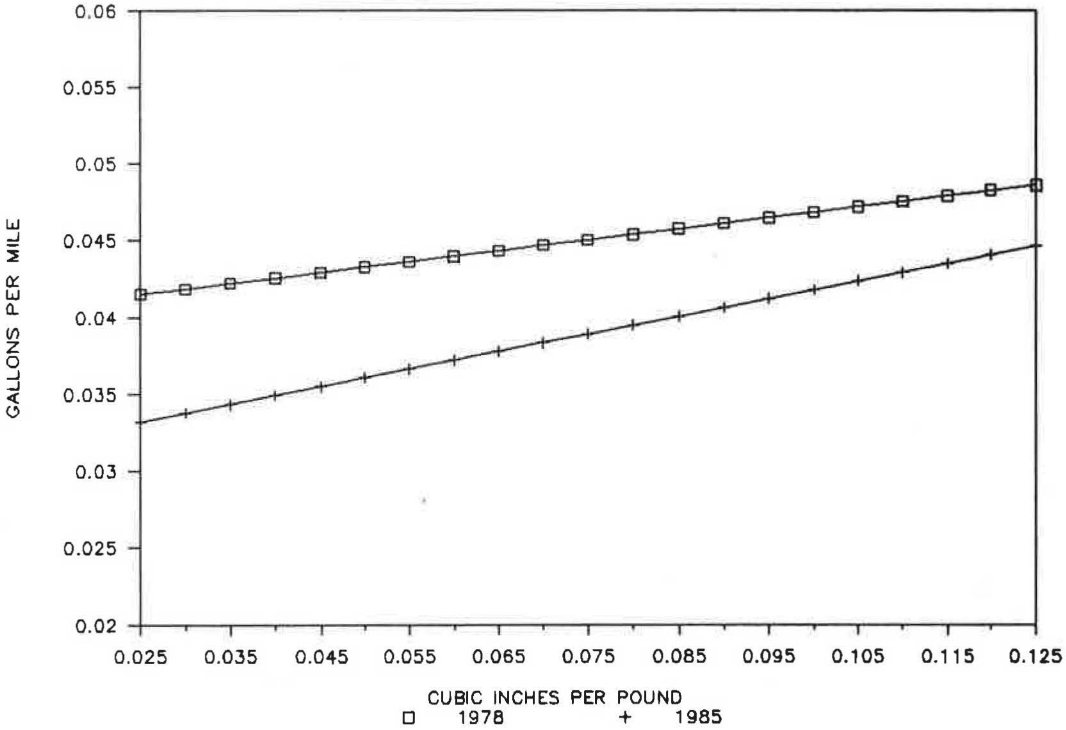

FIGURE 8 Engine displacement/weight versus gpm, 1978 versus 1985 automobiles.

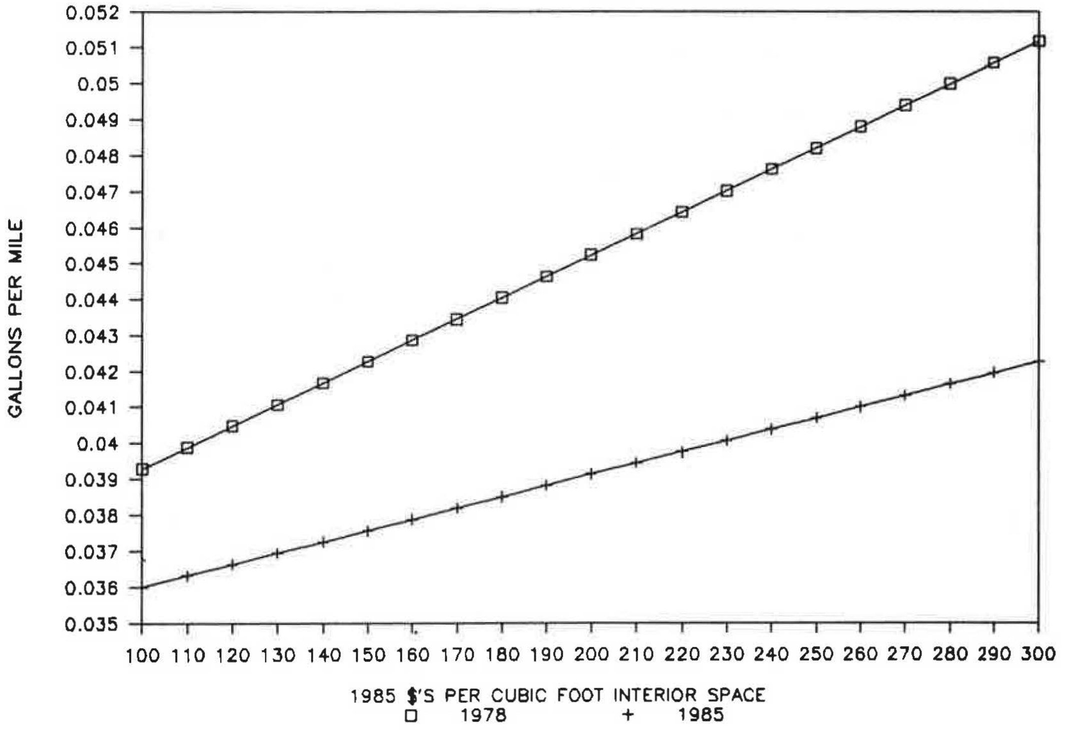

FIGURE 9 Luxury versus efficiency frontier, 1978 and 1985 automobiles.

Component 4 represents engineering and design changes that improve the efficiency of nameplate-engine-transmission combinations offered for sale in both years. If new nameplates or configurations are more efficient than the average for their class the previous year, this will show up as an introduction improvement (5 or 6). Discontinuation improvements are similarly defined.

The components of mpg changes from 1978 to the first 6 months of model year 1986 are given in Table 5. These calculations put to rest the popular notion that fuel-efficiency improvements have been achieved largely by consumers buying smaller automobiles, at least in terms of interior volume. Size class sales shifts account for 0.94 mpg over the 8-year period, only 11 percent of the total 8.35 mpg improvement. All sales shifts

TABLE 4 ALLOCATION OF MPG CHANGES FOR PASSENGER CARS, 1975–1985 (percent)

Mfg	1975 mpg	Power-Train	Trans-mission	Engine	Weight	1985 mpg
Domestic	14.7	41.8	–0.0	–0.5	26.1	26.2
European	23.0	24.8	–0.3	–1.8	–3.9	27.6
Japanese	23.5	39.7	–1.8	2.7	–2.4	32.3

TABLE 6 ANALYSIS OF 1978–1985 MPG IMPROVEMENT INTO TECHNOLOGICAL CHANGE AND CHANGES IN AUTOMOBILE CHARACTERISTICS

Frontier Function	Automobile Characteristics (year) 1978	1985
Gallons per Mile		
1978	0.0474	0.0399
1985	0.0412	0.0342
Miles per Gallon		
1978	21.0853	25.0645
1985	24.2641	29.2745

account for about 35 percent of the gain, while all engineering and design changes account for 65 percent.

The contribution of sales shifts is significant because if the engineering changes manufacturers were offering to consumers were considered less desirable, the effect of sales shifts would be expected to be negative, away from the more efficient nameplates and configurations and toward the less efficient (perhaps more powerful and heavier) ones. Consumer demand shifts in favor of higher fuel efficiency at the same time that improved fuel economy technology is introduced (movement from point A to B in Figure 1) are consistent with the assertion that consumer demand has shifted in favor of greater efficiency at the same time that technology has advanced.

The 1978 and 1985 technology frontiers provide a means of separating the effects on mpg of changed vehicle attributes (whether because of sales shifts or design changes) versus pure technological improvement (Table 6). This is done by making four mpg predictions with all four combinations of the 1978 and 1985 frontiers and the 1978 and 1985 average automobile characteristics (the averages used here, unlike those discussed previously, are sales-weighted averages of all automobiles in the respective years). For example, the average 1978 automobile has a predicted fuel economy of 0.0474 gpm or 21.1 mpg when the 1978 frontier function is used (recall that the frontier is the best technology and that nearly all automobiles will not do that well). An automobile with the same attributes produced in 1985 would have a fuel efficiency of 0.0412 or 24.3 mpg, according to the 1985 frontier function. Similarly, an automobile with average 1985 attributes produced in 1978 would have a predicted efficiency of 25.1 mpg, but if produced in 1985 would have a predicted efficiency of 29.3 mpg. The predicted 8.2 mpg increase from 1978 to 1985 can be divided between the advance of the frontier and changed vehicle attributes in two ways: (a) by predicting the effect of changed attributes and then the effect of the new frontier function or (b) by predicting the effect of the frontier function and then that of changed attributes. The first method allocates 49 percent of the mpg gain to the frontier's advance; the second allocates 39 percent.

CONCLUSIONS

There is considerable evidence that the goal of increasing automotive fuel efficiency by means of technological improvements was substantially achieved. It appears that the fuel efficiency technology frontier has advanced on all fronts and that this advance accounts for up to one-half of the total mpg gain. At the same time, however, the range of attribute bundles offered to consumers has been reduced by elimination of the heaviest and most powerful automobile choices. It is also clear that increased consumer demand for fuel economy played an important role. Consumers have not only accepted the improvements offered by manufacturers but have gone further, opting for still more efficient engine-drive-train configurations, nameplates, and size classes.

TABLE 5 ANALYSIS OF AUTOMOBILE MPG CHANGES BETWEEN CONSECUTIVE MODEL YEARS 1978–1986

		Difference in mpg Due to:										
		Sales Shift		Configuration Information								
Beginning Model Year	Beginning mpg[a]	Between Classes	Within Classes	Efficiency Improvement	Sales Shift	Introduction	Discontinuation	Model Introduction	Model Discontinuation	Total Change in mpg	Ending mpg[b]	Ending Model Year
1978	19.73	0.37	0.24	–0.13	0.14	–0.03	–0.01	0.17	0.03	0.79	20.52	1979
1979	20.52	0.44	0.59	0.89	0.25	0.30	0.03	0.10	0.12	2.72	23.24	1980
1980	23.24	–0.18	0.36	1.04	0.04	0.08	0.01	0.59	0.08	2.03	25.27	1981
1981	25.27	0.14	–0.19	0.63	–0.04	0.38	0.02	0.07	0.05	1.06	26.33	1982
1982	26.33	–0.08	–0.10	–0.07	–0.13	–	0.08	0.12	–0.05	–0.22	26.11	1983
1983	26.11	–0.13	0.13	–0.14	0.13	–0.01	0.11	–0.02	0.15	0.23	26.33	1984
1984	26.33	0.23	–0.16	0.02	0.04	0.38	0.08	0.11	–0.06	0.64	26.98	1985
1985	26.93	0.15	0.40	0.21	0.28	0.09	0.03	–0.01	–	1.15	28.08	1986[c]
Total		0.94	1.27	2.45	0.71	1.19	0.32	1.13	0.33	8.35		

[a] Fuel economy of the beginning model year.
[b] Fuel economy of the ending model year.
[c] 1986 data are for the first six months of the model year.

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The Roadway-Powered Electric Transit Vehicle—Progress and Prospects

STEVEN E. SHLADOVER

In this paper, progress in the development of the roadway powered electric vehicle (RPEV) technology for use on a transit bus is reviewed, and the possible future applications of this technology are explored. The paper focuses on the Santa Barbara Electric Bus project, for which this development work was conducted. The various phases of this project are reviewed, and the baseline roadway powered electric vehicle system for Santa Barbara is described. Its costs are compared with those for more conventional bus technologies. The implications of the progress made in the Santa Barbara project for the future of roadway powered electric vehicle technology are explored, leading to an evolutionary step toward highway automation.

The roadway powered electric vehicle (RPEV) system is an electric-electric hybrid vehicle system that uses a fairly standard battery-electric powertrain to handle the full dynamic range of an urban driving cycle and that receives its energy supply at a relatively steady rate from a special electromagnetic inductive coupling system. The overall design of the RPEV system is described by Lechner and Shladover *(1)*, while the inductive coupling system is explained by Lashkari et al. *(2)*.

RPEV technology has advanced from its initial laboratory implementation to the prototype development and testing stage on a transit bus. At this point, the RPEV system represents one of the most promising developments in the long path leading to a practical electric automobile. The electric automobile has not yet become practical because of the limitations of the available storage batteries, particularly their limited energy density. This means that electric automobiles are heavier and less powerful and have much less operating range than their conventional counterparts. The RPEV system overcomes these limitations by providing a semicontinuous charging current to the vehicle's battery whether the vehicle is moving or parked. In this way, the vehicle can operate with virtually unlimited range on a relatively moderate-sized battery. It can operate for significant periods of time on the energy stored in its battery, so that its operations are not restricted to the powered roadway.

The RPEV system includes vehicles and fixed facilities in the roadway and alongside the road, as shown in Figure 1. Each vehicle is propelled by a separately excited DC motor that draws current from a lead-acid battery by means of a transistorized motor control system. In addition to the battery-electric powertrain, the vehicle also contains a pickup inductor to interact with the magnetic field produced by the roadway inductor and a custom-designed onboard circuit to control and condition the output of the pickup inductor so that it can be used to charge the battery. The onboard control circuit provides rectification, ripple filtering, and computer-controlled power factor correction from a switchable capacitor bank. The roadway inductor, like the pickup inductor, is composed of laminations of grain-oriented silicon steel, for high magnetic permeability and low losses, and large-gauge cables to carry electric current. The roadway inductor is energized by a solid-state power conditioner, a rectifier-inverter system that converts the standard 60-Hz mains power to 400 Hz and isolates the roadway power system from the local electric utility. For the electric bus system described in this paper, the roadway inductor is about 37 in. wide and 4 in. deep, and is buried immediately below the road surface coating. Its cables carry about 1,000 amps at 400 Hz, and the system is capable of transferring 67 kW of power across an air gap of 3 in. to the pickup inductor on the vehicle, at an efficiency of about 95

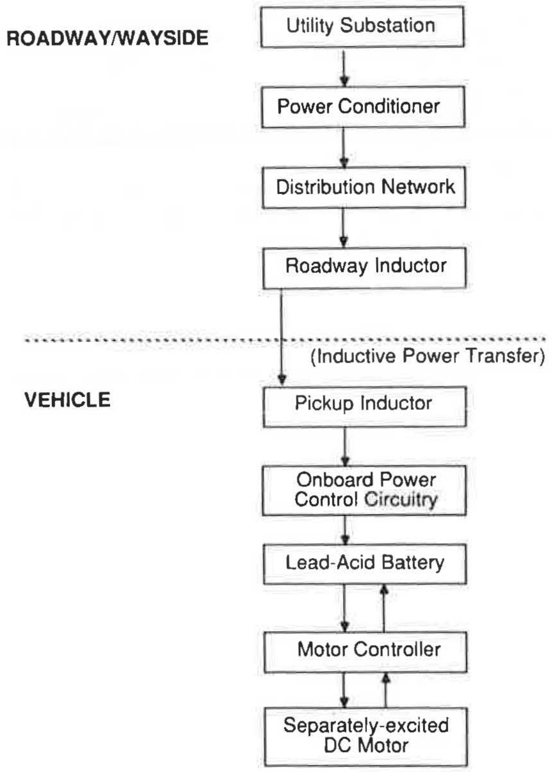

FIGURE 1 Power flow through RPEV system elements.

Systems Control Technology, Inc., 2300 Geng Rd., Palo Alto, Calif. 94303.

percent. The 3-in. air gap height is maintained to within acceptable tolerances by simply suspending the pickup inductor beneath the vehicle, without any special provisions for controlling the gap height. The cross sections of the roadway and pickup inductors are shown in Figure 2.

By providing the electric vehicle with practical daily range, the RPEV technology makes it possible to enjoy the inherent advantages of electric propulsion with respect to internal combustion engines (ICEs). These advantages include greatly reduced noise and mobile-source pollution for use in sensitive locations, such as enclosed areas, pedestrian malls, parks, and historic districts. In the longer term, the electric power train is much more amenable than the ICE to the tight closed-loop spacing control that will be needed to effect highway automation.

An overview of the development of the RPEV technology for an urban transit bus system in Santa Barbara, California, is presented. The technological features of this system have been described elsewhere, in the references cited throughout this paper. The emphasis here is on explaining the background of the development work, its current status, and the steps remaining to full-scale implementation. The economics of the system at its present early stage of development are described, with comparisons to competing standard technologies, and the prospects for future development and application of the RPEV system are then explored.

THE SANTA BARBARA ELECTRIC BUS PROJECT

The development activities reported here were performed as part of the Santa Barbara Electric Bus Project, sponsored by the Santa Barbara Metropolitan Transit District (SBMTD), with funding from the Urban Mass Transportation Administration (UMTA), the California Department of Transportation (Caltrans), and the city of Santa Barbara. The history of this project from its inception through the present, and then its future anticipated completion, are reviewed in the next section, followed by a description of the baseline system design and a status report on the accomplishments to date.

History of Santa Barbara Electric Bus Project

The concept of inductive transfer of electric power to a vehicle is not new but was the subject of patents dating back to the turn of the century. The modern incarnation of this technology began at the Lawrence Berkeley Laboratory and the Lawrence Livermore National Laboratory (LLNL), under the primary sponsorship of the Department of Energy, during the period 1976 to 1982. That work was effectively reported at the 1982 TRB meeting by Carl Walter of LLNL *(3)*. Little was accomplished on the project subsequently because of funding limitations.

While the LLNL work was in progress, the city of Santa Barbara was developing plans for a new downtown circulation bus service, focused on the State Street Mall. At this location, urban redevelopment activity had created an attractive pedestrian-oriented environment, with fountains and carefully coordinated street furniture enhancing the atmosphere for shoppers and tourists. State Street was reduced to a single lane in each direction, with additional right-turn pockets, for the approximately 1-mi length of the mall, but vehicular traffic was not otherwise restricted. The environmental sensitivity of the citizens of Santa Barbara ruled against the use of either diesel buses or trolley buses along the Mall, the former because of their noise and smell and the latter because of the unsightliness of their overhead wires. Battery electric buses were not a reasonable alternative because of their severely limited range, so the developing RPEV technology appeared to be a promising alternative.

A feasibility study of the use of the RPEV technology for the bus service in downtown Santa Barbara was conducted for SBMTD, with funding from Caltrans, in 1979 and 1980. This study, which has since been referred to as Phase 1 of the Santa Barbara Electric Bus Project, included planning, some computer simulations to predict system performance, an overview of the technological and environmental issues surrounding the RPEV technology, and an outline of the subsequent phases needed to bring the complete project to fruition *(4)*.

Phase 2 of the project, involving detailed planning and preliminary engineering work, was funded by Caltrans and the

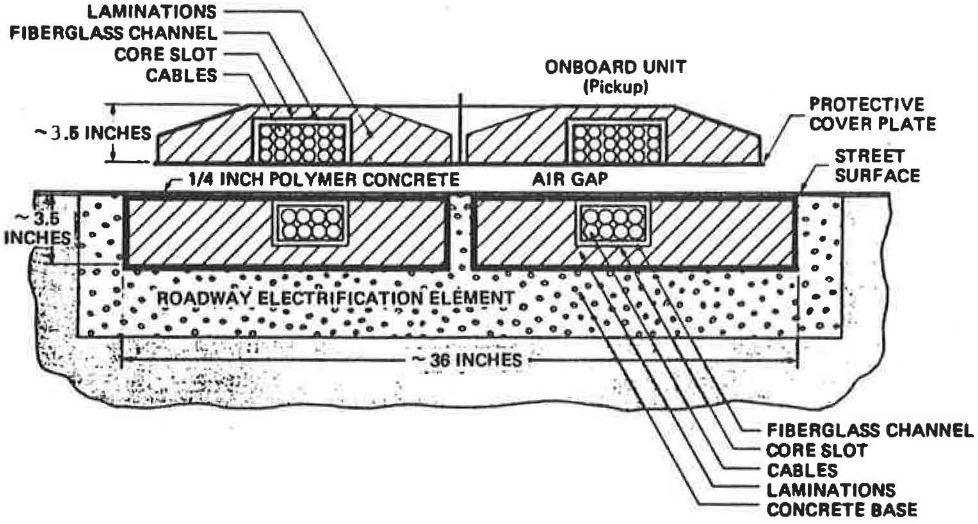

FIGURE 2 Schematic diagram of roadway and pickup inductors.

city of Santa Barbara. This work, conducted between July 1981 and June 1982, led to more detailed and quantitative analysis of RPEV service on specific bus routes in downtown Santa Barbara, with the benefit of specific design and engineering information about the prototype vehicle and inductive coupling system. The basic vehicle and route service characteristics assumed today were originally developed during Phase 2 and can be found in the Phase 2 final report *(5)*. During this time, the much more complicated Phase 3 work plans and institutional arrangements were also under development.

Phase 3 of the project was divided into two parallel programs, distinguished from each other by their funding sources but closely coordinated technically. The Prototype Development and Test Program of Phase 3 was funded by UMTA and the Santa Barbara Redevelopment Agency, while the Test Facilities Development and Testing Program was funded by Caltrans. Although the latter program was performed under a single long-term contract, it was necessary to split the former program into four separate increments, corresponding to the four federal fiscal years of funding to be supplied by UMTA. These four increments, known as Phases 3A, 3B, 3C, and 3D, corresponded to the federal fiscal years 1982, 1983, 1984, and 1985, respectively.

