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Authors of the Papers in This Record

Adler, Thomas J., Resource Policy Center, Thayer School of Engineering, Dartmouth College, Hanover, NH 03755
Bertram, Kenneth M., Argonne National Laboratory, 9700 South Cass Avenue, Argonne, IL 60439
Bester, Christo J., National Institute for Transport and Road Research, P.O. Box 395, Pretoria 0001, Republic of South Africa
Bixby, Ronald H., System Design Concepts, Inc., 1 Pennsylvania Plaza, New York, NY 10119
Boyce, D.E., Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801
Cabrera, Dianne, New York State Department of Transportation, 1220 Washington Avenue, State Campus, Albany, NY 12232
Cato, Derriel B., Energy Information Administration, U.S. Department of Energy, 1200 Pennsylvania Avenue, N.W., Washington, DC 20461
Corsi, Thomas M., College of Business and Management, University of Maryland, College Park, MD 20742
Dansker, Benjamin, Boston Central Transportation Planning Staff, 27 School Street, Boston, MA 02108
Eash, R.W., Chicago Area Transportation Study, 300 West Adams Street, Chicago, IL 60606
Greene, David L., Oak Ridge National Laboratory, P.O. Box X, Oak Ridge, TN 37830
Harrington, Ian E., Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, MA 02139
Hartgen, David T., New York State Department of Transportation, 1220 Washington Avenue, State Campus, Albany, NY 12232
Hartmann, John W., Energy Information Administration, U.S. Department of Energy, 1200 Pennsylvania Avenue, N.W., Washington, DC 20461
Hopkins, Frank E., ORI, Inc., 7923 Eastern Avenue, Room 505, Silver Spring, MD 27910
Ison, John W., Arthur D. Little, Inc., Acorn Park, Cambridge, MA 02140
Janson, B.N., Department of Civil Engineering, University of Illinois at Urbana-Champaign, Urbana, IL 61801
Kalauskas, Charles, Boston Survey Consultants, 263 Summer Street, Boston, MA 02143
Kocis, Michael A., New York State Department of Transportation, 1220 Washington Avenue, State Campus, Albany, NY 12232
Luchter, Stephen, National Highway Traffic Safety Administration, U.S. Department of Transportation, 400 Seventh Street, S.W., Washington, DC 20590
Mannering, Fred L., Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, MA 02139
Mufti, Rasin K., Delaware Valley Regional Planning Commission, 1819 JFK Boulevard, Philadelphia, PA 19103; formerly at Princeton University
Munson, Michael J., Research and Evaluation Specialists of Vermont, Inc., 83 Park Street, Essex Junction, VT 05452; formerly at Princeton University
Prins, Victor, Department of Civil Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139
Schreiber, Deborah, Boston Central Transportation Planning Staff, 27 School Street, Boston, MA 02108
Sheffi, Yosef, Department of Civil Engineering, Massachusetts Institute of Technology, 77 Massachusetts Avenue, Cambridge, MA 02139
Strombotne, Richard L., National Highway Traffic Safety Administration, U.S. Department of Transportation, 400 Seventh Street, S.W., Washington, DC 20590

Projected Potential Piggyback Energy Savings Through the Year 2000

KENNETH M. BERTRAM

Recent research concerning the energy advantage of using piggyback traffic (trailer-on-flatcar/container-on-flatcar) versus trucks is described and evaluated, and the potential energy savings that may result from capitalizing on this advantage are projected to the year 2000. Projections are based on an approximation of this energy advantage and scenarios of low, medium, and high levels of growth in piggyback traffic developed at the Center for Transportation Research, Argonne National Laboratory.

This paper surveys the results of six recent studies related to the energy-saving potential of piggyback traffic [trailer-on-flatcar/container-on-flatcar (TOFC/COFC)]. It begins by cautioning intermodal advocates to be conservative in their expectations concerning this potential. Although conventional rail traffic has an overall average energy consumption of about 700 Btu/ton mile versus about 2500 Btu/ton mile for trucks, the 3.5:1 energy-use advantage implied by these figures is not applicable to most present and potential piggyback traffic.

A major reason for this is that average rail energy use is heavily influenced by shipments of commodities that are far more dense than piggyback shipments. For instance, about 20 percent of rail ton miles consists of coal traffic that moves in shipments of 100 tons/car, whereas average TOFC/COFC cargo weights are about 30 tons/car. As a result, when the resistance effects of these relative weights are used to compute fuel use, unit coal trains have energy intensities of less than 500 Btu/ton mile, whereas piggyback cars on conventional mixed trains have energy intensities of more than 1500 Btu/ton mile. However, piggyback energy intensities vary considerably depending on whether piggyback cars are part of conventional mixed trains, conventional dedicated trains, or dedicated trains with new, innovative equipment. This paper, therefore, discusses each of these piggyback systems in terms of operational energy use. Then alternative scenarios of TOFC/COFC traffic growth are set forth, and potential energy savings are estimated. Operational improvements that can increase piggyback energy efficiencies are also mentioned. The relative amounts of indirect energy consumption involved in the construction and operation of the various types of equipment are not discussed.

TYPES OF PIGGYBACK OPERATION

Piggyback Cars in Conventional Trains

The approximate energy intensity of TOFC/COFC traffic moving in conventional mixed trains can be derived by using a recently developed algorithm that compares cargo-specific carload weights and resistances with average carload weight and energy intensity for the overall railroad system (1). Because the typical piggyback car has two trailers that carry 16 tons of cargo each and 6 tons of tare weight each (2), versus a rail system average carload cargo weight of about 50 tons each (3), the piggyback car on a mixed train has an average energy intensity of about 1700 Btu/ton mile. It is not known what portion of total TOFC/COFC ton mileage is traveled in conventional trains. However, since a recent Federal Railroad Administration (FRA) study indicates that about 80 percent of all 1976 piggyback tonnage traveled more than 500 miles (4, p. III-25) and that in 1977 there were 67 dedicated piggyback train routes (4, pp. III-15 and III-16), mostly between long-distance city pairs, this portion is relatively small.

Dedicated Piggyback Trains

Two recent studies have estimated the line-haul energy uses of dedicated piggyback trains. Although, as will be shown later, neither of these studies is conclusive or extensive enough to yield definitive, universally applicable results, their findings are similar. One of the studies compiled actual fuel-use data for dedicated piggyback trains versus trucks, whereas the other estimated fuel use by dedicated piggyback trains on six different routes by using a computer model and highly detailed data on route characteristics. The U.S. Department of Energy (DOE) sponsored the first study, which was done in conjunction with the FRA Intermodal Freight Program (of which the second study was a part) and the Federal Highway Administration.

The DOE study began in late 1978 and involved a six-month comparison of the "Sprint" piggyback operations of the Milwaukee Road with those of 45-ft highway trailers of C. W. Transportation, Inc. The objective of the project was to determine the relative, operational energy use of the two modes under the specific conditions existing in the Chicago-Twin Cities corridor.

It was not possible to control all pertinent parameters, although both a truck tractor and a locomotive were equipped with fuel flow meters. The highway and railroad trailers did not operate with the same cargo weights because of weighing complications in the railroad's operations, which resulted in rail trailer weights not being available in time to make possible equivalent loadings of the truck trailers. Other problems that hindered the project and prevented its findings from being conclusive were

1. Increases in locomotive fuel temperature due to use in cooling fuel injectors, which expanded fuel volumes by about 3-4 percent and caused slight inaccuracies in locomotive fuel-use readings;
2. An extremely severe winter and a truck strike that reduced the 26 planned simultaneous rail and truck runs to 12;
3. Determinations of railroad-trailer weight on only half of the simultaneous runs; and
4. Use of estimated rather than actual energy use for rail-terminal loading and unloading.

In addition, care must be taken in applying the study's results to other corridors because of requirements of the Chicago truckers' union that even full truckloads be returned from the shipper to the trucking company terminal before going over the road. This created a situation in which measurements could not be made of the pickup-and-delivery energy-use advantages that truckers enjoy in many other cities.