Phase 3A, conducted between September 1982 and February 1983, began the detailed analysis and design of all of the RPEV system equipment. Mathematical models were developed of the inductive coupling system and of the performance of the complete vehicle system as well, and capital and operating cost comparisons were made with other transit bus technologies. The design and specifications for the prototype electric bus were developed, and concentrated study of the available storage battery technologies was undertaken. The systematic tradeoffs among the many different attributes that influence performance of the entire system were begun and were reported at considerable length in the Phase 3A final report *(6)*.

A lengthy funding hiatus ensued before Phase 3B could be initiated in August 1983. During this phase, the prototype vehicle was built, the onboard control system to regulate the power supplied to the battery was designed and its hardware acquired, batteries were tested, and an environmental assessment of the system was prepared. The analyses and predictions of system and subsystem performance were continued with ever greater precision and sophistication, to ensure that the RPEV technology would satisfy the system requirements. This work, which was conducted in parallel with the Caltrans-funded program until August 1984, was reported in detail in the Phase 3B final report *(7)*.

The Caltrans-funded Test Facilities Development and Testing Program began concurrently with Phase 3B in August 1983 and continued to the end of June 1985. This program encompassed the development of the inductive coupling technology, from initial design to comprehensive laboratory testing. Computer models were used to analyze the magnetic fields in and about the roadway and pickup inductors, and these analyses provided vital input to the designs and specifications for construction of these inductors. The inductors were built at full scale, and a laboratory facility was designed and constructed to house a roadway section about 20 ft long, as well as a complete inductive pickup of a size suitable for powering the prototype electric bus (13 ft long). A power conditioner was specified, fabricated, and installed at the facility, and about 5 months of intensive testing were performed to prove the performance of the inductive coupling system under a wide range of conditions. The results of this work were reported at great length in the Static Test Report *(8)*.

Phase 3C of the project was conducted between August 1984 and April 1986. This phase focused on testing and refinement of the technology developed in the earlier phases. The prototype electric bus was tested under battery power on the baseline route in Santa Barbara, and the test results were used to confirm the prior predictions of its performance. The full-scale inductive power transfer system was tested extensively in the laboratory in Sacramento, with the on-vehicle electric circuitry, including the complete battery system, connected to it. Successful operation of the system was demonstrated, with the battery being charged by the inductive coupling system, under the control of the microcomputer system that will be used on the vehicle. The results of this phase of the project have already been reported *(9)*.

Completion of the RPEV technology development for the Santa Barbara Electric Bus System will require work planned for Phase 3D of the Prototype Development and Test Program and the parallel development of a long test facility (of about 500 ft) on which the prototype vehicle can be operated at speed, while collecting power from a roadway inductor. The existing short test facility developed by Systems Control Technology, Inc., at the Caltrans Transportation Laboratory (Translab) in Sacramento has been used for extensive testing already, but that facility does not have the length needed for testing power collection while the vehicle is in motion. Once these technology development activities are complete and the funding and sponsoring agencies have found the results to be satisfactory, it will be possible to proceed into Phase 4, Construction, and then Phase 5, Demonstration Operation of the complete system.

The Baseline Santa Barbara Electric Bus System

The Santa Barbara Electric Bus System was selected as the initial demonstration site for the RPEV technology for a variety of reasons. Much of the discussion in this paper is therefore focused on the Santa Barbara application. However, this site is just the initial demonstration site, and it does not represent the full potential of the RPEV technology. The baseline system was designed to meet the specific requirements of this application, not to show the full range of what could be done by the RPEV. It is necessary to demonstrate the RPEV on this limited scale, in a relatively benign environment, as a first step before addressing broader applications of the RPEV. Of course, each different application would have somewhat different requirements and a somewhat different optimum system design.

Santa Barbara proved to be a promising demonstration site because of the limited scale of the bus service that was contemplated, the environmental concerns of its citizens, its mild climate, and the open-mindedness of its public officials. In this setting, the RPEV development could be nurtured before the rigors of northern winters, desert summers, large-scale and high-visibility transit operations, or big-city politics were dealt with.

The baseline bus service application is a 5.5-mi round-trip downtown circulation system in Santa Barbara, along the route shown in Figure 3. Only 40 percent of this route, primarily the part along the State Street Mall, needs to be equipped with the roadway inductor. For the remainder of the route, the vehicle operates as a battery bus, using only the energy stored in its battery. The route is essentially flat along the beachfront on Cabrillo Boulevard, with the grade gradually increasing to about 3 percent on the last uphill block on State Street. Tourists are expected to represent a significant portion of the ridership, which is the reason that the route extends along the waterfront to several hotels and a convention center that is under construction in the vicinity of Punta Gorda Street and Cabrillo Boulevard.

Bus service is to be provided at 5-min headways for 10 hr per day. Frequent stops are anticipated along State Street with its many shops and restaurants, making the vehicle's duty cycle particularly rigorous and limiting the effective average vehicle speed. A complete round trip is expected to require 40 min, including layovers at both ends of the route, so it will be necessary to have eight buses in service continually to maintain the desired 5-min headway. This short headway is needed to make the service sufficiently convenient and attractive to the shoppers and tourists that they will all park their cars in one place and use the bus system for their movements within the shopping district.

The prototype electric bus, shown in Figure 4, is a mid-sized vehicle 28 ft long, with room for 17 seated passengers and 18 standees. Its floor is less than 15 in. above the street level (less than half the height of the floor on a conventional bus) to promote ease of access by elderly and handicapped riders. The low floor and medium length of the bus help it to maintain a low-profile appearance so that it will not be intrusive on the State Street Mall. The vehicle's curb weight is 25,400 lb, and maximum gross vehicle weight is 31,200 lb. These weights include about 6,000 lb of lead-acid batteries and 2,200 lb for the inductive power transfer system (together representing 32 percent of the curb weight and 26 percent of the gross vehicle weight). A conservative battery selection was made for the prototype vehicle to minimize technical risks in the development program. The tubular lead-acid industrial battery used here has a specific energy of only 23.5 W-h/kg, which means that battery weight could be halved by the use of more advanced batteries that are now in demonstration use on some

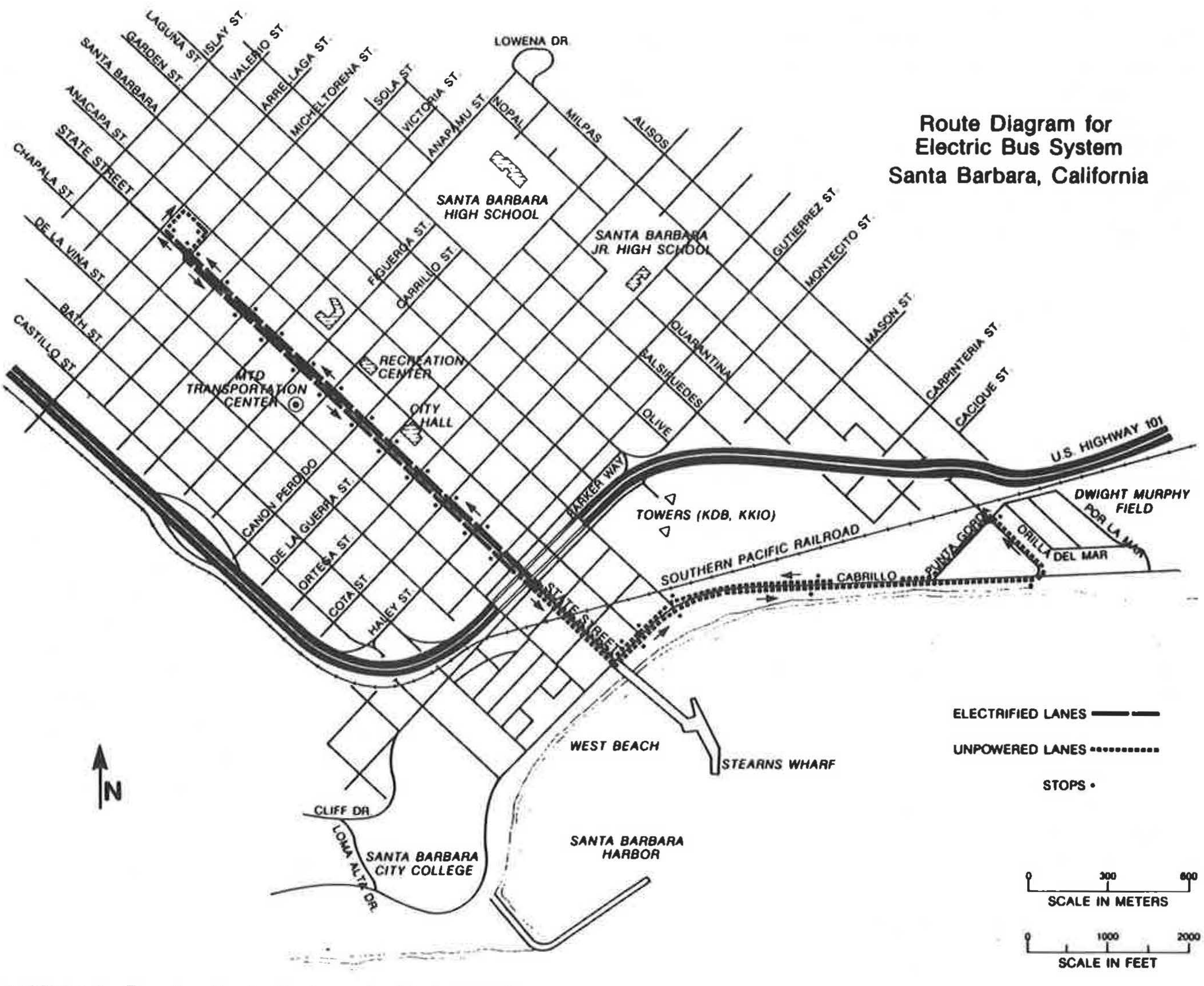

FIGURE 3 Baseline Santa Barbara electric bus route.

FIGURE 4 Prototype Santa Barbara electric bus.

electric vehicles. Expected future improvements in battery technology should further reduce battery weight and improve performance of the RPEV system, which will continue to require less onboard battery capacity than a battery-only vehicle system.

The prototype vehicle is a high-quality, heavy-duty vehicle and not a minibus. Its heavy-duty design and special low floor configuration contribute significantly to its cost and weight, independently of the use of RPEV technology. A diesel-powered version of this vehicle would have a curb weight of about 19,000 lb and would cost about $150,000.

The RPEV system has been designed assuming a top vehicle speed of 20 mph in the stop-and-go operations on the State Street Mall and 30 mph on Cabrillo Boulevard, although the vehicle has been driven at speeds up to 35 to 40 mph (the speed limit) during testing along Cabrillo. As already mentioned, approximately 40 percent of the bus route is to be supplied with the roadway inductor, representing the layover points and the State Street Mall, where the speeds are lowest. For the remainder of the route, the bus will operate entirely off the stored energy in its battery. When it is driving along the powered roadway, the vehicle's onboard control system will draw as much power from the roadway as its battery can accept. This means that some of the driving time will represent net battery charging (cruising downhill, for example) while some of the driving time will represent net discharging (accelerating uphill). The system has been designed so that the vehicle's battery will not be discharged by more than 80 percent of its capacity after 10 hr of operation, including all of the alternate charging and discharging it will experience as it traverses the route. Extensive computer simulations, validated by data from testing of the prototype vehicle and the inductive coupling system, have shown how the battery state of charge will decline gradually in the course of a 10-hr operating day (Figure 5). Without the inductive coupling system for recharging the battery, it would be depleted within little more than 2 hr of operation on the baseline route.

Present Status of Development Work

Most of the technology development work on the RPEV system for the Santa Barbara Electric Bus has been completed. The history of this work was covered in a previous section, while its present status is reviewed here.

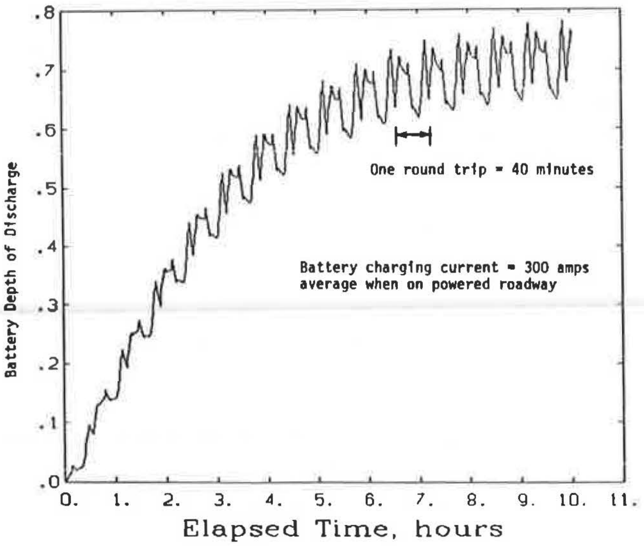

FIGURE 5 Simulation of battery depth of discharge for a full day of bus operation.

The prototype electric bus has been designed, built, and tested under battery power. It has been driven around the baseline route while measurements were made of its speed, steering accuracy, road surface clearance, and energy consumption (battery voltage and current). These measurements have been used to refine the computer models that were used to design the entire system, and the models have continued to predict that the system will perform as desired.

The inductive power transfer system was designed from scratch, using computer models based on electromagnetic theory and electric circuit design principles. The results from the computer modeling formed the basis for specifications for the full-scale hardware, which was then built and tested. The roadway and pickup inductors, in particular, were of such a unique design that special methods were developed to fabricate them. The testing of the inductive power transfer system confirmed its ability to deliver the required power with acceptable efficiency and no adverse environmental impacts. The test results were extremely close to the original design predictions, so that the design models needed only minor adjustments.

The separate testing of the prototype vehicle and the inductive power transfer system has greatly increased confidence that the entire RPEV system will meet its performance goals. Some of these test results were reported by Lechner and Shladover *(1)* and Lashkari et al. *(2)*; complete results can also be found elsewhere *(7–9)*. Virtually all the known areas of technical risk have been investigated, and the risks have been found to be minimal in terms of potential environmental impacts of the magnetic fields, power transfer efficiency, safety, component sizes and weights, tolerance to off-nominal conditions, ability to control power output, and so forth.

It is still necessary to test the power transfer system installed on the vehicle, coupling power while the vehicle is driving. This cannot be accomplished until a test facility longer than the present 20-ft-long facility is available. The longer test facility will also be used to develop the electric power distribution system that connects the entire system of roadway inductors to the power supply. It is expected that the development of the long test facility (500 ft of electrified roadway to represent one full block in downtown Santa Barbara) and the comprehensive testing using that facility will require 2 years more of work. Once that is completed to the satisfaction of all the agencies involved, the detail design of the final system can be specified and construction of the roadway electrification system and the fleet of buses can begin.

ECONOMICS OF RPEV BUS SYSTEM

The RPEV system for Santa Barbara has been designed as a demonstration system to prove the feasibility and applicability of the RPEV technology for use on public vehicles. It was deliberately chosen as a limited-scale system to minimize the risk of introducing this new technology. This factor must be kept in mind when evaluating the economics of the system, because the RPEV technology really needs to be applied on a larger scale to show cost advantages. It is a more capital-intensive technology than the diesel bus, for example, and it cannot be shown to have lower costs than the diesel today. Its substantial benefits can only be realized in a larger-scale system, with a higher density of vehicle usage. Thus, although the demonstration system may appear to be more costly than competing modes, that cost disadvantage should not be present in the longer term when there is an opportunity to apply the RPEV technology on a larger scale, with the roadway costs distributed across a larger vehicle fleet.

Capital Cost of Baseline Santa Barbara System

The capital cost components for the baseline system are primarily the vehicles, the roadway inductor, and the power supply system.

The basic electric bus, in a configuration such as that shown in Figure 4, will cost about $200,000 each for a fleet of 10. This price is more expensive than that of a standard diesel bus because of the unusual low-floor design and the limited production of the electric powertrain components. The inductive power transfer system (inductive pickup and onboard power control system) adds another $45,000 to the cost, based on the costs of the first prototype units. These costs for the inductive coupling equipment are conservative because they include no allowance for production economies or economies of scale. Adding a 10 percent contingency factor to the combined vehicle costs to cover reasonable uncertainties brings the total to $269,500 per vehicle. A fleet of 10 vehicles should be needed, allowing 8 to operate the baseline route at 5-min headways, plus two spares. The capital cost for the entire vehicle fleet should therefore be $2.695 million.

The roadway electrification unit costs have been estimated on a per-foot basis and then multiplied by the length of roadway inductor needed to obtain the total cost. If the experience of constructing the first roadway unit for testing plus discussions with manufacturers about economical means of constructing large quantities of roadway inductors are used as a basis, the materials cost is estimated to be $200/lane-ft, of which three-fourths is for the steel inductor cores. An installation cost of $38 and a 10 percent contingency factor of $24 are added to produce an overall estimate of $262/lane-ft. The total length of the powered blocks on the baseline route is 11,530 ft. However, this length must be adjusted by adding the lengths of the static charging units at the bus stops and subtracting the lengths of the intersections and pedestrian crossings where the inductor would not be installed. After these adjustments, the inductor length is 10,180 ft, which should cost $2.668 million to install.

The fixed wayside facilities other than the roadway unit include the vehicle maintenance and storage facility, the power supply and distribution network, and the battery chargers for overnight recharging. The maintenance facility is expected to cost $150,000, the battery chargers $28,000, and the power supply and distribution system $478,000. Adding these to the roadway inductor cost leads to a total facility cost of $3.296 million. When the cost of the 10-vehicle fleet is added, the system capital cost is about $6 million.

Annual Operating Cost for Baseline Santa Barbara System

The system operating costs are based on the assumed use of eight buses for 10 hr per day, 365 days per year, providing service at 5-min headways. The annual vehicle operating hours will total 29,200, during which the vehicles will travel about 239,000 revenue miles at an average speed of 8.18 mph. This low average speed is characteristic of downtown circulation and distribution systems.

The largest single operating cost component is driver labor, which at an assumed rate of $15/hr totals $438,000/year. This cost component is mode-independent and would therefore be the same regardless of whether the service were provided by a diesel or trolley bus. Maintenance costs are more difficult to estimate for a system that has yet to see any revenue service experience. The estimates have been subdivided into power supply system maintenance and vehicle maintenance. The power supply system is expected to cost only about $6,000/year to maintain, on the basis of the maintenance needs for similar power systems operating around the clock in foundries. The vehicle drivetrain and power transfer system maintenance is expected to require the use of a dedicated specialist in electric vehicle technology because the requisite skills are not typically found in a transit operating agency. On the other hand, much of the normal bus maintenance burden associated with diesel engines and transmissions can be avoided, producing a compensating saving. When these factors are considered, the estimated annual maintenance cost for the vehicle fleet is about $103,000. A special additional maintenance item that must be considered with the RPEV system is battery replacement, because the traction batteries have only a limited life. Each battery costs about $12,000 and is estimated to last for 1,000 deep discharge cycles, corresponding to 1,000 days of operation. This translates into an annual system cost for battery replacement of about $35,000. If the battery life is found to be significantly different from the 1,000 cycles assumed here, this cost factor would be expected to scale accordingly.

The energy cost for the RPEV system includes several different components, the peak power (demand) charge, the energy cost for the roadway power, and the energy cost for overnight battery recharging. The peak power demand for the baseline system is estimated to be 334 kW, which should incur a demand charge of about $15,000/year. The computer simulations of vehicle performance predict an average power draw from the roadway of 20.1 kW/vehicle throughout the day. If a system efficiency of 75 percent and 29,200 vehicle-hr of operation per year are assumed, the cost for the roadway energy will be about $46,600 at the prevailing utility rate of about 6¢/kWh. The energy cost for overnight recharging is estimated to be another $16,000/year. The sum of all of these energy costs is about $77,600/year, which translates into 32.5¢ per vehicle mile (3.8 kwh/mi energy consumption, reflecting the strenuous duty cycle with stops every block along State Street).

The total annual operating costs for the system are the sum of the preceding factors plus an assumed incremental allowance for system administration of 10¢ per vehicle mile. This total is about $684,000, which corresponds to $2.86 per vehicle mile. Of this total, 64 percent is for driver labor, 21 percent is for maintenance (including battery replacement), 11 percent is for energy, and 4 percent is for administration.

The expected capital and operating costs for the system are summarized as follows:

Item	*Capital Costs ($million)*
Vehicles	2.695
Roadway inductor	2.668
Wayside facilities	0.656
	6.019

Item	*Annual Operating Costs ($thousands)*	*Percent*
Driver labor	438	64
Maintenance	144	21
Energy	78	11
Administration	24	4
	684	

Costs to Provide Same Service with Diesel Buses

The diesel bus is a mature technology that has had the opportunity to develop considerable economies of scale during its evolution. It remains the most economical mode to provide urban transit service if its environmental disadvantages do not enter the evaluation. The capital cost for a diesel bus is somewhat more than half the cost of an RPEV bus. Furthermore, the diesel bus does not need the extensive fixed facilities (roadway inductor and power supply system) of the RPEV, so its overall capital cost for the Santa Barbara application would be less than 30 percent of the capital cost of the RPEV system. The diesel bus operating costs are expected to be similar to those for the RPEV. The driver labor should be virtually identical, and the maintenance and energy costs are expected to be within a few percent of those costs for the RPEV. Therefore, the system capital cost remains the disadvantage of the RPEV relative to the diesel for this type of application, as indicated in the following comparative cost summary:

	Cost ($millions)		
Cost Component	*RPEV*	*Trolley*	*Diesel*
Vehicles	2.69	2.3	1.5
Fixed facilities			
Continuous power distribution system (inductor or trolley wires)	2.66	2.03	–
Power source	0.48	0.95	–
Maintenance facility	0.18	0.13	0.1
Total	6.01	5.41	1.6

Costs to Provide Same Service with Trolley Buses

The comparison between the costs of the RPEV and the trolley bus is more even because both of these systems require fixed facilities as well as vehicles. The capital cost factors for this comparison are separated into those that depend on the number of vehicles in daily service (the costs for the vehicles and the power supply system) and those that depend on the length of route served.