Nevertheless, the project's findings, which are summarized in Table 1 (5), are a useful addition to the data on route-specific comparisons of piggyback and truck. In addition, as shown later, levels of rail energy use are similar to those found during computer simulations conducted as part of the FRA Intermodal Freight Program.

The estimated energy advantage of piggyback in Table 1 is used, in conjunction with the scenarios of projected increases in TOFC/COFC traffic set forth later, to calculate the preliminary potential piggyback energy savings presented in this paper. Although energy intensity for rail is 802 Btu/ton mile, or about half that for truck, it should be noted that the advantage is not definitive for a number of reasons. One reason is that truck-trailer cargo weights were 42 percent higher than piggyback-trailer cargo weights (17 versus 12 tons). This strongly biases the calculations of energy intensity in favor of trucks in these comparisons and tends to understate the advantage of piggyback. On the other hand, the absence of any truck movements involving twin 27-ft trailers, which are more energy efficient than single 45-ft-trailer truck movements, tends to overstate the energy advantage of piggyback. So does the absence of calculations of pickup-and-delivery energy use. Finally, there were the aforementioned problems during the project, which could easily have affected data accuracy.

Table 1. Comparison of piggyback and truck energy use for 12 one-way trips between Chicago and St. Paul.

Item	Truck	Piggyback
Distance (miles)	420	412
Line-haul speed (miles/h)	42.6	38.2
Fuel consumed (gal)	82.3	1283.2[a]
Trailer data		
Number loaded	1	42
Number empty		3
Miles per gallon	5.1	13.5
Gross weight[b] (tons)	23.1	18.1[c]
Gross ton miles per gallon	117.1	257.8[c]
Revenue weight (tons)	17.1	12.1[c]
Revenue ton route miles per gallon	86.9	172.9[c]
Energy intensity (Btu/revenue ton mile)	1596	802

[a] Includes line-haul and terminal fuel use (estimated).
[b] For 45-ft highway trailers and 40-ft railroad trailers.
[c] Includes only the six runs when trailers were actually weighed.

Table 2. Input data common to all simulations in FRA Intermodal Freight Program.

Train Unit	Value	Amount
Locomotive (SD40-2)	Nominal horsepower	3000
	Gear ratio	62:15
	Number of axles	6
	Unit weight (tons)	184
	Fuel consumption	
	Traction (gal/rail hp-h)	0.067
	Idle (gal/h)	5.5
Railcar (flatcar)	Number of axles	4
	Tare weight (tons)	35
	Payload (tons)	52
	Gross weight (tons)	87
	Loaded trailers per car	2
	Height[a] (ft)	16.96
Trailer (40-ft)	Volume (ft^3)	2713
	Tare weight (tons)	5.75
	Payload (tons)	20.25
	Gross weight (tons)	26
Caboose[b]	Weight (tons)	23.25
	Number of axles	2
	Height from top of rail (ft)	16.96

Note: Maximum trial operating speed = 69 miles/h.
[a] Top of rail to top of trailer.
[b] Caboose used in all train simulations except between Chicago and St. Louis.

There are, however, other factors that favor using this piggyback advantage. Another, independent effort (by the General Motors Transportation Systems Center) under the FRA Intermodal Freight Program obtained similar results by using track profiles on six routes and detailed data on grades and curvatures to perform simulations of dedicated piggyback movements. The piggyback cargo and train data given in Table 2 were used with the track data and a modified version of the Davis formula in the simulations. [The Davis formula was empirically derived in 1926 and is used by energy researchers to calculate railroad energy intensities. Current researchers modify its coefficients based on the relevant characteristics of modern equipment. Additional information is given by Hammitt (6).] The results given in Table 3 (based on the General Motors data) indicate that the effects of a wide range of distances, topographical conditions, and train operating characteristics were simulated.