The capital cost per vehicle in daily service is nearly the same for the RPEV and the trolley system. The trolley vehicles are slightly less expensive, but their power supply systems are somewhat more expensive because they operate on direct current and must be able to supply peak rather than average vehicle power demand. The RPEV roadway inductor costs about 350 percent of a trolley wire system per foot installed, while the length that must be installed is less. For the baseline Santa Barbara application, the actual length of the roadway inductor is about 35 percent of the route length, so its cost is expected to be about 25 percent higher than the cost of a trolley wire installation. However, if the roadway inductor only needs to cover 30 percent of the route length, the capital costs of the two systems should be virtually identical. This highlights an important feature of the RPEV system, the need to electrify only a portion of the route rather than the entire route. In a higher-density application for an urban bus system, with many routes overlapping on some streets, the percentage of the overall bus route lengths needing to be electrified could be reduced dramatically and the RPEV system could display significant economies.

No significant difference is expected in operating cost between the RPEV and trolley bus systems, so this does not appear to be an issue in the comparison between these two modes.

Costs to Provide Same Service with Battery-Only Buses

Battery electric vehicles are plagued with limited range because of the limited storage capacity of the available batteries. The baseline Santa Barbara Electric Bus can operate for slightly more than 2 hr on a single charge of its battery if it does not have roadway power available for recharging. A substantially larger battery would be needed to permit it to operate much longer, but diminishing returns set in as the battery weight increases (because of increasing vehicle weight or decreasing payload, or both). If the baseline downtown circulation bus service were to be provided with battery-only buses in Santa Barbara, it would be necessary to provide substantially more vehicles in the fleet so that some of them could be recharging while the others were operating. The exact numbers would depend on the battery size and type chosen, but it is likely that the fleet would need to be two to three times the size of the RPEV fleet to provide 10 hr of service per day (assuming no battery exchange schemes were attempted). This would lead to system capital costs comparable to the RPEV system costs, with the avoided roadway unit cost replaced by increased vehicle purchase costs. Operating costs would be substantially higher than for the RPEV and the other modes because of increased battery stress (and therefore increased battery replacement cost) and increased driver labor costs for ferrying the buses back and forth between the operating route and the maintenance and recharging facility. This is not an attractive alternative with presently available battery technology.

IMPLICATIONS FOR EVOLUTION OF THE RPEV TECHNOLOGY

The RPEV technology is currently in its infancy, which makes it challenging to predict how it will mature and grow over time. The application to the Santa Barbara Electric Bus Project described in this paper is intended to serve as its initial demonstration, but hardly as its ultimate incarnation. This limited-scope application is an appropriate one for demonstrating the basic feasibility of the RPEV, even while it cannot demonstrate the ultimate benefits of larger-scale applications. As explained, a simple economic comparison with other modes is not especially favorable today because of the relative immaturity of the RPEV technology and the limited scope and density of the Santa Barbara application. This does not mean that the RPEV cannot compete with the other modes.

If only the immediate transit bus service application in downtown Santa Barbara is considered, opportunity recharging of the electric vehicle batteries could probably be provided at lower capital cost (albeit at higher battery stress levels) by installing recharging stations at several carefully selected stopping and layover points, as demonstrated previously in Germany *(10, 11)*. However, unlike the RPEV technology, that approach would not be applicable to more general vehicle fleets and certainly could not be extended readily to the electric automobile, which is the eventual goal of the RPEV development work.

The position of the RPEV technology today is analogous to that of the automobile at the dawn of the 20th century. The people who focused on the cost of transportation in 1900 favored the horse and buggy over the automobile, scoffing at the latter as a toy for wealthy eccentrics. They did not have the vision to see the longer-term advantages the automobile would offer, even though it was not the most economical means of transport at that time. The longer-term promise of the RPEV technology must not be overlooked today simply because it is not now the most cost-effective mode.

Introduction of RPEV technology should be considered now for special applications for which its environmental advantages can be balanced against its high capital cost. These applications can be characterized by their environmental and aesthetic sensitivity, use of special vehicle fleets, and relatively high density. Examples could include national parks and monuments (such as Yosemite Valley), special historical districts of architectural interest (Colonial Williamsburg, Georgetown, and Boston's North End or Back Bay), urban pedestrian malls or shopping districts, enclosed shopping malls, major commercial office parks, amusement parks, and expositions. In many of these applications, the elimination of diesel bus noise and pollution and the avoidance of overhead trolley wires could heavily favor an RPEV system. A somewhat different application with near-term promise is airport circulation service at major hub airports with separate terminals, such as New York's JFK or Los Angeles International, where present diesel buses impose significant pollution burdens on travelers and the operational patterns, including low speeds, much dwell time, and special-purpose bus fleets, tend to favor RPEV.

The RPEV system can evolve beyond use in special activity centers by application to limited-access busways and busway/HOV lanes in freeways. In several California counties (Marin, Contra Costa, Orange), abandoned railroad rights-of-way could be developed for use as busway/HOV facilities in congested suburban areas, where freeways are already saturated. These rights-of-way adjoin suburban backyards, and the residents in those areas will object strenuously to the introduction of noisy and smelly bus traffic so close to their homes. The clean, quiet RPEV system may possibly be able to overcome such objections (if, indeed, any mode can).

The busway/HOV application extends the RPEV envelope to higher speeds than the activity center circulation systems described before, and it also provides the opportunity to widen the RPEV population to include vans used by vanpoolers. As the number of vehicles per electrified roadway mile increases, the economics of the RPEV system improve because the cost of the fixed facility can be distributed more widely. As the fleet of RPEV vehicles expands, the potential for electrification of more roadway facilities also expands. The RPEV system is vulnerable to the classic dilemma of the chicken and the egg. Before private vehicle owners are willing to purchase special RPEV vehicles, there must be enough powered roadway facilities to make it desirable to own these vehicles. On the other hand, there will be little motivation for public agencies to construct powered roadway facilities until there are enough RPEV owners to clamor for these facilities. This cycle can be broken by a careful, evolutionary introduction of RPEV vehicles into large special-purpose fleets such as those owned by public utility companies, telephone companies, the postal service, public service agencies, parcel delivery services, and so forth.

The most dramatic long-term benefits from the RPEV technology will come when urban freeways can be electrified, even if only partially. Substantial mobile-source pollutant emissions could be eliminated and substantial amounts of petroleum could be saved, as long as the electricity supplied to the roadway is generated from other prime energy sources. Even more important, this could be a major evolutionary step toward the automated highway, on which vehicles would travel under automatic steering and spacing control.

The automated highway represents an opportunity to substantially increase the capacity of each freeway lane by enabling automobiles to travel closer together safely. This means that the capacity of existing freeway corridors could be increased without the major capital cost of double-decking the freeways or the inevitable sociopolitical problems of condemning homes and businesses in densely developed neighborhoods for widening the freeways. It does not appear to be practical to automate conventional internal combustion engine vehicles because of their relatively slow and uncertain dynamic response. Electric powertrains are much more amenable to tight closed-loop control and will therefore probably be a prerequisite for complete highway automation. The most practical means for providing automobiles with electric powertrains that can be used on both conventional public streets and the special automated highways appears to be the RPEV. Thus the potential benefits of eventual highway automation must also be considered when the prospects for the RPEV system are being evaluated.

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Integrating Research on Public Attitudes and Behavior into Energy Contingency Planning

MARTIN E. H. LEE-GOSSELIN AND KATHRYN M. CLINTON

As part of the development of a contingency plan for oil shortages, the Ontario Ministry of Energy undertook a study to identify and develop research methodologies that could be used before, during, and after a shortage to monitor public attitudes and behavior. The study consisted of an information needs assessment, methodology development, and implementation plan. The needs assessment was based on contingency management experience in Ontario and elsewhere, and on a shortage simulation session in which the utility of hypothetical research results was evaluated. Methodological development involved the review and modification of existing survey methods with which public response to a shortage and demand restraint interventions could be assessed. These included a home interview survey and an interview-game method—both directed at households and with a major emphasis on gasoline consumption—and a telephone survey directed at individual consumers. In addition, a brief driver interview conducted in service stations was developed to monitor problems at the retail level. The study further specifies the use of both public and expert panels to provide information when contingency events make more formal research methods difficult to implement, and proposes a design for an organized network of key informers to keep emergency operations staff up to date. These methodologies are not all active at the same time. The implementation plan assigns different sets of methods to six shortage stages for evolving contingencies, and to four stages for shock contingencies.

There is now modestly extensive literature available to energy planners on how the public responds to energy shortages. Many of the data cited come from retrospective surveys in which the public is asked to report how it coped during the shortages of 1973–1974 or 1979 *(1, 2)*. Other research *(3, 4)* has focused on measuring reactions to hypothetical future shortages. In addition, there are examples of the application of behavioral theory *(5)* and policy analysis *(6, 7)* to the study of consumer response to energy shortages.

Many of these sources contain serious cautions about the extrapolation of their findings. Often, the energy planner must interpret findings in the light of idiosyncratic circumstances of geography, supply, public information, and government posture at the time the study was completed. In this paper, an effort to address these limitations by making behavioral research an integrated and concurrent part of energy shortage management for a Canadian province is described. In support of Canadian federal oil emergency planning and in recognition of the responsibility of provincial governments to ensure public health and welfare during a serious oil supply shortfall, the government of Ontario undertook the development of a contingency plan for oil shortages. The work has progressed over the past few years, and in September 1985, it was decided to conduct a research methodology study as input to the final stages of plan development. The need for such a study arose from the recognition that the successful development and implementation of this plan depends on public willingness and ability to change fuel use behaviors abruptly. The primary task was to develop a package of quantitative and qualititative methodologies appropriate to the assessment of public attitudes and behavior before, during, and after an oil shortage.

NATURE OF THE PROBLEM

To integrate behavioral research into contingency planning implies a flexible approach to the implementation of countermeasures. Idealistically, research is a way to improve the government's up-to-the-moment understanding of the actual and potential impact of an oil shortage on different population sectors, and to enable it to respond to real and perceived distress in the most equitable, efficient, and effective manner. While the practical reality may fall far short of this intention, contingency planning is a learning-planning cycle par excellence, and the research methods used should serve the goal of understanding past errors. The Ontario contingency planning effort has profited from published research on past shortages but has at the same time recognized that a well-planned set of research activities at all stages of a future shortage would make subsequent shortage management much more likely to succeed.

The potential for serious error on the part of governments in oil shortage management is high. Perhaps this helps explain why, according to a 1983 international review of oil shortage policy, many countries have announced their intention to "leave the problem to market forces." Nevertheless, most governments recognize that extreme shortages will ultimately require intervention *(8)*. Perhaps the most compelling reason for research on public attitudes and behavior is to be found here. Governments have now tasted the central policy dilemma in contingency planning: identifying the right level of intervention. Either too little or too much intervention can have profound economic and political consequences. The dilemma can

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be concretely illustrated by the following proposition about a gasoline shortage:

> The nature and extent to which a government must intervene in a gasoline shortfall depends critically on the extent to which the public is motivated to voluntarily reduce usage, and is not self-evident for any given size of shortfall.

Those responsible for emergency management know that this proposition is not as obvious as it sounds. A number of jurisdictions in the United States reacted to the 1973–1974 and 1979 shortages by announcing that certain types of voluntary and mandatory demand restraint would be introduced if the shortage reached given levels. They did this with the best of intentions to warn the public up front, as clearly as possible, that X percent shortage would mean intervention Y. What happened was that different levels of voluntary response made the planned interventions quite unnecessary in some cases, and too feeble in others. One state energy emergency office administrator has helped conceptualize the resolution of this policy dilemma. She described an alternative approach as "knowing where the public mood is heading," and "negotiating openly with them to postpone intervention in exchange for some voluntary, short-term sacrifices" *(9)*. Contingency planning can be improved by finding ways to measure "public mood" in all stages of a shortage, including when there is no expectation of a shortage, and by finding ways to predict major trends in the willingness and ability of the public to cope with a shortage.

Attitude and behavior research also has a role in keeping contingency planning up to date with respect to major changes in life-style and the population itself. It is increasingly recognized from research into consumption that demand for goods and resources cannot be interpreted without reference to values and life-style. Although contingency research need not include elaborate marketing strategies, such as VALS *(10)*, Canadian work in this area suggests that differences in coping response are most effectively characterized by using life-style categories *(11)*. Of major importance is the fact that the scope for coping with energy shortages is changing because life-styles are not frozen, and the flexibility has much to do with ongoing changes in the division of labor and responsibilities in the household. Contingency research should help the questioning of assumptions about who is able to take the initiative in shortage, within households as well as between households. An important related point for Canada is the need to understand how coping with an energy shortage is perceived in the growing number of ethnic communities.

The nature of the problem of shortage management is summarized as the need to follow a fast-moving target, the shape of which is slowly changing. This definition provides an initial framework for a contingency research program. The instruments and methods adopted must include techniques for the rapid assessment of changing public attitudes and behavior throughout a period of crisis, and techniques for understanding how attitudes and behavior related to a shortage situation are evolving over time. However, it must be recognized that such a program of research support must be applied in the expectation of limited resources, especially during periods when oil shortages are remote from the public policy agenda.

SHORTAGE TYPES AND STAGES: A FRAMEWORK FOR RESEARCH

A major source of complexity in designing research support derives from the different types of shortage that may occur. It is possible that research methods that are appropriate in one situation will not work in another. Contingency plans are sometimes built around a multiplicity of scenarios characterized by differences in severity, speed of onset, geographical extent, and degree of advanced warning. After a number of scenarios that might affect Ontario were considered, there were only two classes of scenario for which it was appropriate to develop distinctive research approaches:

1. Evolving shortages: slowly evolving or relatively long-lasting shortages, probably international in origin and possibly involving perceived shortages before a shortfall has worked its way through the supply system, and
2. Shock shortages: very abrupt, severe shortages of short duration, notably as a result of major pipeline disruption or industrial action.

For research design purposes, the rapidity of onset and lack of advance warning set the second scenario apart more than the size of the shortfall.

Further, there are different stages in the development of any shortage that may generate different public response characteristics. Federal and provincial officials have distinguished four shortage stages applicable to Canadian conditions.

- Preemergency: A period of growing concerns and alertness about tightening supplies, accompanied by increased shortage readiness and publicity advocating conservation.
- Perceived Shortfall: Stage I—a period of no real shortage, but some potential supply imbalances following reaction to media reports; invocation of mandatory countermeasures within the public sector, and voluntary measures within the private sector and the public.
- Moderate Shortfall: Stage II—actual shortage up to 7 percent of supplies, with the continuation of Stage I countermeasures and the introduction of mandatory countermeasures for the private and public sector.
- Severe Shortage: Stage III—shortage more than 7 percent of supplies, with the invocation of federal emergency powers, involving product allocation and end-user coupon rationing if needed; strict enforcement of a full range of mandatory countermeasures for everyone, and other actions necessary to protect public health, safety, and welfare.

The two classes of shortage scenario, and six stages—comprising the four listed, plus normal times and a postshortage recovery period—offered the best framework for the design and implementation of appropriate research methodologies. However, as shock scenarios were conceptualized as developing rapidly from preemergency conditions into a severe shortage, research support for Stages I and II was developed only for the evolving class of shortages.

ASSESSMENT OF CONTINGENCY PLANNING RESEARCH INFORMATION NEEDS

This study attempted to answer the question "What do we really need to know about public attitudes and behavior to effectively manage each stage of an oil shortage?" Recalling that the shortages of the 1970s had only minor impacts on Canada, the question is not easily answered from experience. The assessment of research information needs had three components: an analysis of the Energy Contingency Planning Program (ECPP) activities, a series of interviews with state and provincial officials who held positions of responsibility during the shortages of 1973–1974 and 1979, and a simulation exercise to evaluate the utility of different types of hypothetical research results during a shortage in a mythical province of Canada.

ECPP Activities

Ontario's ECPP activities are broad in scope and include the areas of communications, emergency management, planning and analysis of countermeasures for use by both public and private sectors, and analysis of legislation. The study consultants initially outlined a range of attitudinal and behavioral research applications pertinent to each of these areas. Then, in joint review with the Ministry, priorities were set among types of research to be developed in support of ECPP activities, both now as part of plan development and during each stage of a shortage once the plan is implemented.

The major outcome of this part of the assessment was an initial emphasis on these categories of research information: public perceptions of government efforts to support coping by individuals and households, preferences among different mandatory and voluntary fuel reduction options, and any data that would help judge when the introduction of mandatory measures would be seen as the only fair way to deal with a serious shortage.

Interviews with State and Provincial Energy Officials

A limited number of officials who held positions of responsibility during the shortages of the 1970s were contacted in various parts of North America. In addition, information gathered in New Zealand, Australia, and Europe for a study on demand restraint policy was reviewed.

Part of the reason for emphasizing the distinction between the evolving and shock classes of scenario comes from observations on several sudden shortages experienced in New South Wales in 1979–1982 and in South Australia in 1980 as a result of industrial action. Their time frame for response was days, not months, and it is clear that government actions under such circumstances were quite different from those planned for use in a protracted international shortage situation. The type of information needed on public response reflected a preoccupation with panic and rumor control, especially for the first such shock shortage.

By contrast, information needs in the "Evolving" class of scenario can be seen to have much more to do with strategy and tactics for restraining demand and helping the public cope. But this is not to say that there is agreement on the value of intervention. Most of the North American officials contacted, and especially those in the United States, focused first on the need to understand how the retail market was functioning and second, if at all, on measuring public attitude and behavior. These responses must be read in the light of the decline of much contingency planning in the United States since 1980.

Two stereotypical views of public response information needs emerged from these discussions. The first view is that there is little for the government to do except develop a good baseline picture of the energy market and to work closely with the energy industry to help each sector understand how the market must adjust to the new supply realities. In this view, publicizing supply facts and helping people identify the price level at which they will cut their usage are much more important than asking how the contingency is affecting them. Thus the public response information priority is to detect whether perceptions about the supply shortfall are realistic, with a view to correcting these perceptions if necessary. But the government should be little more than an impartial and credible source of information.

The second view is that government must pay most attention to geographic and demographic inequities. From this view, mere tracking of fuel use behavior in normal times is of little value unless it is accompanied by some study of adaptive slack in the system, such as unfulfilled ridesharing potential. In a shortage, the first priority is the coordinated collection of the best supply and price data available, together with information on the consequences of inequitable supply. Initially, the consequences monitored should be the most visible (e.g., gasoline lineups and residences without heat), and the most threatening to the economy (e.g., collapse of tourism and loss of employment). However, there should also be efforts to survey individuals and households on their responses (e.g., queueing, price paid, and new ways adopted to save fuel), and on the consequences of the shortage (e.g., discomfort, impact on family activities, and opportunity costs of high fuel prices). The second view assumes that potential government interventions from a variety of ministries or departments will then be weighed on their merits.

The second (and more interventionist) viewpoint is closer to Canadian conditions, and is based, in part, on views collected in Canada. These reviews provided initial guidance on the policy objectives that could best be served by collecting information on public response. Perhaps the major lesson from earlier shortages may be inferred from the sense, common to both viewpoints, that the public should be allowed as much flexibility as possible in choosing how to cope with a shortage.

Simulation Exercise

The simulation exercise served well to get at a variety of viewpoints on priority public response information needs. It consisted of a series of focusing exercises based on the critical success factors techniques developed by Rockart *(12)* and a two-round simulation of a provincial government "war room" during an oil shortage that reached Stage III over a period of 6 months. The simulation, developed especially for the exercise, involved the preparation of scenario information for a mythical province and written digests of results for some 22 imaginary research projects carried out in support of contingency planning and management. Players were provincial government officials assigned roles in a Division of Emergency Preparedness. The major activity of the simulation consisted of the requisitioning of research information and evaluating its usefulness in writing and in a group debriefing. The first priority of the session leaders was to observe and follow up the characteristics of the research information seen as necessary to the successful management of the shortage. The imaginary research digests prepared for this exercise were systematically chosen to cover

1. At least one example of each of the categories of information previously identified for each ECPP area, and
2. Examples of both hard and soft information sources gathered under the described scenarios during five contingency stages—normal times, preemergency, and Stage I–III shortfalls. (N.B.: "hard" here indicates methodological rigor but not necessarily quantitative results.) The exercise was based on an evolving type of scenario so that all shortage stages could be included.

The participants provided a substantial amount of written feedback during the exercise and after reflecting on it for a day or two. From the synthesis of the needs expressed by each role (i.e., organizational position) in the simulation, the following generalizations were made:

- Although roughly equal amounts of hard and soft information were matched to the requests, a majority of evaluations as to what would be more useful indicate that up-to-date soft information is preferable to more rigorously collected but slightly older data, and that this trend gets stronger as the shortage worsens.
- Even allowing for an artificial thirst for detail after reading only a brief history of a crisis, the simulation demonstrated that there is a strongly perceived need to have a view of the crisis and the government's response to it through the eyes of the public, region by region.
- There was a consensus that government should be an honest broker of information about the crisis, not only on supply issues but also on the immediate and secondary effects it is having on the economy and the province's way of life, and that such information should be systematically sought out.
- Baseline information about energy consumption and conservation tended to be overlooked in the heat of crisis developments.
- Several role players said that, in a real shortage, more effort than was made in the exercise would be needed to pool information resources with others.
- Two role players wanted public response information from other provinces for comparison purposes; information was also requested on current and past shortages in the United States.

As a result of the simulation session, the priorities were adjusted in two related ways. First, the importance of sources of detailed, up-to-date information on public attitudes and behavior was upgraded. This action meant that soft methods got more attention and development effort. Second, the view of the purposes to be served by research information in the severest levels of the crisis was modified. It is not enough to seek feedback on demand restraint and allocation programs: it is also necessary to gather intelligence on what different sectors of the public expect of the government in the shortage.

Synthesis

The assessment of ECPP research information needs was synthesized as a series of six purposes, each of which was given a level of priority in each stage of a shortage. The purposes, and the priorities, are given in Table 1. The purposes are numbered in Table 1 more or less in the chronological order in which they take on high priority as a shortage develops. Thus Purposes 1 and 2 aid preparation of the details of the contingency plan, Purposes 3–5 focus on the dynamics of public response in a shortage, and Purpose 6 is the "postmortem." The next step was to identify and develop a set of methodologies that could fulfill the higher-priority purposes in each stage both of evolving and shock shortages.

TABLE 1 IMPORTANCE OF ECPP RESEARCH PURPOSES BY STAGE

	Stage of Shortage					
Purpose	N	PE	SI	SII	SIII	R
Investigate the relationship between evolving family life-styles and potential ability/willingness to adapt to a shortage, with or without government intervention	H	M	L	—	—	M
Measure anxiety about energy supply, and sensitivity to contingency events	M	H	H	H	M	M
Evaluate the human impact of supply inequalities and high energy cost, and the behaviors adopted to cope	—	L	M	H	H	M
Provide frequent feedback on changing public response to demand restraint and allocation programs, and on associated communications	—	H	H	H	H	—
Provide up-to-the-moment intelligence on what different population sectors expect of government and industry in the shortage	—	L	M	M	H	—
Synthesize what was learned in the shortage about reducing demand and minimizing public inconvenience and distress	—	—	—	—	—	H

NOTE: H = high, M = medium, L = low, N = "normal times," PE = preemergency, SI = perceived shortage, SII = moderate shortage, SIII = severe shortage, and R = recovery.

TYPES OF RESEARCH METHODOLOGY FOR USE IN ENERGY CONTINGENCY PLANNING

It became clear that three types of methodology were needed: survey instruments, soft data collection methods, and selected reuse of existing research information. The development work built, to the maximum extent possible, on methodologies that had been applied to energy issues in Ontario and elsewhere.

Survey Instruments

The need was identified both for in-depth techniques suited to understanding evolving trends in the public's willingness and ability to respond to an oil shortage and for rapid-response barometers of public opinion for use during an actual shortage. Four techniques were modified or developed as follows:

- Telephone Contingency Tracking (TCT): This is a modification of a 34-question instrument aimed at measuring changes in public attitudes to various aspects of fuel shortages over time. A set of core items makes it particularly useful for tracking the level of public anxiety and satisfaction with government and industry responses from stage to stage in a shortage. Transitory items can be inserted to provide limited feedback on specific policies or events. TCT is applied to province-wide random samples, with new selection for each wave. This survey offers the advantages of implementation at very short notice and the provision of results within hours of completing the interviews.
- Home Interview Tracking (HIT): Home interview surveys are already used for other ministry purposes, and a set of items relating to participation by household members in identified fuel-saving actions as well as some prospective shortage questions have been developed for such surveys. The items use a procedure in which a respondent evaluates the significance of fuel-saving actions for the household by sorting cards into piles. However, the main focus is to infer the level of participation by different household members in fuel conservation. The prospective shortage questions include views on government and employer roles. The HIT instrument is for use with province-wide stratified random samples, with a recommended oversampling of subjects shown from a previous Canadian study *(13)* to be important contributors to conservation, or for whom fuel saving presents unusual difficulties.
- Interview-Game Method (IGM): This is the latest version of an instrument known as Car Use Patterns Interview-Game (CUPIG), which was used in 1984 and 1985 for two federal studies on transportation energy use in Canada. The methodology is described by Lee *(4)*. This technique permits careful validation of what households believe they could change during a gasoline shortage. It is structured around 7 days of trip data logged in each of the household's vehicles, which are presented during the game as a detailed time-trace chart. The logged trip data are also summarized as a fuel budget, using an accounting board on which poker chips represent fuel used by each vehicle and activity served. Householders are asked to retrofit constraints imaginable in a simulated shortage on to this concrete picture of recent car use, and the implications of all suggested coping actions are fully explored in a 1–3-hr interview. A cumulative record of actions adopted and fuel saved is displayed on the time-trace chart and the accounting board. The technique is applied to quota samples of 36 households or more. The major output from the CUPIG technique is a considerable amount of qualitative data about the choice of different demand restraint methods and the factors associated with those choices among different types of household. The method also provides important insights into the role of different family members in making decisions about automobile and energy use, attitudes of households toward energy shortages and the role of government intervention, and the distribution of voluntary savings across the population.
- Service Station Survey (SSS): This completely new instrument was developed as an off-the-shelf rapid-response technique that can be used at times of severe shortage to gauge the public's mood on problems associated with retail shortages of gasoline. It consists of a 3–4 min "clipboard" personal interview of drivers at retail points of sale. A few data elements are also collected by observation of the vehicle and of the pump. The data sought are those needed to assess the seriousness of public concerns about delays and uncertainty of supply experienced by motorists, price fluctuation and gouging, voluntary suppression of long automobile trips, and tank topping. In addition, information is sought on coping actions adopted since the shortage began. No demand restraint (DR) measures are specifically covered. However, if queue management and DR interventions are in force or anticipated, the instrument can be modified to capture feedback on them.

Soft Data Collection Methods

Specifications were developed for three soft data methods, the first two of which involve the use of groups. Groups with special interests or expertise can operate in a consultative role to substitute for incomplete research information and to help interpret what is known in a crisis. The objectives of general public panels (GPPs) and expert groups (EXGs) are related, but not identical. In both cases, the aim is to gain insights into public mood and response by talking directly to selected groups of individuals, knowing from the outset that this is not a source of statistically representative data.

There are two main reasons for including these group techniques. First, this is a valid way of making sure that the researcher's assumptions about public behavior and attitudes do not filter all the information gathered. Such assumptions are a necessary part of the design process and inevitably constrain the results obtained with a more formal instrument such as TCT or HIT—or even with the simulation approach of IGM. The group techniques, however, depend on listening in an open way to what people have to say about what has been done, and might be done, to help deal with the shortage. This process provides a much needed reality check on conclusions drawn from the formal instruments. Second, the group techniques are ideally suited to the exploration of changes in public mood on fairly complex issues. The group meetings may be implemented and analyzed within 2 to 4 days if necessary and thus can help quickly interpret public response in an evolving situation.

- General Public Panels (GPPs): The GPPs would perform two major functions. The first would be to check on the meaning of findings from the earlier IGM, HIT, and TCT work. In particular, they should examine conclusions about to whom in the household communications should be addressed and about the underlying reasons for the way different groups of people cope with the shortage. The second major function is to get public input on the language used to explain regulations, voluntary restrictions, and the status of the shortage.
- Expert Groups (EXGs): At least two roles exist for organized groups of experts to help the Ministry evaluate the probable consequences of policy options during serious, and especially, rapidly developing shortages. Perhaps the more important role is one of pooling judgments about the government's options in the light of incomplete information. This role

would come into effect only in a Stage III situation. Although it is clear that a number of government experts and industry representatives would in any event be available to those managing a severe shortage, planning for group activity is recommended. The other role for expert groups occurs earlier: there is considerable value in having a small number of interest groups work with the government on a consultative basis.

In contrast to the role of these two types of group in interpreting soft data, organized networks were also specified to take an information-gathering role under circumstances in which traditional survey methods would be insufficient.

- Key Informer Intelligence Network (KIN): KIN is a planned hierarchical system for obtaining recent information on public attitudes and behavior in the later stages of a shortage. The objective of KIN is to make the best possible use of people placed in key positions around the province to synthesize the impact of the shortage and the direction of public sentiment. The network should give early warning of incipient problems and, in particular, help identify the incidence of distress among those who had only limited organized political voice. The role of information gathering is preeminent except in the special case of preemergency conditions for a shock type of shortage, when KIN also has a more interpretative role. It is necessary to include in the network a representative range of sources, but the intention is not to be fully representative in the parliamentary sense. When there are groups of people who have a legitimate interest in becoming part of the network, such as municipal energy emergency coordinators, the principle should be to try to find someone who can summarize the current thinking for a peer group. KIN should, in general, build on existing channels rather than trying to be an all-purpose network for everybody involved in managing the shortage in all sectors and regions. It is thus a type of clearinghouse for current intelligence, and as such an important decision must be made as to whether the information flows only in one direction. It is suggested that some level of feedback be provided to the participants, although it is clear that alarming information needs careful handling. A related decision is whether the existence of the network is tied in some visible way to a rumor control system through which the government helps the news media avoid false or exaggerated reports of problems.

Reuse of Existing Research Information

- Demand Trend Analysis (DTA): Several existing or potential sources of fuel demand data for population sectors were identified.
- Review Other Research (ROR): Three classes of research in related fields that are helpful background to the planning of contingency measures were suggested: consumer behavior and income dynamics studies, studies of ethnic communities, and research on family roles.

IMPLEMENTATION

The need to implement ECPP research within the framework of evolving scenarios versus shock scenarios and six stages in the development of a shortage have been discussed. These two dimensions are presented in matrix form in Table 2. Recall that of the twelve cells, two are eliminated by definition: shock shortages do not have a perceived or moderate phase for long enough to justify delaying the implementation of methods appropriate to a severe shortage.

The importance of different ECPP research purposes by stage is demonstrated in Table 1. In Table 2, all the instances of high or medium importance in Table 1 are given in conjunction with the allocation of the nine research methods, by stage and scenario. A method may serve more than one purpose, and it may serve different purposes in different cells. When a method serves two or three purposes in a single cell, it is shown as high importance if any one purpose is of high importance. The most important purpose is cited first in the table.

Summary of Implementation Approach for Normal Times

These research methods must, of course, serve contingency planning for both types of shortage scenarios. The IGM and HIT surveys provide a baseline on fuel-saving experience and attitudes and, in the case of gasoline, for anticipated shortage behavior. A province-wide IGM survey would provide an up-to-date understanding of the willingness and ability of different population sectors to reduce fuel use in a shortage (Purpose 1). Findings about who is primarily involved in effecting fuel savings within different classes of household, and about efficient target groups, could be checked with a random sample by using HIT techniques. Of lesser importance is the use of HIT to report on anxiety levels (Purpose 2), thus providing a comparison for the later TCT questions in the same area. At the same time, it would be worthwhile although of less direct significance to check on available demand data by population subgroup (DTA) and on relevant other research (ROR). Taken together, these four methods provide the best possible check on the assumptions that underlie the most difficult aspects of contingency planning — the choice, sequencing, and publicizing of demand restraint interventions and controls.

Summary of Implementation Approach for Evolving Shortages

Survey methods dominate the preemergency and perceived shortage stages. HIT and IGM are focused on evaluating demand restraint policy options and potential government and employer interventions, as well as assessing the adaptive slack in households' views of their energy use (Purposes 4 and 1). The first wave of the TCT survey occurs in the preemergency stage to provide a common measure of public anxiety throughout the shortage.

TCT is the only survey technique used in the moderate shortage stage. By this time, the emphasis has shifted to the GPP panels, which had their start in the perceived shortage stage. The mandate also shifts away from investigating the level of threat and toward understanding the actual sources of distress and the potential for government intervention to help (Purposes 3 and 4). Also during the moderate shortage stage, use of expert groups is recommended for the first time, emphasizing consultation on and evaluation of planned interventions. It is at this stage that groups with a legitimate interest, operating within either a specialized or a representative format, become highly motivated to participate. At the same time, the

TABLE 2 IMPLEMENTATION OF RESEARCH METHODS

		SHORTAGE STAGE											
	Impor-tance	N Normal times	P*	PE Pre-Emer-gency	P*	I Perceived	P*	II Moderate	P*	III Severe	P*	R Recovery	P*
EVOLVING SCENARIOS	High	IGM HIT	1 1,2	HIT TCT	4,2,1 2	TCT	2,4	GPP TCT	3,4 2,4	KIN EXG SSS	3,5 4 4	HIT IGM	6,3 6,1,3
	Medium	DTA ROR	1 1	IGM	1	GPP	5,3	EXG KIN	4 5	TCT	2,4	TCT	2
SHOCK SCENARIOS	High	same as 'evolving'		KIN TCT	4,2 2	n/a		n/a		EXG KIN	4,3 3,5	same as 'evolving'	
	Medium			IGM	2,4					TCT SSS	2,4 4		

METHODOLOGY CODES

DTA	Demand Trend Analysis
EXG	Expert Group
GPP	General Public Panel
HIT	Home Interview Tracking
IGM	Interview-Game Method
KIN	Key Informer Intelligence Network
ROR	Review Other Research
SSS	Service Station Survey
TCT	Telephone Contingency Tracking

P* = PURPOSES FOR CONTINGENCY PLANNING RESEARCH

1. Investigate the relationship between evolving family lifestyles and ability/willingness to adapt to a shortage
2. Measure anxiety about energy supply, and sensitivity to contingency events
3. Evaluate the human impact of supply inequities and high energy costs, and the behaviours adopted to cope
4. Provide frequent feedback on public response to demand restraint and allocation programs, and on associated communications
5. Provide up-to-the-moment intelligence on what different population sectors expect of the government in the shortage
6. Synthesize what was learnt in the shortage about reducing demand and minimizing public inconvenience and distress

KIN network is invoked to measure public expectations of government action (Purpose 5), and its comprehensiveness should be evaluated.

The severe shortage stage uses a mix of hard and soft methods to pragmatically support rapid decision making that is inevitably based on incomplete information. Here, the highest priority is given to the effective flow of information in the KIN network, and its periodic revision to investigate new areas of concern. Its focus is now on the human impact of the federal and provincial restrictions and on what people expect of the government (Purposes 3 and 5). A pair of expert groups, one internal and one external to the government, concentrates their efforts on helping interpret what information is available. At the same time, to meet the most critical need for hard data on public response in a severe shortage, the service station survey can operate province-wide, or just in designated trouble spots.

Summary of Implementation Approach for Shock Shortages

The knowledge that the shortage is likely to become severe very quickly places research on a different status. At the preemergency stage, the focus is on providing the best possible information on public response to an emergency operations center that is in the process of being set up. The most useful roles for research would be to muster the KIN network and implement the off-the-shelf TCT barometer of public anxiety. Note that only in the preemergency/shock cell is it suggested that KIN should give priority to interpreting information on public fears and to estimating reaction to DR and allocation programs (Purposes 2 and 4). This is because there may not be enough time to obtain detailed hard data on which to base countermeasure implementation strategies. It should be possible to make the combined information from KIN and TCT available in a matter of days. However, a HIT application is also shown to cover Purposes 2 and 4. This is a highly desirable addition if the pace of events allows.

In the severe shortage stage, techniques were selected to assist with a process that will inevitably resemble disaster management. Many difficult decisions may be needed at the provincial level to minimize the human and economic disruption resulting from a dramatic reduction in fuel supply. Under these circumstances, the question of monitoring and responding to the general anxiety level is secondary to acting fast on the best intelligence available. The highest priority is given to the use of expert groups in their crisis interpreter role, together with the KIN network that should now be functioning. Between them, the emphasis is on frequent update on the distribution of distress, public response to restrictions (including their evasion), and public expectations (Purposes 3–5). Being adequately informed—daily or more often if needed—is essential to public confidence in the ability of the government to take control of the situation. As with evolving/severe shortage research support, TCT is of lesser importance, but worthwhile if the pace of events permits it to be timed during a period of relative stability. In contrast to the evolving/severe shortage, the service station survey should not be given the highest priority, but it would be of great value in establishing the seriousness of trouble spots. A province-wide service station survey would also make sense if the duration of the shock shortage ran into weeks.

Summary of Implementation Approach for a Recovery Period

Regardless of the shortage scenario, it is recommended that the IGM and HIT methods be used to help synthesize what was learned about reducing demand and minimizing public inconvenience and distress (Purpose 6). In addition, the HIT survey should concentrate on the reasons for the choice of fuel-saving actions that were adopted (Purpose 3). The IGM could readily be adapted to investigate which (if any) contingency responses are being sustained in the recovery period, and why (Purposes 1 and 3). There is much important policy analysis work to be done with the HIT and IGM data as a postmortem on DR and other interventions.

Although a lower priority, the telephone tracking surveys can be continued to complete the longitudinal picture of general anxiety about energy and satisfaction with the roles of governments and industry.

CONCLUSION

In this study, the best available social research methodologies have been fit to what is known about the evolution of oil shortages and to the planning dilemmas faced by provincial governments that must respond. The advice of knowledgeable government officials was obtained through interviews with those who faced those dilemmas in previous shortages in several countries and through a critique of stereotypical research results in a simulated shortage. A research program to measure public response in support of energy contingency planning at six stages in the life of a shortage, while respecting the different imperatives of evolving and shock shortage scenarios, has been designed. The design depends more heavily than was initially anticipated on methods less analytically rigorous than surveys. However, this is not to say that the program is any the less disciplined in its approach. Indeed, obtaining data on public attitudes and behavior under these circumstances requires careful management of the balance between structured, off-the-shelf instruments, and the more informal information sources.

Contingency planning classically turns out to be too little and too late if support is lacking to keep plans current during periods when the contingency seems remote. The research program designed here is part of an attempt to take advantage of a period of stable supply, and it proposes immediate action on a modest scale to update understanding of fuel consumption behavior. It is consistent with continuing interprovincial and federal efforts in Canada to improve energy emergency preparedness. Paradoxically, the more secure the public feels because of recent overproduction of oil, and the more consumption, conservation, and substitution patterns shift as a result, the less likely it is that the accumulated experience will be adequate to deal with increasingly problematical public response in future contingencies, and the more important it becomes to implement this type of research.

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Demographic Influences on Household Travel and Fuel Purchase Behavior

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Monthly fuel purchase logs from the Residential Energy Consumption Survey's Household Transportation Panel (TP) were analyzed to determine the relationship between various household characteristics and purchase frequency, tank inventories, vehicle miles traveled, and fuel expenditures. Multiple classification analysis (MCA) was used to relate observed differences in dependent variables to such index-type household characteristics as income and residence location, as well as sex, race, and age of household head. Because it isolates the net effect of each parameter, after accounting for the effects of all other parameters, MCA is particularly appropriate for this type of analysis. Results reveal clear differences in travel and fuel purchase behavior for four distinct groups of vehicle-owning households. Black households tend to (a) own far fewer vehicles with less fuel economy, (b) use them more intensively, (c) purchase fuel more frequently, and (d) maintain smaller fuel inventories than do white households. Similarly, poor households own fewer vehicles with less fuel economy, but drive them less intensively, purchase fuel more frequently, and maintain smaller fuel inventories than do nonpoor households. Elderly households also own fewer vehicles with less fuel economy. But because they drive them much less intensively, their fuel purchases are much less frequent, and their fuel inventories are larger than those of nonelderly households. Female-headed households also own fewer vehicles but with somewhat larger fuel economy. They drive them less intensively, maintain larger fuel inventories, and purchase fuel less frequently than do male-headed households.

In this paper, differences in travel and fuel purchase patterns by demographically distinct groups of households are discussed. The analysis was conducted as part of an ongoing effort at Argonne National Laboratory (ANL) to analyze the relationship between various household attributes (primarily race and income) and transportation fuel use and expenditures. A number of racial differences in vehicle ownership and use have been found previously *(1, 2)*, particularly among low-income households living in central cities of metropolitan areas. Minority and poor households may respond differently to changes in fuel price and availability, either because of earlier investments in energy-intensive capital equipment or reduced flexibility to adjust household expenditure patterns [*1, 2,* and as described by S. J. LaBelle et al. (unpublished)].

DATA

The Residential Energy Consumption Survey (RECS) Household Transportation Panel (TP) (Energy Information Administration public use tape, U.S. Department of Energy) *(3)* was the principal data source used in this effort. The TP data set contains detailed fuel purchase, demographic, and socioeconomic information for a monthly sample of approximately 1,000 households that used vehicles for personal transportation, along with weighting factors for expanding the estimates to national monthly totals (e.g., gallons purchased, fuel expenditures, and miles traveled). Each month's panel was a representative national sample selected from the 48 contiguous states and the District of Columbia. Obtained by monthly logs, purchase data included total cost and quantity of each fuel purchase, price per gallon, the vehicle's fuel gauge reading before and after purchase, the odometer reading, and type of fuel. Demographic and socioeconomic data included income, size, and residence location of household, and race or Spanish origin, age, and sex of the household head. (Because Spanish origin was coded on only about one-third of the records, it was not used in the analysis reported in this paper.) The weights accounted for sampling, household nonresponse, and, in some cases, partial purchase data, as determined by an edit check. The data were collected over the 28-month period from June 1979 through September 1981.