Note that the Milwaukee Road's Chicago-St. Paul route is one of those simulated and that Table 3 indicates roughly equivalent trailer miles per gallon for the FRA study (14.2) in comparison with the DOE tests (13.5). In addition, although the FRA tests show a lower energy intensity for piggyback than the DOE test, this difference is due largely to the greater cargo weight assumed in Table 2 (no empty trailers and 20.25 tons/trailer versus three empties per train and 12.1 tons/trailer) and the absence in the simulations of terminal energy spent for loading and unloading operations. When the actual line-haul energy uses of two of the DOE test trips were compared with simulations that used the

Table 3. Summary of baseline-condition train simulations performed by General Motors as part of FRA Intermodal Freight Program.

City Pair	Route Length (miles)	Avg Grade Equivalent of Curvature (%)	Avg Gradient (%)	One-Way Dwell Time (h)	No. of Locomotives	No. of Flatcars[a]	Total Trip Time[b] (h)	Trip Fuel[c] (gal)	Avg Travel Speed (miles/h)	Trailer Miles per Gallon	Net Ton Miles per Gallon	Btu per Net Ton Mile
Chicago-St. Paul	403	0.0149	−0.0022	2	3	45	9.86	2 513	40.9	14.43	292	475
St. Paul-Chicago	403	0.0149	0.0022	2	3	45	10.07	2 580	40.0	14.06	285	487
Chicago-St. Louis	268	0.0010	−0.0192	1	1	15	7.02	489	38.1	16.43	333	416
St. Louis-Chicago	268	0.0010	0.0192	1	1	15	7.61	540	35.2	14.86	301	460
San Francisco-Los Angeles	586	0.0239	−0.0004	2	4	45	14.03	5 413	42.1	9.78	198	700
Los Angeles-San Francisco	586	0.0239	0.0004	2	4	45	13.95	5 397	41.8	9.75	197	704
Chicago-Detroit	279	0.0046	−0.0014	1	2	30	6.22	1 267	44.8	13.19	267	519
Detroit-Chicago	279	0.0046	0.0014	1	2	30	6.22	1 282	44.8	13.03	264	525
Chicago-Houston	1350	0.0122	−0.0032	3	2	30	29.59	6 496	45.6	12.47	253	548
Houston-Chicago	1350	0.0122	0.0032	3	2	30	29.51	6 644	45.7	12.19	247	562
Chicago-Los Angeles	2204	0.0150	0.0028	7	5	60	47.40	24 429	46.5	10.83	219	633
Los Angeles-Chicago	2204	0.0150	−0.0028	7	5	60	47.87	23 545	46.1	11.23	227	611

[a] Number of loaded trailers = 2 x number of railcars (two loaded trailers per car).
[b] Includes dwell time.
[c] Includes dwell-time fuel consumption.

same train consists, the simulation estimates of fuel used were about 4 percent lower than the DOE tests both times. This indicates that, if one adds the real conditions experienced on the trips in the DOE tests, it raises the energy intensity for that route in Table 3 to near the value of 802 Btu/net ton mile found in the DOE tests.

In addition, it should be noted that net ton miles per gallon for the Chicago-St. Paul route are only 12 percent higher than the average of 257 net ton miles per gallon for all the routes simulated and that none of the routes varied by more than 23 percent from this average. This information, combined with the fact that the truck fuel-consumption rate of 5.1 miles/gal in the DOE tests falls comfortably within the 4.5-5.5 range generally experienced in the trucking industry, tends to support 800 Btu/ton mile as a reasonable approximation of the energy advantage of dedicated piggyback.

Finally, an important practical reason for using this approximation is that it is impossible to state a definitive TOFC/COFC energy-use relation to trucks without a very large sample of route-specific comparisons. This is because the energy uses of each of these alternatives vary significantly on different routes due to major differences in route characteristics. For example, relative circuity is important and varies greatly between routes. In addition, the grades on the same routes of each mode may be quite different and significantly affect their relative energy uses. Therefore, in the absence of the extensive research a large sample would require, the approximate energy advantage developed here, used with appropriate caveats, is currently the most practical approach to estimating overall potential piggyback energy savings.

The above approximation does not include the expected energy savings of the recent equipment innovations discussed in the next section of this paper. Nor does it include the new energy-saving operating techniques developed under the FRA Intermodal Freight Program. Instead, as will be shown later in the energy-savings calculations and sensitivity analysis, the incremental energy saving of these measures tends to be offset by TOFC/COFC traffic in less efficient mixed trains and improvements in truck energy efficiencies.