DATA STRUCTURE

The TP public use tape has a four-level hierarchy: (a) all records for a given survey month, (b) household records (all records pertaining to a given household participating in the panel during that month), (c) vehicle records (all records pertaining to a vehicle used in that month), and (d) purchase records (all records pertaining to each fuel purchase). The household record is particularly rich. In addition to variables describing the household's demographic, social, and economic attributes, it includes responses to several qualitative questions on the 1979 fuel shortage.

Because the SAS software does not support hierarchical data structures, data restructuring was necessary. Restructuring involved four operations:

1. Creating classifying variables. On the basis of data in the household record, a set of binary classifying variables was created. The full list of classifying variables follows. It includes Shortage (identifying the most acute portion of the 1979 shortage), Short (marking those households claiming some problem in obtaining fuel), and numerous demographic variables.

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Classifying Variable	*Definition*
Black	Household head is black.
Other race	Household head is neither white nor black.
Poor	Household income <125 percent of poverty level.
Elderly	Household head >64 years old.
Female head	Household is headed by a female.
Suburbs	Household resides in standard metropolitan statistical area (SMSA) outside the central city.
Rural	Household resides outside an SMSA.
Short	Household reported that obtaining fuel was a problem.
Shortage	Reporting month is June or July 1979, the period when most purchase difficulties occurred.
RegNE	Household resides in Northeast census region.
RegS	Household resides in South census region.
RegW	Household resides in West census region.
PXYZZ	Reporting month is between *x* and *y* (inclusive) in the year *zz*. P101280 is 1 if reporting month is October, November, or December 1980.
Winter	Reporting month is December, January, or February.
Summer	Reporting month is June, July, or August.
First	Vehicle is the first listed for the household.

2. Data merging. The classifying variables were posted on the corresponding vehicle and purchase records.

3. Stage 1 aggregation. Vehicle and purchase records were aggregated one level upward (i.e., vehicle record data were summarized to create one household record describing all household vehicles; purchase record data were aggregated to create one vehicle record describing all fuel purchased for that vehicle).

4. Stage 2 aggregation. All data describing one stratum (i.e., one month, or one group of households defined by the classifying variables) were aggregated into a single, representative record.

Depending on which level of aggregation is used to summarize a particular variable, degrees of freedom (*df*) and R^2 can vary substantially. When the analysis is performed on Stage 1 data (with much inherent sampling variability), it is not surprising that the model tends to yield a relatively low R^2, that is, it explains only that part of the variability attributable to the independent variables. Because identification of the effects of specific factors is of primary concern, the model's R^2 is far less relevant than the *F* statistics associated with each of the factors. These tend to be highly significant.

Much of the analysis was performed on the fully aggregated data. Because of its relatively small size, the aggregated data set is convenient to work with and can be downloaded to a personal computer. At the same time, it contains all the information relevant for analysis and produces the same results as the disaggregated data set.

METHODOLOGY

Multiple classification analysis (MCA) was the major analytical tool used in this project. MCA quantifies the effect of class or index-type independent variables on a particular dependent variable by estimating the mean deviation of any particular class from a base or standard case.

Mechanically, MCA can be implemented with either multiple linear regression (with binary or dummy independent variables) or analysis of variance (ANOVA) procedures. (MCA is described in some detail by Nie et al. *(4)* under ANOVA.) In this application, MCA permitted testing of various hypotheses on the effect of such factors as race, sex, and age of household head, poverty status, residence location, and the fuel shortage on driving and fuel purchase behavior. Although standard behavior was defined somewhat differently for each dependent variable, it generally corresponded to the mean value observed for a vehicle in a household headed by a nonpoor, nonelderly, white male who lived in the central city of an SMSA and reported no fuel purchase problems. For variables strongly influenced by (a) weather, (b) time, or (c) the availability of more than one household vehicle, the standard was further constrained. These constraints were (a) spring or autumn months, (b) the last quarter year in the data set (i.e., July through September 1981), or (c) multivehicle households, respectively.

MCA is especially powerful in finding the pure effects of individual factors, after discounting the effects of other factors in the model. For example, because the percentage of poor black households is greater than the percentage of poor white households, one might ask whether poverty is responsible for many observed differences between black and white households. The magnitude of the *F* statistic for the variable Black (after accounting for all other variables, including poor) shows whether this is the case.

DATA ANALYSIS

Fuel Purchases

Purchase Frequency

The effect of significant independent variables on monthly fuel purchases per vehicle is given in Table 1. In the standard case, 4.97 purchases are made per month. Elderly households have about 1.5 fewer purchases per month, whereas black households have 0.58 more purchases per month. Other factors that significantly affect purchase frequency are rural (non-SMSA residence), other race, and female head.

Variations in the percentage of fuel purchases when the vehicle tank is filled to capacity are given in Table 2. In the standard case, the tank is filled in 66 percent of all purchases. Blacks tend to fill their vehicles' tanks about 20 percent less often. Members of other races, as well as elderly, poor, and rural residents, tend to fill their tanks more often by 11, 14, 9, and 8 percent, respectively. During June and July 1979 (shortage), an additional 12 percent of purchases ended in full tanks.

Recall that MCA gives the net effect of each variable after accounting for the effects of all other variables. Thus differences between any two population groups could vary substantially from the coefficient obtained by MCA. For example, because blacks have a higher proportion of poor and single-vehicle households and a lower proportion of elderly households, the total difference between whites and blacks is greater than the value given in Table 2. In MCA, the high *F* statistic associated with the variable Black indicates that race explains more of the variability in the data than other variables such as poverty, residence location, vehicle ownership, and so forth. If it is assumed that most of the significant variables have been

TABLE 1 EFFECT OF INDEPENDENT VARIABLES ON MONTHLY FUEL PURCHASES PER VEHICLE, COMPARED WITH STANDARD CASE

Variable	B (fuel purchases per mo)	Std. Error	F	Prob>F
Intercept	4.97	-	-	-
Black	0.58	0.14	16.86	0.0001
Other Race	-0.54	0.23	5.66	0.0175
Poor	0.20	0.13	2.36	0.1250
Elderly	-1.50	0.13	139.91	0.0001
Rural	-0.42	0.13	10.25	0.0014
Winter	-0.25	0.16	2.54	0.1108
Summer	0.24	0.14	2.84	0.0918
Female Head	-0.29	0.13	5.27	0.0218
Short	0.68	0.34	3.97	0.0466

Standard case (4.97 purchases per month) = monthly purchases per vehicle in a household headed by a nonelderly, nonpoor white male who lives in the central city of an SMSA and does not report fuel purchase problems.

Note: $R^2 = 0.10$ (df = 1916);
$F_{tot} = 23.29$ (<0.0001).

included, the data suggest that blacks, because of their special attributes and circumstances (e.g., social effects, access to wealth and capital, fixed investments, and expenditure patterns), behave differently from nonblacks.

The data also suggest interesting differences between actual versus perceived effects of the shortage. In the model, short identifies households that report some fuel supply problem, and shortage identifies purchases made during the most acute shortage period. The analysis shows that shortage is a much more powerful predictor of tank topping (i.e., it has a much higher *F* statistic), suggesting that fuel purchase behavior was affected more by news reports and rumors about the shortage than by individual households' actually experiencing purchase difficulties.

Stability of Fuel-Type Purchases

It can be hypothesized that in a free market without supply problems, drivers purchase a single grade (i.e., premium or regular octane) and type (leaded or unleaded) of fuel, the selection of which is based primarily on the manufacturer's recommendation and price, possibly slightly modified by individual preferences. Hence variability in the type or grade of fuel purchased could indicate supply interruptions that limited motorists' choices.

To test this hypothesis, purchase records were sorted into single versus multiple types or grades purchased for the same vehicle during the survey month. The types that were bought and the extent of type or grade switches were not of concern. The frequency with which more than one fuel type or grade was used during the same month was examined. Results showed that a single grade was used in more than 99 percent of the vehicles surveyed; a single type was used in more than 99.5 percent. Fuel shortages had no effect on misfueling or any other variability in fuel type and grade purchases.

TABLE 2 EFFECT OF INDEPENDENT VARIABLES ON PERCENTAGE OF PURCHASES WITH COMPLETE FILL-UP, COMPARED WITH STANDARD CASE

Variable	B (% of fill-ups)	Std. Error	F	Prob>F
Intercept	65.66	-	-	-
Black	-19.63	1.70	132.17	0.0001
Other Race	10.73	2.54	17.79	0.0001
Poor	-8.42	1.50	31.39	0.0001
Elderly	14.15	1.45	94.04	0.0001
Rural	-7.82	1.49	27.37	0.0001
Shortage	11.74	2.60	20.42	0.0001
Short	4.02	3.85	1.09	0.2966
First	-5.42	1.39	15.14	0.0001

Standard case (65.66% of purchases) - percentage of purchases with complete fill-up in a multivehicle household headed by a nonelderly, nonpoor white male who lives in the central city of an SMSA and does not report fuel purchase problems.

Note: $R^2 = 0.10$ (df = 1916);
$F_{tot} = 23.29$ (<0.0001).

Fuel Inventory

Fuel inventories provide additional insight into fuel purchase behavior, as well as important indicators of the relative ability of particular population groups to deal with a sudden shortage. Four measures of fuel inventory were examined in this study: average inventory (the weighted average volume of fuel in the vehicle tank at any moment, expressed as a percentage of tank capacity), minimum inventory (the average volume just before refueling, also expressed as a percentage of capacity), average range (the number of miles that can be driven on the average inventory), and minimum range (the number of miles that can be driven on the minimum inventory).

Average and Minimum Inventories

In the standard case, the vehicle tank is filled to 58.5 percent of capacity on average, declining to 30.3 percent of capacity at minimum. During the TP survey, the data show a slight trend for inventories to decline with time. This decrease can be attributed to the end of the 1979 shortage, which reduced public apprehension about fuel supplies and hence should have prompted a return to normal fuel purchase habits. At least a portion of the decline can be attributed to the recession and rising fuel prices that reduced both ready cash for fuel purchases and the amount of fuel obtained for a given outlay.

Table 3 shows that the variable Elderly—followed by Other Race and the Shortage period itself—increases both average and minimum inventories. Black—followed by Poor, Rural, and First—significantly decreases inventories. Again, Black and Elderly have the highest coefficients in the model.

Fuel Inventory Expressed as Available Range

Available range (i.e., percentage of tank filled × tank capacity × mpg) represents both a safety factor against sudden fuel supply interruptions and the extent of required changes in behavior (i.e., having to build up large inventories) that might accompany the expectation of a shortage. Figure 1 shows the average range calculated from average inventory and minimum range calculated from minimum inventory of vehicles in black and white households. Several trends are clear. First, whites have much longer ranges than blacks—about 125 mi on average with a minimum of about 45 mi, versus 75 mi on average with a minimum of only about 20 mi. Because blacks and whites purchase about the same average quantity of fuel (~11 gal) the difference is attributable to both the inventory variation and racial differences in the fuel economy and tank capacity of household vehicles (Figure 2). Fuel economy is also responsible for the clear seasonality shown in Figure 1. Average inventories exhibit virtually no monthly variability.

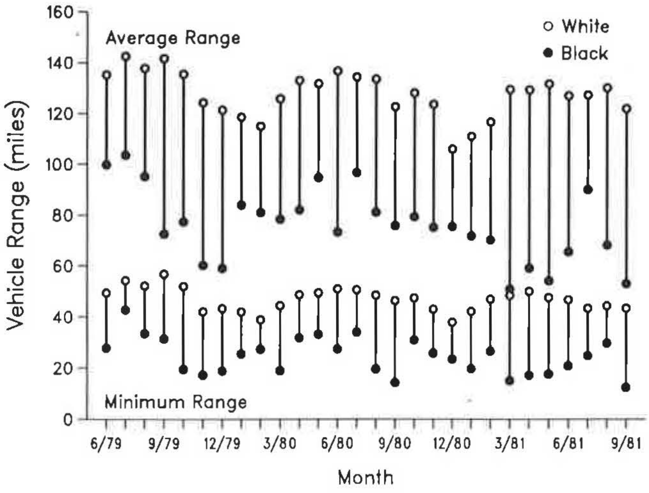

FIGURE 1 Available vehicle range on average and minimum volumes of fuel in vehicle tank, by Black and White households.

Fuel Economy

As presented in Table 4, fuel economy for the standard case is 14.5 mpg. Winter (–0.91), Black (–1.25), Elderly (–0.75), and Poor (–0.95) all affect fuel economy negatively. Only female head (+0.70) and those variables associated with relatively less traffic congestion (i.e., rural and suburbs) increase fuel economy (by 0.49 and 0.65 mpg, respectively).

A likely explanation for the lower fuel economy of vehicles owned by black, poor, and elderly households lies in average vehicle age. As was shown by Millar et al. *(1)*, these groups tend to own vehicles that predate the fuel economy improvements achieved since the late 1970s. Figure 2 shows a comparison of the average fuel economy of vehicles in black versus

TABLE 3 EFFECT OF INDEPENDENT VARIABLES ON FUEL INVENTORY, EXPRESSED IN PERCENTAGE OF TANK CAPACITY, COMPARED WITH STANDARD CASE

	Average Inventory				Minimum Inventory			
Variable	B (% tank capacity)	Std. Error	F	Prob>F	B (% tank capacity)	Std. Error	F	Prob>F
Intercept	58.53	–	–	–	–	30.26	–	–
Black	-6.77	0.75	80.59	0.0001	-2.84	0.63	20.11	0.0001
Other Race	5.35	1.12	22.70	0.0001	2.69	0.93	8.34	0.0039
Poor	-3.47	0.65	28.45	0.0001	-2.07	0.54	14.60	0.0001
Elderly	8.51	0.63	181.82	0.0001	8.89	0.52	285.10	0.0001
Rural	-3.15	0.64	23.81	0.0001	-1.07	0.60	3.10	0.0785
Winter	-0.60	0.77	0.61	0.4339	1.99	0.62	10.24	0.0014
Summer	-0.71	0.73	0.95	0.3295	0.69	0.58	1.43	0.2318
Shortage	4.37	1.23	12.64	0.0004	4.98	1.01	24.31	0.0001
Female Head	1.89	0.62	9.18	0.0025	1.50	0.52	8.25	0.0041
Short	2.29	1.68	1.85	0.1740	–	–	–	–
First	-2.90	0.60	23.31	0.0001	-2.33	0.50	21.10	0.0001

Standard case (58.53% of tank capacity filled on average; 30.26% at minimum) = percentage of vehicle tank filled during spring and autumn months in a multivehicle household headed by a nonelderly, nonpoor white male who lives in the central city of an SMSA and does not report fuel purchase problems.

Note: For average inventory, $R^2 = 0.20$ (df = 1655); $F_{tot} = 38.63$ (<0.0001).
For minimum inventory, $R^2 = 0.20$ (df = 1712); $F_{tot} = 42.8$ (<0.0001).

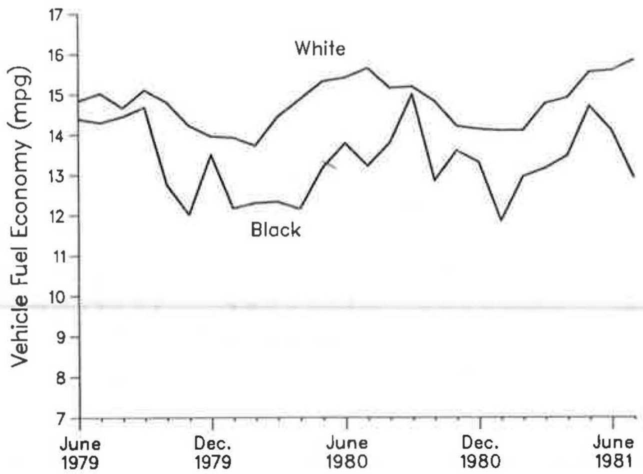

FIGURE 2 Fuel economy of vehicles in Black and White households.

TABLE 4 EFFECT OF INDEPENDENT VARIABLES ON AVERAGE FUEL ECONOMY, COMPARED WITH STANDARD CASE

Variable	B (mpg)	Std. Error	F	Prob>F
Intercept	14.53	-	-	-
Black	-1.25	0.14	75.25	0.0001
Other Race	0.83	0.31	7.15	0.0075
Poor	-0.95	0.13	52.73	0.0001
Elderly	-0.75	0.09	68.82	0.0001
Suburbs	0.65	0.09	52.48	0.0001
Rural	0.49	0.09	27.89	0.0001
Winter	-0.91	0.09	107.28	0.0001
Summer	0.56	0.08	47.30	0.0001
Shortage	-0.46	0.14	10.71	0.0011
Female Head	0.71	0.11	43.11	0.0001

Standard case (14.53 mpg) = average fuel economy (in mpg) during spring and autumn for vehicles in a household headed by a nonpoor, nonelderly white male who lives in the central city of an SMSA.

Note: R^2 = 0.032 (df = 16841);
F_{tot} = 62.25 (<0.0001).

white households. The consistently lower fuel economy of blacks is the cumulative result of all variables contained in Table 4 (as well as other unmeasured variables).

Vehicle Ownership and Use

Tables 5–7 present MCA results that relate rates of vehicle ownership and use to household characteristics. The standard vehicle-owning household owns 1.76 vehicles. The most significant variables that reduce this rate are female head (–0.45), elderly (–0.30), and poor (–0.23). Race has a lower (though significant) effect, decreasing vehicle ownership by 0.18 in black households. Rural and suburban residences increase ownership by 0.24 and 0.195, respectively. A slightly increasing temporal trend in vehicle ownership is given in Table 5. Over the TP data collection period, average ownership increased by 0.06 vehicles per household (about 1.7 percent annual growth).

TABLE 5 EFFECT OF INDEPENDENT VARIABLES ON OWNERSHIP RATES OF VEHICLE-OWNING HOUSEHOLDS, COMPARED WITH STANDARD CASE

Variable	B (vehicles per household)	Std. Error	F	Prob>F
Intercept	1.76	-	-	-
Black	-0.18	0.02	56.28	0.0001
Other Race	-0.04	0.05	0.55	0.4578
Poor	-0.23	0.02	130.52	0.0001
Elderly	-0.30	0.01	496.15	0.0001
Suburbs	0.20	0.02	174.45	0.0001
Rural	0.24	0.02	246.18	0.0001
Winter	-0.04	0.02	5.89	0.0154
Summer	-0.02	0.01	1.96	0.1615
Shortage	0.15	0.08	3.87	0.0495
Female Head	-0.45	0.02	843.47	0.0001
P6979	-0.06	0.02	12.29	0.0005
P101279	-0.04	0.02	4.56	0.0330
P1380	-0.05	0.02	6.23	0.0127
P4680	-0.03	0.02	1.63	0.2027

Standard case (1.76 vehicles per household) = vehicle ownership rate during summer 1981 in a household headed by a nonpoor, nonelderly white male who lives in the central city of an SMSA.

The number of vehicles is computed using weights in the vehicle data file (after removing vehicles not used during the survey month), while the number of households is computed from the household file. If vehicles had been computed from the household file, average ownership would be higher by about 0.1, although relationships would remain the same.

Note: R^2 = 0.685 (df = 1144);
F_{tot} = 177.4 (<0.0001).

According to the MCA results, monthly mileage per vehicle (768 mi in the standard case) and per household (1,400 mi in the standard case) is higher for households residing outside a central city and sharply lower for poor, elderly, or female-headed households (Tables 6 and 7). Mileage also exhibits a regular seasonal pattern, as well as a clear sensitivity to fuel price changes. That sensitivity may be seen in the sign and magnitude of the coefficients for those months (variables in the form PXYZZ) in which prices increased most sharply.

Note that each of the variables has a somewhat different effect on vehicle ownership and travel. Elderly or female-headed households and poverty reduce both ownership and travel, while non–central-city residence increases both ownership and travel. The variable black has a smaller, mixed effect:

TABLE 6 EFFECT OF INDEPENDENT VARIABLES ON MONTHLY MILES PER VEHICLE, COMPARED WITH STANDARD CASE

Variable	B (miles per month)	Std. Error	F	Prob>F
Intercept	768.2	-	-	-
Black	57.3	15.7	13.28	0.0003
Poor	-44.9	13.3	11.37	0.0007
Elderly	-261.7	8.4	953.18	0.0001
Suburbs	77.6	9.1	72.36	0.0001
Rural	86.6	9.4	84.66	0.0001
Winter	-47.0	9.0	26.98	0.0001
Summer	70.5	7.9	79.40	0.0001
Female Head	-51.1	10.5	23.52	0.0001

Standard case (768.2 miles per vehicle = average monthly miles during spring and autumn by a vehicle in a household headed by a nonpoor, nonelderly white male who lives in the central city of an SMSA.

Note: $R^2 = 0.076$ (df = 16871);
$F_{tot} = 172.89$ (<0.0001).

slightly fewer vehicles and miles per household, but slightly more miles per vehicle.

Fuel Expenditures

The data in Table 8 describe monthly household fuel expenditures. In the standard case, a household spent $124.19/month on transportation fuel, discounting the effects of all other variables. Temporal effects, primarily inflation and price increases (see variables of the form PXYZZ), increased expenditures by $39.42/month compared with summer 1979. In addition to price, the major variables associated with expenditure differences are elderly (–$44.65) or female head (–$36.28), and rural (+$21.78) or suburbs (+$18.03). For each of these household groups, expenditure differences represent the net result of differences in vehicle ownership, fuel economy, vehicle utilization, and fuel price.