Innovative Piggyback Equipment and Improved Operating Procedures

Recent FRA wind-tunnel tests have confirmed that certain types of innovative piggyback equipment can reduce aerodynamic drag. This new equipment also has lower tare weights so that it reduces other resistance forces and the inertia of TOFC/COFC trains and thus energy consumption. Dedicated piggyback trains that use this new equipment can achieve significantly better energy intensities than those that use conventional TOFC/COFC equipment. These new types of equipment included the following (7,8):

1. Santa Fe Ten-Pack cars are 10-unit articulated-frame cars, each capable of carrying one 45- or 40-ft trailer. Construction is lightweight: 42 700-lb tare weight per pair of trailers versus 68 000 lb for equivalent conventional two-trailer flatcar.
2. Trailer Train Prototype cars are two-unit short-frame cars, each capable of handling one 45-ft, or shorter, trailer. Construction is lightweight: estimated 50 000-lb tare weight per two-unit car.
3. Paton Low-Profile cars are six-unit, articulated, low-profile frame cars capable of handling 45- or 40-ft trailers as well as 20-, 35-, and 45-ft containers. Construction is lightweight: approximately 50 000-lb tare weight per pair of trailers.
4. Bi-Modal Corporation Roadrailers are highway trailers, each equipped with one pair of steel flanged wheels and couplers for assembly into a train. Tare weight is 17 200 lb/unit but eliminates the need for a railcar.
5. Southern Pacific Double-Stack cars are three-unit depressed-center cars capable of handling six 40-ft containers. Construction is lightweight: estimated 40 000-lb tare weight per pair of containers.

One example of the implementation of these equipment innovations is the "Ten-Packer". Because of tests that indicate fuel savings of 6000 gal/round trip for 100-trailer Ten-Packer trains between Los Angeles and Chicago, the Atchison, Topeka, and Santa Fe (AT&SF) Railroad has increased its commitment to this new equipment. Ten-Packer cars are currently being constructed for four additional trains to ply this Santa Fe route. The improved energy efficiency of this equipment has been further verified by the FRA wind-tunnel tests, which indicate an 11 percent decrease in wind resistance over conventional piggyback operations (7,9). In addition, the Ten-Packer cars are 35 percent lighter than conventional piggyback flatcars and require one less locomotive per 100-trailer train. Use of the Davis formula with modifications based on the FRA wind-tunnel tests indicates that this equipment has a fuel advantage of about 15 percent, which closely corresponds to the AT&SF stated fuel savings (9).

Even greater savings have been claimed for the Bi-Modal Corporation Roadrailers, which combine lower aerodynamic resistance verified by FRA wind-tunnel tests (7) with much lower tare weights to produce an estimated 50 percent fuel-consumption savings over conventional TOFC/COFC operations. An FRA study due by the end of 1981 will estimate the energy intensities of this and other piggyback equipment innovations. However, there has been an analysis of the relative energy uses of these types of equipment by the manufacturer of the Roadrailer. That analysis used the Davis formula and was conducted prior to the FRA wind-tunnel tests by using estimates of bearing, mechanical, and aerodynamic resistance coefficients. The estimated coefficients, train consists, and operational energy intensities of the conventional and innovative dedicated piggyback train types at 60 miles/h with a 15-mile/h head wind on level terrain are given in Table 4 (8). All of the innovations except double-stack container cars show substantial energy improvements.

On the other hand, these equipment innovations have certain disadvantages that will tend to inhibit their acceptance and the realization of their potential energy savings. Another independent effort in the FRA Intermodal Freight Program identified the disadvantages of each of the innovative equipment types (10). Space does not permit delineation of these disadvantages here.

Improved operating procedures can also decrease piggyback energy use. A number of measures for saving energy in TOFC/COFC line-haul operations were developed during the FRA program and presented at the Intermodal Technology Conference in Chicago in late 1979. Some of these measures that could be applied to all rail operations include decreasing train speed and increasing acceleration rates in order to travel at a constant speed for the longest possible time. The measures specific to piggyback operations were having all trailers in the train consist facing forward and reducing gaps between trailers to as close to zero as possible to reduce

Table 4. Dedicated piggyback train consists, resistance coefficients, and Davis formula energy intensities.