DISCUSSION

Vehicle Fuel Economy

Lower fuel economy is the major factor responsible for observed differences in fuel consumption and tank-filling behavior between the standard case and either black or poor

TABLE 7 EFFECT OF INDEPENDENT VARIABLES ON MONTHLY VEHICLE MILES PER HOUSEHOLD, COMPARED WITH STANDARD CASE

Variable	B (vehicle-miles per household)	Std. Error	F	Prob>F
Intercept	1399.9			
Black	-61.1	31.3	3.81	0.0513
Poor	-219.9	25.9	71.81	0.0001
Elderly	-627.1	17.4	1290.86	0.0001
Suburbs	276.6	19.3	205.83	0.0001
Rural	327.2	20.0	268.64	0.0001
Winter	-91.7	23.6	15.09	0.0001
Summer	107.6	19.3	31.05	0.0001
Short	309.1	102.3	9.14	0.0026
Female Head	-414.4	20.3	417.13	0.0001
P6979	-98.2	26.5	13.73	0.0002
P1380	-104.9	28.8	13.28	0.0003
P4680	-106.9	27.1	15.54	0.0001
P7980	-56.7	28.1	4.05	0.0443
P1381	-113.4	28.6	15.75	0.0001
P4681	-54.9	26.9	4.16	0.0417

Standard case (1399.9 vehicle-miles monthly per household) = average monthly vehicle-miles during summer 1981 in a vehicle-owning household headed by a nonpoor, nonelderly white male who lives in the central city of an SMSA.

Note: $R^2 = 0.708$ (df = 1650);
$F_{tot} = 184.92$ (<0.0001).

TABLE 8 EFFECT OF INDEPENDENT VARIABLES ON MONTHLY HOUSEHOLD FUEL EXPENDITURES, COMPARED WITH STANDARD CASE

Variable	B (fuel expenditures, $ per month)	Std. Error	F	Prob>F
Intercept	124.19	-	-	-
Black	4.84	2.54	3.62	0.0572
Other Race	-6.96	5.59	1.55	0.2137
Poor	-12.23	2.10	33.78	0.0001
Elderly	-44.64	1.41	993.54	0.0001
Suburbs	18.03	1.56	132.88	0.0001
Rural	21.78	1.62	180.56	0.0001
Winter	-4.24	1.97	4.61	0.0321
Summer	5.53	1.74	10.05	0.0016
Short	21.52	8.29	6.73	0.0096
Female Head	-36.28	1.64	486.69	0.0001
P6979	-39.42	2.47	253.22	0.0001
P101279	-24.16	2.95	66.91	0.0001
P1380	-17.19	2.16	29.55	0.0001
P4680	-17.52	2.68	42.46	0.0001
P7980	-13.93	2.62	28.23	0.0001
P101280	-7.69	2.94	6.84	0.0090
P1381	-7.41	3.15	5.53	0.0188
P4681	-4.51	2.67	2.85	0.0918

Standard case ($124.19 per month = average monthly expenditures during summer 1981 in a household headed by a nonpoor, nonelderly white male who lives in the central city of an SMSA.

Note: $R^2 = 0.69$ (df = 1139);
$F_{tot} = 138.83$ (<0.0001).

households. Clearly, lower fuel economy increases fuel expenditures for a given volume of travel, reduces vehicle range on a given volume of fuel, and—unless additional inventories are used to compensate for these effects—increases vulnerability to price runups and supply shortages.

Presumably, the tendency of poor households to own vehicles with lower fuel economy is a direct reflection of (a) the dynamics of the secondary market and (b) the lead time needed for vehicles with improved fuel economy to pass into the low-cost segment of that market:

1. Until fairly recently, fuel prices were either increasing or expected to increase, and older—generally less fuel-efficient—vehicles retained less of their value in the secondary market. In terms of first cost, these vehicles became increasingly affordable to households with limited means; in terms of variable cost, they became increasingly expensive to operate.
2. Between 1976 and 1984, as newer and more fuel-efficient vehicles came to account for a larger share of the automotive fleet, average fuel economy increased by nearly 25 percent *(5, 6)*. However, because buyers of new and late-model used cars tend to be concentrated in the more affluent population, most fuel economy improvements were confined to those segments, and little, if any, improvement occurred in the fleet operated by lower-income households. By September 1981, the last month of TP data collection, more fuel-efficient vehicles had not yet trickled down to lower income households. Not until quite recently (Millar, 1986, unpublished data) could the fuel economy gains achieved in late-model vehicles be discerned in the gasoline expenditure patterns of lower-income households.

Elderly and black groups also tend to own vehicles with substantially lower fuel economy. Among the elderly, low fuel economy is probably a function of preference and usage patterns. Market research has repeatedly shown that elderly households prefer larger, more comfortable vehicles and are more likely to own domestic makes *(7–9)*. Further, given their shorter daily travel distances, a substantial portion of their travel is likely to be under cold-start conditions, with a consequent loss in fuel economy. Low fuel economy among black households is less readily explained but is probably attributable to income. Because the only income variable is poor or nonpoor, Black may be picking up an income effect. Further, because of racial differences in the yearly fluctuation or dynamics of income *(1, 2)* among poor households, Black may be explaining some of the variability within Poor.

Risk-Taking and Fuel Purchase Behavior

It can be hypothesized that under normal (i.e., nonshortage) conditions, motorists' fill-up rates, fuel inventories, and refueling frequencies reflect their general attitude toward risk, perhaps modified by such external factors as available cash (or credit) and their amount and type of driving. Thus the much higher fill-up percentages and fuel inventories, in combination with much less frequent fuel purchases, suggest that elderly households tend to be risk-averse, perhaps because of physical limitations that increase the difficulty associated with running out of fuel. Conversely, the much lower fill-up percentages and fuel inventories, in combination with more frequent fuel purchases, suggest that black households tend to be risk-prone.

To test this hypothesis, the average volume of fuel per purchase for black and elderly households was calculated and compared with the average volume for the standard case. If elderly households are indeed risk-averse and black households are risk-prone, the elderly should purchase fuel in equal or larger quantities than the standard case, whereas blacks should purchase it in equal or smaller quantities. The results showed virtually no difference in average purchase quantity for elderly and standard households (10.5 versus 10.6 gal), and somewhat higher volumes (11.2 gal) for black households. Thus the hypothesis that fuel inventories and purchase frequency reflect fundamental differences in risk-taking is not supported for black households, and it is neither confirmed nor denied for elderly households.

Among black households, observed differences in fuel inventories, purchase frequencies, and fill-up rates are more likely related to household expenditure patterns, tank capacity, and fuel economy. The purchase quantities noted translate into an average outlay of approximately $14 to $15 per purchase. Many of those transactions are 10-gal or $10 purchases, either reflecting long-standing habits or household budget constraints. At the same time, differences in average vehicle age and size (hence, tank capacity) reported by Millar et al. *(1, 2)* suggest that black households would have to purchase larger quantities of fuel to maintain standard inventories measured as a percentage of tank capacity. Conceivably, the combination of larger tanks and habit- or budget-constrained purchase quantities accounts for the lower inventories and fill-up rates, as well as the more frequent purchases by black households. Along with lower fuel economy, these differences in turn produce lower available range and fewer inventory days (i.e., 2.7 driving days for the average inventory versus approximately 5 for the standard case).

Among elderly households, differences in fuel inventories, purchase frequencies, and fill-up rates are complicated by vehicle utilization rates only two-thirds those of the standard case. Purchase frequencies 30 percent below the standard are consistent with these extremely low utilization rates. Although purchase habits (e.g., weekly, fixed-dollar, or fixed-quantity) probably account for some of the difference in fuel inventories and fill-up rates, extremely high minimum inventories (tank is nearly 40 percent full just before refueling) suggest that risk aversion is also a factor.

SUMMARY AND CONCLUSIONS

Results of the MCA models may be synthesized into a general description of the vehicle ownership, travel, and fuel purchase tendencies of population groups defined by the independent variables (i.e., household attributes) that enter the models. Recall that MCA isolates the contribution of each attribute in explaining the difference between all households with that attribute and a standard case. The resulting, single-attribute-defined population group is more homogeneous than the actual population of such households, and because the influence of covariant attributes has been removed, it highlights attribute-linked tendencies. For example, low vehicle ownership in female-headed households is usually attributed to a combination of gender, poverty, and race [because 47 percent of the families below the poverty line in 1983 were headed by women, 43 percent of whom were black *(10)*]. By breaking out the influence of each of those factors, MCA shows that having a female head has a greater impact on ownership rates among vehicle-owning households—almost twice that of poverty alone and approximately 2.5 times that of race alone. Quite likely, Female head is a surrogate for a combination of low income and few licensed drivers.

The MCA results displayed in Tables 1–8 may be summarized in the following general descriptions of vehicle ownership, travel, and fuel purchase tendencies by vehicle-owning households with the following attributes:

1. Black households tend to own fewer vehicles with much lower fuel economy, to use them somewhat more intensively, and to purchase fuel more frequently than do standard households. Although they purchase fuel in approximately equal quantities, they maintain much lower fuel inventories than do standard households.
2. Poor households also tend to (a) own far fewer vehicles with much lower fuel economy, (b) purchase fuel more frequently, and (c) maintain lower fuel inventories than do standard households. However, unlike black households, members of poor households use their vehicles less intensively.
3. Elderly households are unique among the attribute-defined groups. Although they, too, tend to own far fewer vehicles with much lower fuel economy, they drive them much less intensively. Thus they refuel much less frequently and maintain much higher fuel inventories than do standard households.
4. Female-headed households also own far fewer vehicles but with higher fuel economy. They drive them less intensively, maintain higher fuel inventories, and purchase fuel somewhat less frequently than do standard households.

These attribute-linked tendencies may be plotted for various pairs of dependent variables for which an expected behavior pattern can be hypothesized. Figures 3–5 show three such scatter diagrams in which the origin represents the standard case. Single-attribute-defined groups are represented by their deviation from the standard along each of the two dimensions.

As shown in Figure 3, fuel economy tends to be inversely associated with purchase frequency. Although all of the groups diverge substantially from the standard, most do so in the expected direction. The key exception, the elderly, drive their vehicles much less than the standard. If corrected for vehicle utilization, the Elderly data point would shift to the vertical axis, close to the Poor data point.

Figure 4 shows the positive relationship between average inventories and fill-up rate. All groups diverge substantially

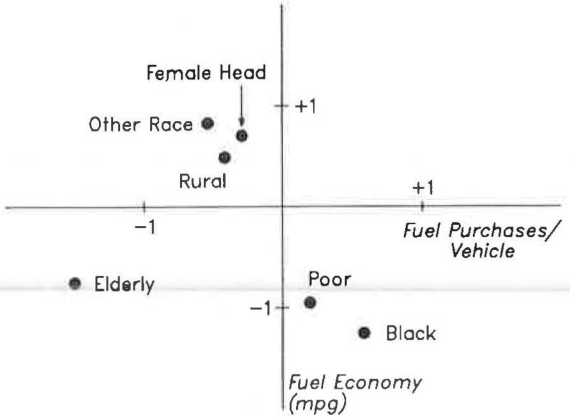

FIGURE 3 Relationship between variations in fuel purchase frequency and fuel economy, by population group.

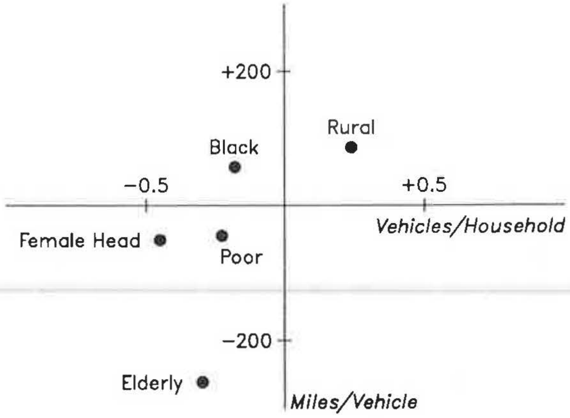

FIGURE 5 Relationship between variations in ownership rate and vehicle utilization, by population group.

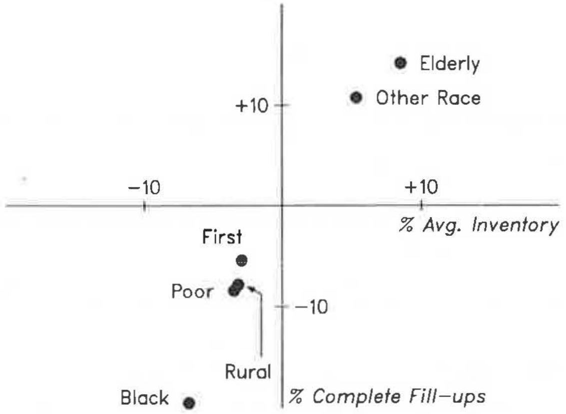

FIGURE 4 Relationship between variations in inventory level and fill-up rate, by population group.

from the standard case, but in the expected direction. Black and elderly groups diverge the most. Because there is no true income variable, Black may be capturing part of the income effect.

Figure 5 shows no clear association between vehicle ownership and utilization, primarily because of intervening factors such as household size (or number of drivers), life-style, and income. Black households are the only group whose position is as expected, but this may be the result of countervailing factors (e.g., income, household size, and life-style). Rural households drive more—because of longer distances, larger household sizes, and more dispersed travel opportunities—whereas elderly households drive less, primarily because of smaller household sizes and fewer travel needs. Poor and female-headed households also tend to drive less than the standard case, a finding that may be interpreted as fewer drivers per household, less income, life-style, and fewer travel needs (if there are fewer workers per household).

Some of the unexplained divergence apparent in Figures 3–5 may arise from limitations of the analysis, particularly from the omission of significant dependent variables. Although predictive ability has not been a focus of this effort, improvements in that regard are a logical direction for further research. As shown, overall rates of household vehicle ownership, travel, and fuel expenditures are fairly well predicted by household demographic characteristics that reflect underlying travel needs. However, variables that are more vehicle-dependent (e.g., fuel economy, vehicle utilization, fuel purchase rates, and fuel inventories) are not so well predicted by demographic factors. These variables are either dependent on vehicle attributes not considered in this effort or have so much internal variance (even within the same household) that a host of additional household- and location-specific variables would be needed to improve the predictive ability of the models.

As a next step to this research, such vehicle characteristics as model year and some measure of engine size could be entered into the models. This should improve predictive ability, but vehicle condition—the basic variable that influences utilization and refueling—would remain unmeasured and thus would continue to account for substantial variance. Likewise, such factors as local weather and road conditions, unanticipated vehicle breakdowns, amount of travel in nonhousehold vehicles (e.g., vacation travel in rental cars), and household illness are not readily modeled. Hence, future research will find it difficult to increase the amount of variance explained by the models.

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Transportation Energy Outlook Under Conditions of Persistently Low Petroleum Prices

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In much the same way that rising oil prices in the 1970s profoundly influenced petroleum production and consumption, an era of persistently low prices will have far-reaching consequences for petroleum supply and demand. Many of those consequences are indirect and will not be widely understood for some time; others are more clear-cut. In this paper, some of the anticipated consequences will be explored, including revised estimates of domestic petroleum reserves, production, and consumption, as well as oil imports. The focus is on transportation, the largest consumer of petroleum products and the most petroleum-dependent sector of the U.S. economy, and the conclusion is that persistently low oil prices will result in a significant decline in domestic oil production, a modest increase in petroleum consumption overall and in transportation (primarily due to reduced fuel efficiency in the vehicle fleet), and a substantial increase in our import dependence and vulnerability to supply interruptions and price shocks. Together, these effects increase the need for improved fuel efficiency and fuel flexibility, yet reduce the market incentive to develop and introduce new fuel-saving echnologies.

Few would argue that oil price forecasting is a risky endeavor. After the second price shock, most forecasters believed that the Organization of Petroleum Exporting Countries (OPEC) would successfully manipulate world oil prices for the foreseeable future, constraining production by both political and physical means. According to that logic, the OPEC cartel would only supply the marginal barrel at the "right" price, and real oil prices would continue their inexorable rise. By 1983, however, the combined effects of conservation, fuel switching, a world recession, and new non-OPEC supplies brought on a striking reversal in actual and predicted oil prices. While demand remained slack and crude prices hovered around $29 per barrel (bbl), forecasts became more demand driven. While prices were still expected to resume an upward path, the timing and slope of that trajectory became increasingly dependent on assumptions about world economic growth and exchange rates, as well as such supply-side factors as non-OPEC oil production and the development and market penetration of non-oil energy supplies.

To a certain extent, the oil price forecasts produced in 1983–1985 supplemented "OPEC-watching" with basic economics. These forecasts, characterized by the expectation that real prices would remain flat or decline slightly in the near term and then rise at annual rates of 1 to 3 percent, differed mainly in the timing of the price upswing *(1)*. The turning point, which was largely a function of when the forecast was generated, was placed variously between 1986 and 1992 [*1–3*; see also the *Annual Energy of Outlook*, U.S. Department of Energy, Report DOE/EIA-0383(83), May 1983 and later editions]. Thus crude oil prices were projected to range from $37 to $49/bbl (in 1985 dollars) in 1990, rising to about $55/bbl in 1995 and $65/bbl in 2000.

In retrospect, it is clear that the forecasts underestimated both the magnitude of the production surplus and Saudi Arabia's commitment to maintaining its oil revenues. Not until prices plunged below $14/bbl in early 1986 did a new round of postcollapse forecasts begin. While it is still too early to verify general trends from this new generation of forecasts, the peaking of non-OPEC oil production and the continued sluggishness in world demand appear to be major considerations. Thus prices are now expected to remain in the $15–20/bbl range for the near term and to rise gradually over the longer term as low levels of investment in nonpetroleum (alternative) energy and non-OPEC oil production increase U.S. dependence on OPEC supplies. The new forcests, unlike the 1983–1985 round of price forecasts, see declining supply (not rising demand) as the major impetus for eventual price growth.

Figure 1 shows the difference between pre- and postcollapse price expectations by contrasting the spring 1984 and autumn 1986 projections of world oil prices published by Data

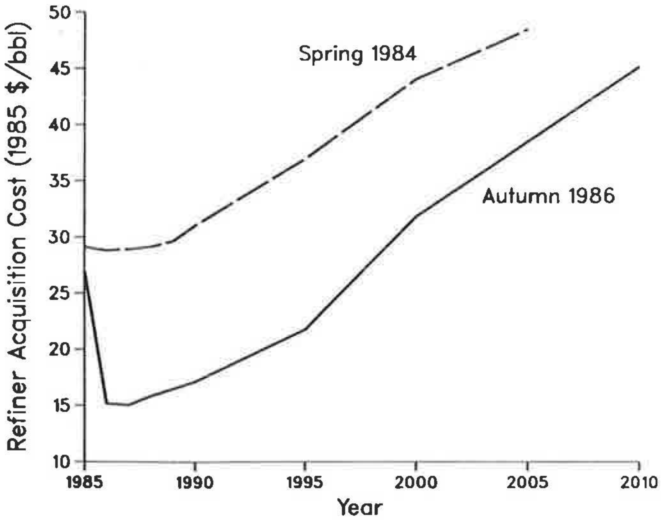

FIGURE 1 DRI oil price forecasts, 1984 versus 1986 [adapted from the *DRI Energy Review (4, 5)*].

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Resources, Inc. (DRI) *(4, 5)*. The decline is particularly dramatic over the next decade, forcing analysts to reevaluate their forecasts of domestic and world consumption, production, and imports. The relevant aspects of that reevaluation will be briefly summarized here with particular emphasis on the impact of persistently low oil prices on the transportation sector and the outlook for new vehicles and fuels.

PETROLEUM CONSUMPTION, PRODUCTION, AND IMPORTS IN AN ERA OF LOW OIL PRICES

Petroleum Consumption

While lower oil prices will not bring commensurate increases in petroleum consumption, they will significantly affect demand. In a recent survey of representatives of industry, utilities, government, consulting firms, and the financial community, the National Petroleum Council (NPC) estimated that crude oil prices of \$21 versus \$36/bbl (1986 dollars) in the year 2000 would increase U.S. petroleum demand by 2.5 million (2.5×10^6) bbl/day (about 14 percent) *(6)*. Similarly, the Energy Information Administration (EIA) within the U.S. Department of Energy has estimated that a \$10 reduction in crude oil prices (from \$30 to \$20/bbl) will increase 1995 U.S. oil consumption by 1.5×10^6 bbl/day (9 percent) *(7)*.

Frequently, however, revised economic forecasts obscure much of the impact of falling prices. For example, the DRI 1986 projection for U.S. petroleum consumption in 2000 is nearly equivalent to the value in the DRI 1984 forecast, despite the price decline mentioned earlier (Figure 2) *(4, 5)*. The similarity is due to a dramatic reduction in DRI's near-term industrial production forecast. Conoco's 1986 forecast also shows considerably less growth in oil consumption than price effects would otherwise suggest *(8)*. Conoco attributes its results to assumed declines in energy intensity from (a) new capital equipment and structures that require less energy than the existing stock, (b) increased cogeneration, and (c) a continuing shift in the economy toward less energy-intensive services and light manufacturing.

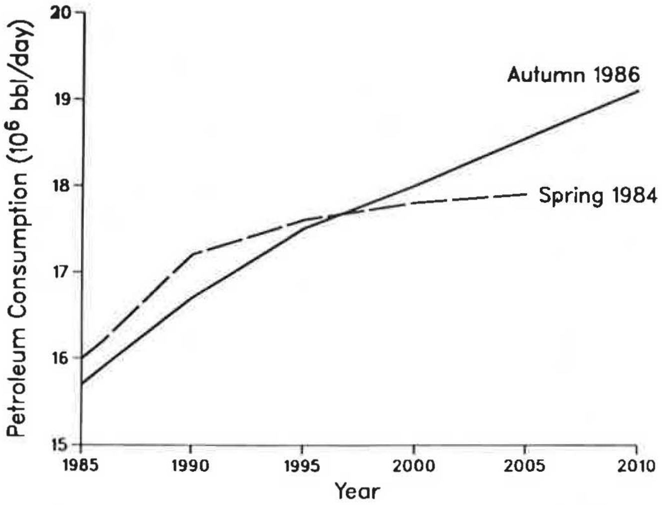

FIGURE 2 DRI forecasts of U.S. petroleum consumption, 1984 versus 1986 [adapted from the *DRI Energy Review* (4, 5)].

Persistently low oil prices are expected to have a much greater effect on oil demand outside the United States. While EIA predicts a 9 percent increase in U.S. demand, its Oil Market Simulation Model forecasts an increase of 9 to 13 × 106 bbl/day in 1995 world oil demand (20 to 28 percent) because of a \$10 reduction in crude oil prices *(7)*.

Petroleum Production

On a percentage basis, lower prices are likely to have a far greater effect on production than on consumption. The United States is already a relatively high-cost producer, and much of its oil comes from low-volume stripper wells, many of which are becoming uneconomical at current oil prices. Further, the United States accounts for only 4 percent of world crude oil reserves, and despite dramatic increases in drilling after the price shocks of the 1970s, reserve additions have barely offset production in recent years *(9, 10)*. As shown in Figure 3, no giant domestic fields have been discovered since 1970, and recent drilling off the California and Alaska coasts has yielded several highly publicized disappointments *(6, 11)*. Because of declining prices, exploration has been drastically cut, and drilling has virtually stopped in many areas *(6, 12*; see also *Rotary Rigs Running, by State*, Hughes Tool Co., Houston, Texas; various issues). Between 1981 and mid-1986, domestic drilling—as measured by the average number of active rotary rigs—plummeted from a high of 3,970 to about 700 *(11)*. The data in Table 1 indicate the decline since 1983. Note that drilling in 1986 declined more sharply in the United States than in any other world region.

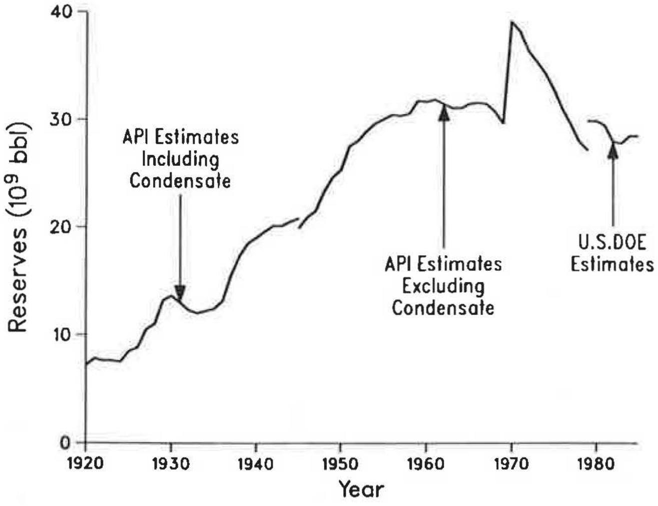

FIGURE 3 Estimates of U.S. crude oil reserves. Condensate is included in estimates until 1945 [adapted from *Twentieth Century Petroleum Statistics 1982 (10)* for pre-1980 estimates and from *Annual Energy Review 1985 (12)*].

As shown in Figure 4, U.S. oil exploration is particularly sensitive to crude oil prices. According to a recent NPC survey of members of the Independent Petroleum Association of America and the Society of Earth Scientists, drilling could decline by 85 percent (i.e., to fewer than 300 active rigs) by 1990 if crude oil prices remain at current levels *(6)*.

TABLE 1 AVERAGE NUMBER OF ACTIVE ROTARY DRILLING RIGS BY WORLD REGION, 1983–1986 *(11)*

				1986	
Region	1983	1984	1985	First Half	June
United States	2233 (-28)	2428 (9)	1970 (-19)	1131 (-44)	705
Other Developed Countries					
Canada	203 (2)	257 (29)	313 (22)	235 (-20)	64
Western Europe	184 (-21)	203 (10)	231 (14)	218 (-4)	179
South Pacific	38 (-18)	37 (3)	36 (-3)	25 (-30)	17
Non-OPEC Developing Countries					
Middle East	59 (18)	71 (20)	77 (8)	84 (14)	78
Africa	47 (-19)	36 (-23)	36 (0)	24 (-33)	21
Far East[a]	187 (-2)	175 (-6)	181 (3)	165 (-9)	160
OPEC	802 (NA)	716 (-11)	729 (2)	669 (-8)	649
Total Noncommunist World	3723 (-22)	3923 (5)	3573 (-9)	2551 (-29)	1873

[a] Includes China.

Note: Numbers in parentheses are percent change from previous year.

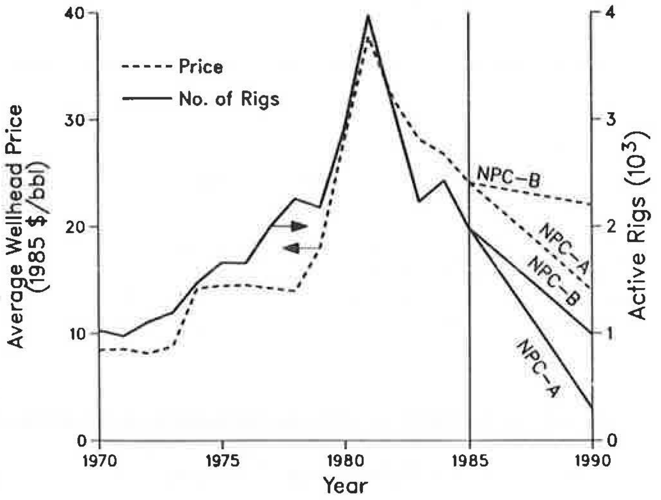

FIGURE 4 Crude oil price and drilling rig activity [adapted from various sources *(6, 12)*].

Similarly, the American Petroleum Institute (API) estimates 1991 drilling declines of 60 percent for $15/bbl crude oil and 80 percent for $10/bbl crude oil *(15)*.

Because it takes several years for economic quantities of crude oil to begin flowing from newly discovered reserves, such reductions have little impact on current domestic production, but they do have an increasingly negative impact on long-term production *(8, 14)*. According to the NPC survey discussed previously, if prices drop from $36 to $21/bbl, domestic production could decline by 30 percent (nearly 2×10^6 bbl day) in the year 2000 *(6)*. DRI and EIA forecast similar declines *(5, 7, 15)*.

Imports

Table 2 summarizes the effect of persistently low oil prices on import dependence, as well as on domestic drilling activity, production, and consumption. Over time, lower prices reduce

TABLE 2 OIL CONSUMPTION, PRODUCTION, AND IMPORT SHARES UNDER ALTERNATIVE PRICE ASSUMPTIONS, 1985–2000 *(5, 9–10, 15, 17, 21)*

Parameter	1985	1990	1995	2000
Crude Oil Price (1985 $)				
EIA	27	17-27[a]	20-30	NA[b]
DRI	27	17-31	22-37	32-44
NPC	27	14-22	17-28	21-36
API	27	15-28[c]	-	NA
Domestic Drilling Index				
EIA[d]	1.0	0.58-0.80	0.56-0.86	NA
NPC[e]	1.0	0.15-0.50	NA	NA
API[e]	1.0	0.4-1.0	NA	NA
Oil Consumption (10^6 bbl/day)				
EIA	15.7	17.1-16.1	18.2-16.6	NA
DRI	15.7	16.7-17.2	17.5-17.6	18.0-17.8
NPC	15.7	17.6-16.3	19.0-17.0	19.9-17.4
Domestic Production[f] (10^6 bbl/day)				
EIA	8.9	7.2-8.1	5.0-6.5	NA
DRI	9.0	7.9-8.5	6.4-8.2	5.6-8.0
NPC	8.9	7.1-8.0	5.7-7.0	4.5-6.4
Imports (10^6 bbl/day)				
EIA	4.3	7.4-5.8	11.0-7.8	NA
DRI	4.2	7.0-6.6	9.5-7.4	10.9-8.1
NPC	4.3	8.4-6.2	11.4-7.9	13.6-9.1
Import Share of Total Supply (%)				
EIA	27	43-36	60-47	NA
DRI	27	42-39	54-42	60-46
NPC	27	48-38	60-46	68-52

[a] First value in range refers to source's lower-price case, second value to source's higher-price case.

[b] NA = not applicable.

[c] 1991.

[d] Indexed to 1985 total oil and gas footage drilled.

[e] Indexed to 1985 count of average active rotary rigs.

[f] Excluding natural-gas liquids.

Note: EIA = Energy Information Administration; DRI = Data Resources, Inc.; NPC = National Petroleum Council; API = American Petroleum Institute.

domestic production and encourage growth in oil demand. Clearly, this increases dependence on imported oil.

From a macroeconomic standpoint, increased oil imports can have either positive or negative effects, depending on whether they stimulate or reduce economic growth. In the near term, increased imports of lower-priced oil increase economic growth *(5, 15)*. In the longer term, low prices have mixed effects. Their impact on U.S. oil import expenditures is illustrated in Figure 5. On the basis of crude oil and refined product prices and import quantities presented in the most recent DRI forecast, Figure 5 shows import expenditures declining through the late 1980s and staying well below historical levels through the mid-1990s because sharply lower prices more than offset increased quantities, thereby producing a net benefit to the U.S. economy. By 2000, however, the combination of greater quantities, rising prices, and relatively more valuable refined products constituting a larger share of import quantities results in higher import expenditures in the lower-price (1986) case. (In the 1986 forecast the share of refined products rises from about one-third to more than one-half of petroleum import volumes by 1995.)

Increased oil imports also pose serious strategic implications. In 1983–1985, most forecasts estimated that U.S. petroleum imports in the year 2000 would range from 40 to 50 percent of supply, a share roughly comparable to that prevailing in the late 1970s. Since the price collapse, import share forecasts have been revised upward to 60 percent or more of

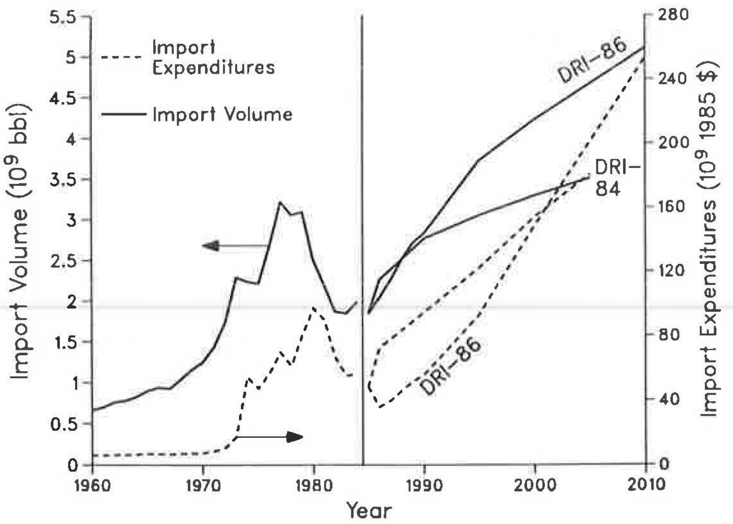

FIGURE 5 U.S. oil imports and oil import expenditures [adapted from various sources *(4, 5, 12)*].

U.S. petroleum supply in 2000. Such levels of import dependence significantly increase U.S. vulnerability to supply disruptions *(6, 8, 16, 17)*. Further, because 55 percent of the world's proven crude oil reserves and the bulk of surplus production capacity are located in the Middle East, U.S. import dependence will become increasingly concentrated on that region.

As the most petroleum-dependent demand sector, transportation is particularly at risk from supply disruptions. The dramatic price runups of the 1970s prompted large-scale shifts from petroleum to coal and nuclear fuels for power generation and to electricity for industrial process heat and for residential and commercial space conditioning *(12)*. Because many conversions (particularly by electric utilities) retained a multifuel capability, much of the price-induced increase in petroleum use in response to falling oil prices may come from a steady shift back to oil by fuel-flexible users. In the short run, this additional demand could compete with transportation for the marginal barrel in a sudden supply disruption, thereby further exacerbating the impact.

Analysts agree that the degree of U.S. vulnerability to possible oil price shocks and supply shortages depends on such factors as (a) level of domestic oil production, (b) size and accessibility of the Strategic Petroleum Reserve (SPR) and other surge production capability, (c) stability and diversity of U.S. energy sources, and (d) availability of alternative fuels and the technologies to use them. In the past decade, rising prices made it economically feasible to drill in marginal, geologically difficult or environmentally hostile areas, to devote substantial resources to R&D on enhanced recovery techniques and alternative fuels, and to maintain marginally productive stripper wells. Despite these significant efforts, no breakthroughs have dramatically increased U.S. reserves (either by new discoveries or enhanced productivity of existing wells) or made alternative fuels technically or economically competitive with petroleum. Without such breakthroughs, the United States is likely to be just as vulnerable to supply disruptions in the future as it was in the past. With increased consumption in response to persistently low oil prices, the issue of vulnerability, particularly for such oil-dependent sectors as transportation, becomes especially critical.

THE TRANSPORTATION SECTOR IN AN ERA OF LOW OIL PRICES

In 1985 the transportation sector accounted for 63 percent of U.S. petroleum consumption *(3)*. Unlike other sectors, in which relative prices influence fuel-switching decisions, transportation has no viable fuel flexibility in the near term. Thus the rising prices of the past decade did not promote significant fuel shifts. They did, however, encourage motorists to purchase vehicles that were more fuel efficient and to adopt various conservation practices. Although falling oil prices should reduce consumer incentives to maintain demand-restraining practices, the overall effect of a price drop on demand for transportation fuel is less clear. Obviously, motorists are not going to trade in their current automobiles for pre-1973 gas guzzlers, and truckers are not going to dismantle air deflectors or fan clutches. Many conservation gains have been integrated into the structure of the transportation sector, and unless these improvements are perceived as reducing mobility or providing an inferior level of service (as measured by vehicle comfort, maintainability, performance, etc.), they are not likely to be abandoned in the face of a price drop. However, just as consumers responded to rising prices by conserving, they may be expected to react to falling prices by making incremental changes in their purchase decisions and travel patterns. In the aggregate and over time, these behavioral changes could produce a marked increase in petroleum demand.

The following discussion focuses on the long-term effects of lower petroleum prices on transportation activity and fuel use, as well as the implications for development of alternative fuels. Effects are identified by comparing the results of two scenarios, one with persistently low oil prices and moderately high economic activity, the other a prior "trend," or reference, forecast based on the assumptions in the most recent National Energy Plan *(18)*. The trend scenario, referred to as ANL-85N (or simply 85N) in the following discussion, is described further elsewhere (unpublished information, M. Millar and A. Vyas, Argonne National Laboratory). The low-price scenario, based on DRI's spring 1986 low world oil price and optimistic economic growth forecasts, is described by DRI *(19, 20)* and referred to as ANL-86LOW (or simply 86L).

Both forecasts were generated with the Transportation Energy and Emissions Modeling System (TEEMS), a series of models developed and maintained by the Center for Transportation Research at Argonne National Laboratory (Argonne, Illinois). TEEMS is a disaggregate system of behavioral models that is sensitive to such economic and demographic factors as fuel price; household size, composition, and income; and sectoral economic activity, as well as to such vehicle and system attributes as relative modal cost, performance, and level of service. By using the economic and demographic features of the two input scenarios, TEEMS projects activity levels (i.e., vehicle-, ton-, or passenger-miles traveled) and energy consumption for all passenger and freight modes, as well as vehicle stocks and fleet average fuel economy for all highway modes. Because of the disaggregate nature of TEEMS, fuel price effects appear not only as changes in vehicle operating cost but also as changes in overall economic activity, household income, and other household attributes. Thus differences between the resulting forecasts reflect both direct and indirect price effects. [For a further discussion of the TEEMS methodology, see Vyas et al. *(21)*].

Features of the Two Scenarios

Figures 6 and 7 compare the major demographic and economic assumptions of both scenarios. Differences in labor force participation and household formation produce widening gaps (of more than 6 and 7 percent, respectively) in the numbers of employed individuals and households by 2010. Similarly, with a difference of 0.4 percent per year in economic growth, the gross national product (GNP) gap between the two scenarios widens to nearly 9 percent by 2010.

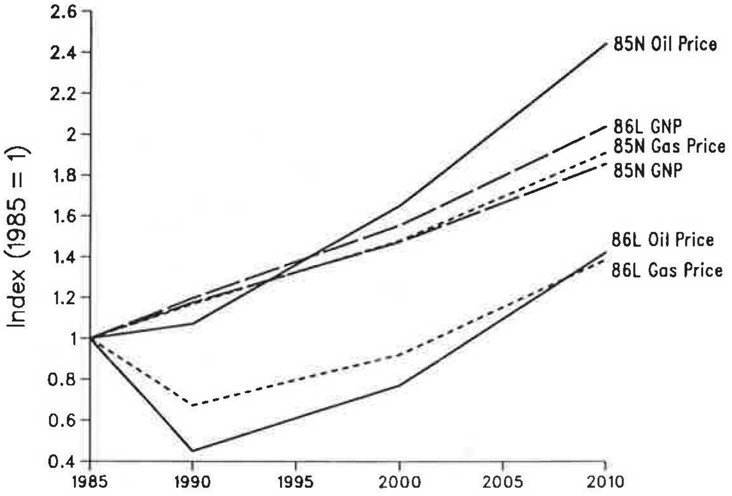

FIGURE 6 Key economic assumptions, ANL-85N and ANL-86L.

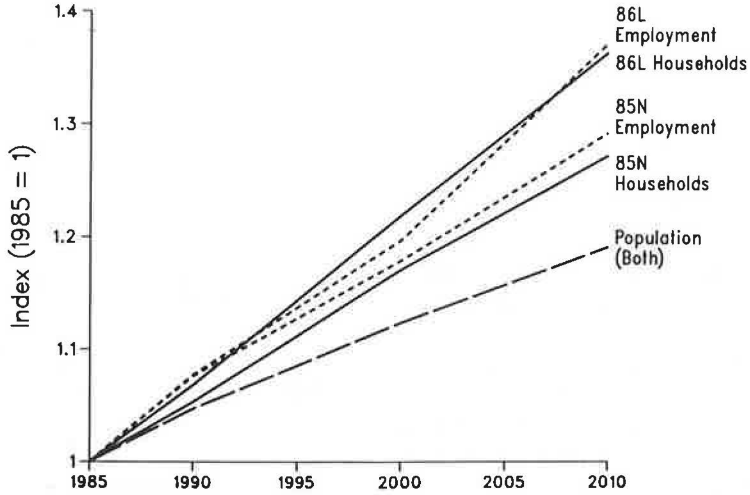

FIGURE 7 Key demographic assumptions, ANL-85N and ANL-86L.

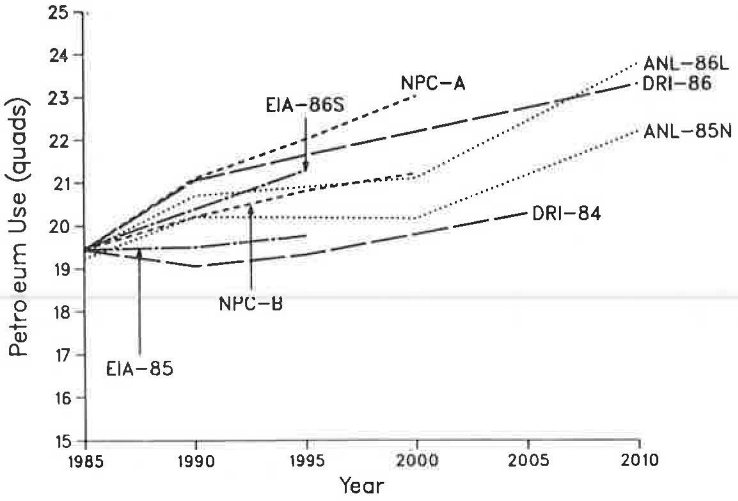

FIGURE 8 **Forecasts of petroleum use in transportation. 1 quad = 10^{15} Btu [adapted from various sources (4–7)].**

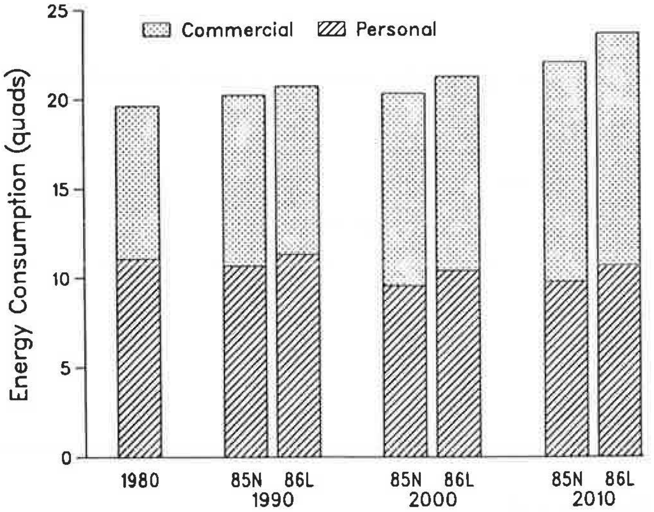

FIGURE 9 **Energy consumption by commercial and personal vehicle uses, ANL-85N and ANL-86L. 1 quad = 10^{15} Btu.**

Economic differences are even more pronounced at the sectoral level. Under the 86L scenario, growth varies from less than the overall GNP difference (i.e., less than 9.1 percent in 2010) in such sectors as primary metals and coal to more than twice the GNP difference in the food products, oil, natural gas, services, farm products, paper, and rubber and plastics sectors. As discussed later, these differences translate into relatively slower growth in modes transporting a high proportion of primary goods, despite higher overall growth in the low-price scenario.

Figure 6 also shows trends in world oil and retail gasoline prices. Under the 86L scenario, prices drop further and fail to regain their 1985 levels until beyond the year 2000. However, by that time, they are rising at faster annual rates than under the reference case (i.e., 6.3 percent versus 4.0 percent for crude oil and 4.1 percent versus 2.6 percent for gasoline).

Scenario Results

Tables 3 and 4 summarize energy use by mode under the two scenarios. Despite increased travel, consumption in both cases rises relatively slowly in the short term while currently available technologies continue to improve the efficiency of the vehicle stock. In the longer term, consumption accelerates in the absence of more radical technological improvements that are not considered in this effort. By 2010 the 86LOW forecast estimates 1.8 quads more energy use than the 85N forecast (1 quad = 1015 Btu). The largest differences occur in automobiles, light trucks, rail freight, and domestic water transportation.

As mentioned earlier, the scenarios are based on 1984 and 1986 DRI economic forecasts. Thus they show less overall variation than price effects would suggest because of important

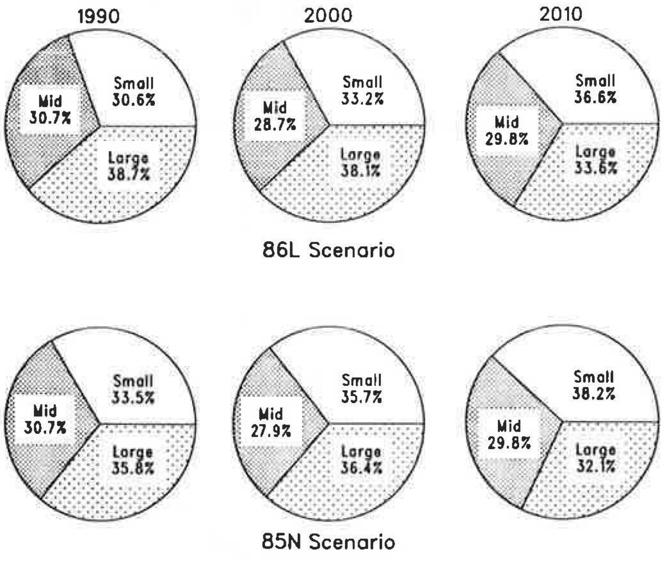

FIGURE 10 **Automobile size shares, ANL-85N and ANL-86L.**

TABLE 3 PROJECTIONS OF TRANSPORTATION ENERGY CONSUMPTION BY MODE AND SUBMODE, ANL-86L

Transportation Mode and Submode	Energy Consumption[a] (quads)				Change, 1980-2010 (%)	
	1980	1990	2000	2010	Total	Annual
Personal Vehicles	11.06	11.30	10.38	10.68	-3.4	-0.1
Automobiles	9.18	8.38	7.79	8.16	-11.1	-0.4
Light trucks[b]	1.88	2.93	2.59	2.52	34.0	1.0
Buses	0.14	0.18	0.21	0.26	85.7	2.1
School	0.05	0.05	0.06	0.07	40.0	1.0
Transit	0.06	0.09	0.11	0.13	96.9	2.3
Intercity	0.03	0.04	0.05	0.06[c]	115.2	2.6
Commercial Trucks	3.42	3.75	4.32	5.12	49.7	1.4
Light	1.02	1.12	1.21	1.42	39.2	1.1
Heavy	2.39	2.62	3.11	3.70	54.8	1.5
Rail	0.61	0.81	1.07	1.42	132.8	2.9
Freight	0.55	0.74	1.00	1.34	143.6	3.0
Passenger	0.07	0.06	0.07	0.08	14.3	0.4
Transit/commuter	0.04	0.05	0.06	0.07	51.2	1.4
Intercity	0.02	0.01	0.01	0.01[c]	-18.8	-0.7
Marine	1.78	1.69	2.13	2.72	52.8	1.4
Domestic freight	0.39	0.46	0.53	0.64	64.1	1.7
International freight[d]	1.22	1.00	1.30	1.71	40.2	1.1
Recreational[b]	0.18	0.24	0.30	0.38	94.4	2.2
Aviation	1.58	1.97	2.10	2.40	51.9	1.4
General aviation	0.18	0.25	0.47	0.40	122.2	2.7
Domestic passenger	1.22	1.47	1.31	1.58[c]	29.5	0.9
International passenger[e]	0.14	0.19	0.22	0.28	100.0	2.3
Domestic freight	0.04	0.07	0.09	0.13	225.0	2.7
Pipeline	0.84	0.83	0.81	0.78	-7.1	-0.2
Natural gas	0.68	0.65	0.62	0.58	-14.7	-0.5
Crude oil	0.09	0.10	0.11	0.12	33.3	1.0
Petroleum products	0.07	0.07	0.07	0.08	14.3	0.4
Coal slurry[f]	0.00	0.00	0.00	0.00	0	0
Miscellaneous Vehicles[b,g]	0.20	0.19	0.21	0.25	25.0	0.7
Total Energy[h]	19.61	20.72	21.23	23.62	20.4	0.6

[a] Modal values may not equal submode totals due to rounding; 1 quad = 10^{15} Btu.

[b] Includes minivans.

[c] Rough estimate derived by extrapolating 1980-2000 growth.

[d] U.S. sales of bunker fuels. Includes foreign-flag and some military consumption.

[e] Fuel purchases in U.S. by domestic carriers (assumes 50% is purchased overseas).

[f] Assumes no new construction of coal slurry pipelines (0.004 quad).

[g] Motorcycles, snowmobiles, and off-highway trucks.

[h] Excludes most military consumption, U.S. fuel purchases by foreign-flag air carriers, and all lubricants.

TABLE 4 PROJECTIONS OF TRANSPORTATION ENERGY CONSUMPTION BY MODE AND SUBMODE, ANL-85N

Transportation Mode and Submode	Energy Consumption[a] (quads)				Change, 1980-2010 (%)	
	1980	1990	2000	2010	Total	Annual
Personal Vehicles	11.06	10.06	9.54	9.75	-11.8	-0.4
Automobiles	9.18	8.03	7.20	7.49	-18.1	-0.7
Light trucks[b]	1.88	2.62	2.34	2.26	20.2	0.6
Buses	0.14	0.18	0.20	0.23	62.9	1.6
School	0.05	0.05	0.05	0.07	40.0	1.0
Transit	0.06	0.09	0.10	0.10	83.3	1.9
Intercity	0.03	0.04	0.05	0.06[c]	115.2	2.6
Commercial Trucks	3.42	3.71	4.08	4.58	33.8	1.0
Light	1.02	1.04	1.10	1.42	20.7	0.6
Heavy	2.39	2.67	2.99	3.35	39.9	1.1
Rail	0.61	0.83	1.11	1.45	140.6	3.0
Freight	0.55	0.77	1.04	1.34	150.4	3.1
Passenger	0.07	0.06	0.07	0.38	0	0
Transit/commuter	0.04	0.05	0.05	0.07	50.0	1.2
Intercity	0.02	0.01	0.01	0.01[c]	-18.8	-0.7
Marine	1.78	1.68	2.06	2.52	41.2	1.2
Domestic freight	0.39	0.43	0.49	0.55	42.3	1.2
International freight[d]	1.22	1.02	1.28	1.61	32.0	0.9
Recreational[b]	0.18	0.23	0.29	0.35	94.4	2.2
Aviation	1.58	1.88	1.89	2.31	46.1	0.5
General aviation	0.18	0.24	0.30	0.38	108.3	2.5
Domestic passenger	1.22	1.40	1.28	1.54[c]	26.6	0.8
International passenger[e]	0.14	0.18	0.22	0.28	97.9	2.3
Domestic freight	0.04	0.06	0.09	0.12	192.5	3.6
Pipeline	0.84	0.82	0.80	0.73	-13.9	-0.5
Natural gas	0.68	0.67	0.64	0.57	-16.2	-0.6
Crude oil	0.09	0.09	0.09	0.09	-4.4	0.2
Petroleum products	0.07	0.07	0.07	0.07	-7.1	0.2
Coal slurry[f]	0.00	0.00	0.00	0.00	0	0
Miscellaneous Vehicles[b,g]	0.20	0.19	0.21	0.25	25.0	0.7
Total Energy[h]	19.61	19.95	20.04	21.83	11.3	0.4

[a] Modal values may not equal submode totals due to rounding; 1 quad = 10^{15} Btu.

[b] Includes minivans.

[c] Rough estimate derived by extrapolating 1980-2000 growth.

[d] U.S. sales of bunker fuels. Includes foreign-flag and some military consumption.

[e] Fuel purchases in U.S. by domestic carriers (assumes 50% is purchased overseas).

[f] Assumes no new construction of coal slurry pipelines (0.004 quad).

[g] Motorcycles, snowmobiles, and off-highway trucks.

[h] Excludes most military consumption, U.S. fuel purchases by foreign-flag air carriers, and all lubricants.

TABLE 5 PRINCIPAL VARIABLES RESPONSIBLE FOR DIFFERENCES IN ENERGY USE BETWEEN THE TWO FORECASTS IN 2000 (PERCENT DIFFERENCE, 86L VERSUS 85N)

	Highway Modes				Nonhighway Modes						
Variable	Auto	Personal Light Truck	Commercial Light Truck	Heavy Truck	Rail Freight	Domestic Water	Intl. Water	Air Passenger[a]	Pipeline	Misc. Modes[b]	Total All Modes
Fuel Price	6.0	7.7	0.7	1.0	0.8	0.4	c	2.5	c	c	3.4
Economic Activity	d	d	10.1	3.2	-5.4	8.4	1.5	d	2.3	2.2	1.2
Household Growth	4.1	6.3	e	e	e	e	e	e	e	c	2.2
Household Demographics	-2.1	-2.9	e	e	e	e	e	e	e	0.6	-1.1
Coal Production[f]	e	e	e	-0.8	-4.4	-2.1	c	e	c	c	-0.4
Synergistic and Other	0.1	-0.2	0.1	0.8	1.8	2.1	0	0	0	0	-0.7
Total Difference (86L/85N)[g]	8.1	10.9	10.9	4.2	-7.2	8.8	1.5	2.5	2.3	2.7	4.6

[a] Domestic and international.

[b] Recreational boating, general aviation, air freight, bus, rail passenger, etc.

[c] Included in economic effect.

[d] Included in price effect.

[e] Not applicable; TEEMS module insensitive to parameter.

[f] Reduced output from the coal sector, all other sectors unchanged.

[g] Values may not sum to total shown due to rounding.

differences in their underlying economic assumptions. This may be seen in Table 5 in which consumption differences are allocated between the two scenarios (4.6 percent in the year 2000) to the influence of several independent variables. Fuel price is clearly the key factor (although household growth and demographic changes are also extremely important) in accounting for variations in automobile and personal light truck energy consumption, while economic activity is most important in explaining differences in commercial vehicle energy consumption.

The marked difference in the influence of economic activity on the forecast of energy use by light versus heavy trucks reflects both (a) the 86L scenario's substantially stronger growth of service sectors, which tend to rely on lighter vehicles; and (b) the forecasting methodology, which simulates the shipment decisions of goods-generating sectors by using modal cost and service attributes. Thus, while trucks compete with rail and water modes for goods shipments, they capture all service traffic. For nonhighway freight modes, differences in energy use also reflect sectoral variability in economic activity. For example, the combination of lower outputs of coal and primary metals and higher outputs of oil and agricultural goods tends to increase waterborne freight in the 86L forecast.

Figure 8 shows a comparison of transportation petroleum use under the 86L and 85N forecasts with that in other recent forecasts. The DRI-4 forecast has both the lowest petroleum use and, as shown in Table 2, the highest oil price. Conversely, the lower of the two NPC price forecasts (termed NPC-A in

TABLE 6 FLEET AVERAGE FUEL ECONOMY BY VEHICLE SIZE CLASS AND FUEL TYPE, ANL-86L

Vehicle Size Class and Fuel Type	On-Road Fuel Economy (mpg)				Improvement, 1980-2010 (%)
	1980[a]	1990	2000	2010	
Automobiles	15.2	21.0	25.3	27.1	79.1
Small	18.7	26.0	31.0	32.6	74.1
Medium	15.2	21.5	25.8	27.2	79.1
Large	13.1	17.8	21.4	22.7	73.3
Gasoline	15.1	20.9	25.2	26.9	78.3
Diesel	21.5	28.4	33.4	36.1	67.9
Trucks	9.8	13.3	14.1	14.7	50.0
Personal light[b]	13.0	18.2	20.7	22.5	73.5
Gasoline	13.9	19.2	21.7	23.6	83.0
Diesel	17.0	22.6	25.2	28.1	65.7
Commercial light (Classes 1-2)[c]	14.0	16.7	19.4	20.6	46.9
Gasoline	14.0	16.7	19.1	20.3	45.0
Diesel	17.0	17.9	21.0	22.2	30.6
Medium (Classes 3-5)	7.0	8.3	8.6	9.0	28.6
Gasoline	7.0	8.2	8.5	8.7	24.3
Diesel	7.3	8.8	9.1	9.4	28.8
Light-heavy (Class 6)	5.8	6.8	7.2	7.6	30.9
Gasoline	5.8	6.4	6.7	6.9	19.0
Diesel[d]	6.0	7.2	7.5	7.8	30.0
Heavy-heavy (Class 7-8)	4.9	5.7	6.0	6.5	33.3
Gasoline	4.4	4.9	5.2	5.2	18.2
Diesel[d]	4.9	5.7	6.1	6.5	32.7

[a] The low variation in historic gasoline vs. diesel truck fuel economy within size classes is attributed to relatively more demanding mission requirements for diesel vehicles. With increased penetration of diesels in vehicles with less-demanding missions, the average fuel economy of diesels should increase so that the gasoline vs. diesel variation will widen.

[b] Includes minivans.

[c] Size classes based on manufacturers' weight classes.

[d] Assumes electronic controls will offset only a portion of the fuel-economy penalty associated with EPA's proposed emission standards for new heavy-duty vehicles.

TABLE 7 FLEET AVERAGE FUEL ECONOMY BY VEHICLE SIZE CLASS AND FUEL TYPE, ANL-85N

Vehicle Size Class and Fuel Type	On-Road Fuel Economy (mpg)				Improvement, 1980-2010 (%)
	1980[a]	1990	2000	2010	
Automobiles	15.2	21.7	26.8	28.4	77.2
Small	18.7	26.7	32.8	34.1	75.2
Medium	15.2	21.6	26.7	27.8	75.5
Large	13.1	18.3	22.7	23.8	72.9
Gasoline	15.1	21.6	26.7	28.2	76.8
Diesel	21.5	29.0	35.1	37.6	63.3
Trucks	9.8	13.1	14.4	14.9	52.0
Personal light[b]	13.0	19.8	22.9	24.4	87.7
Gasoline	12.9	19.7	22.6	23.9	85.3
Diesel	17.0	25.4	30.5	31.7	86.5
Commercial light (Classes 1-2)[c]	14.0	17.8	20.6	22.0	57.1
Gasoline	14.0	17.7	20.4	21.6	54.3
Diesel	17.0	19.1	22.3	23.6	38.8
Medium (Classes 3-5)	7.0	8.3	8.9	9.3	32.9
Gasoline	7.0	8.2	8.5	8.7	24.3
Diesel	7.3	8.8	9.5	9.8	34.2
Light-heavy (Class 6)	5.8	6.8	7.6	8.0	37.9
Gasoline	5.8	6.4	6.7	6.9	19.0
Diesel[d]	6.0	7.2	7.8	8.1	35.0
Heavy-heavy (Class 7-8)	4.0	5.7	6.3	6.8	38.8
Gasoline	4.4	4.9	5.2	5.2	18.2
Diesel[d]	4.9	5.7	6.3	6.8	38.8

[a] The low variation in historic gasoline vs. diesel truck fuel economy within size classes is attributed to relatively more demanding mission requirements for diesel vehicles. With increased penetration of diesels in vehicles with less-demanding missions, the average fuel economy of diesels should increase so that the gasoline vs. diesel variation will widen.

[b] Includes minivans.

[c] Size classes based on manufacturers' weight classes.

[d] Assumes electronic controls will offset only a portion of the fuel-economy penalty associated with EPA's proposed emission standards for new heavy-duty vehicles.

Figure 8) has the highest petroleum use and the lowest oil price (see Table 2). In all cases, lower oil prices appear to result in some two additional quads of oil use by 2010.

Figure 9 shows a comparison of energy consumption by type of vehicle use under the two ANL scenarios. All automobiles and personal light trucks are considered personal vehicles; all other highway and nonhighway modes (e.g., other trucks, aircraft, ships, etc.) are considered commercial vehicles. For both purposes, energy use under the two scenarios differs by approximately 10 percent by 2010. Only a small portion of this difference is attributable to increased travel in response to lower fuel prices. Most occurs as a result of the strong relationship between fuel price and fuel economy (see Tables 6 and 7), mediated by several key intervenors. In the 86L scenario, reduced fuel economy arises from a combination of size shifts (see Figure 10), declines in diesel shares, and a slowing in the pace of technology improvement within individual size classes. All three of these results are produced by lower fuel prices and in turn produce lower fuel efficiency.

Price elasticities calculated from the TEEMS fuel economy forecasts are nonlinear. For the two scenarios described here, results translate into a fuel economy elasticity of 0.1 mpg for the entire automotive fleet in 1990, rising to 0.2 mpg in 2000. These compare with elasticities for new automobiles ranging from 0.1 in the short run to 0.7 mpg or higher in the long run, on the basis of results reported in the general literature *(22–24)*.

CONCLUSIONS

As would be expected, both consumers and businesses were delighted with the dramatic decline in petroleum prices during

1986. Individuals could look forward to an extended period of reduced travel costs, and businesses could anticipate that the costs of one production factor would be lower for perhaps several years.

As in most cases, however, trade-offs are involved. This is especially true with respect to the national policy issues associated with oil supply and demand. Lower world oil prices have the immediate effect of lessening the nation's import costs. Over time, however, lower prices spur consumption, reduce the demand for improved fuel efficiency, and diminish incentives for domestic oil exploration and development. Thus the volume of imported oil increases and the nation's import costs rise over time.

In the short run, increased oil imports do not negatively affect the national economy or dramatically increase the potential for oil supply disruptions. However, this assumption often precludes discussion of longer-run economic effects and vulnerability to supply interruptions. With domestic reserves already declining and lower oil prices increasing the consumption of energy, the United States can expect to be importing more oil by the late 1990s than it ever has. Thus the long-term consequences of low oil prices greatly increase oil import costs and vulnerability to supply interruptions and may, in fact, offset most of the benefits of the Strategic Petroleum Reserve and the fuel efficiency and conservation actions that have been implemented to date.

In such a future, the demand for improved fuel efficiency and fuel flexibility continues to decline. This is already becoming apparent in stable-to-declining new car fuel economy. While lower fuel prices increase economic activity, they also promote demographic and technological changes that elevate transportation energy demand long after fuel price effects have stabilized or even diminished. The increase in economic activity that occurs in the persistently low-price scenario results in a major increase in activity (and energy use) by the trucking sector, especially for commercial light trucks. Rail activity and energy use decline primarily because of a sharp drop in coal shipments that is caused by lower oil prices. Conversely, the increase in crude oil shipments largely benefits the maritime industry, increasing its year 2000 fuel demand by another 9 percent beyond that previously forecast. Changes in household travel demand also continue to be dominated by the influence of fuel prices, although growth in the number of households and a slight decline in average household income will have important effects on demand for transportation services.

Further, the decline in demand for improved fuel efficiency and flexibility is also likely to result in decreased R&D on alternative transportation fuels. Consequently, the transportation sector could be no closer to attaining a fuel-switching capability in the 1990s than it was in the 1970s.

Given the economic effects of oil supply disruptions in the past and the likelihood that oil prices will continue to be volatile in the future, there is some hope that energy policy objectives will shift from the recent desire to avoid government intervention to a need to learn from the past so that stability is introduced into the inevitable transition away from heavy dependence on foreign oil. In summation, persistently low oil prices, rather than being a cause for economic optimism, will accelerate the need for energy policies that reduce transportation petroleum demand while maintaining the expected high level of service in the transportation sector.

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