	Type of Equipment					
Train Characteristic	Conventional	Santa Fe Ten Pack	Trailer Train Prototype	Paton Low Profile	Southern Pacific Double-Stack	Bi-Modal Corporation Roadrailer
Piggyback cars						
Number	22	40	40	40	22	0
Weight (lb)	68 000	21 350	25 000	25 000	40 000	-
Number of locomotives	2	2	2	2	2	1
45-ft trailers[a]						
Number	38	36	36	36	40[a]	36
Empty weight (lb)	11 500	12 000	12 000	12 000	6 500[a]	16 500
Avg loading						
Number	38	34	34	34	38	34
Weight (lb)	36 000	40 235	40 235	40 235	36 000	40 235
Resistance coefficients						
Bearing (lb/ton)	3.06	3.06	3.06	3.06	3.06	3.0
Mechanical [lb/ton/(mile/h)]	0.032	0.031	0.031	0.031	0.029	0.021
Aerodynamic [lb/(mile/h^2)]	0.081	0.040	0.045	0.040	0.210	0.030
Energy intensity[b,c] (Btu/ton mile)	814	723	770	733	1358	456

[a] 40-ft containers.
[b] At 60 miles/h and 15-mile/h head wind on level, straight grade.
[c] Space does not permit full presentation of the Davis formula variation used here to calculate energy intensities. However, it can be summarized by stating that total resistance equals the sums of weight- and velocity-dependent mechanical resistances plus aerodynamic resistances.

drag resistance. Both of these latter improvements to TOFC/COFC operations can also be used by conventional mixed and dedicated trains. In addition, truck operators are already striving to improve the energy efficiency of their operations, which will tend to counterbalance piggyback operational improvements and prevent increases in the energy advantage of piggyback.

Summary

This discussion has described three categories of piggyback traffic that represent three levels of energy efficiency. It illustrates why this paper uses a preliminary estimate of the energy advantage of current conventional dedicated TOFC/COFC operations without equipment innovations or operating improvements to develop projected piggyback energy savings. Two sets of forecasts of growth in piggyback traffic are presented below, followed by projections of energy savings.

PROJECTIONS OF GROWTH IN PIGGYBACK TRAFFIC

Transamerica Interway, Inc.

A recent study for Transamerica Interway, Inc., has projected growth in piggyback traffic through 1990 (2). Like the Argonne National Laboratory projections, which are also discussed in this paper, it uses scenarios. Based on a 1979 base volume of 3.2 million trailer loads, differing assumptions concerning intercity freight market growth and penetration, energy prices, reduced regulation, and TOFC/COFC service levels are used to form the scenarios given below (2):

Scenario (growth level)	Trailer Loads (000 000s) 1979	1990	1979-1990 Growth Rate (%)
Low	3.2	4.5	3
Medium	3.2	5.3-5.5	4.5-5.0
High	3.2	10-12	12

A key assumption is the estimate of the eligible market for piggyback. The estimate, based on an analysis of the 1972 Census of Transportation, is that TOFC/COFC is suitable for moving about 10 percent of total intercity freight and has only captured about 10 percent of that eligible market. This share is about the same today due to the 3 percent annual growth rate of piggyback during the 1970s, which roughly equaled overall intercity traffic growth. In determining the eligible or maximum piggyback market, which the study correctly cautions will be nearly impossible to capture, unsuitable items are excluded, such as high-valued air freight shipments, pipeline movements, average shipment sizes greater than 60 000 lb [which exceed maximum single-trailer loads (multiple-trailer loads are assumed to be minimal)], and movements over distances of less than 200 miles (2).

The conservative scenario assumes an annual growth rate of 3 percent to a level of 4.5 million trailer loads by 1990. An aggregate growth rate of 4 percent in industrial production was assumed. In this scenario, no major changes are forecast in piggyback pricing or service levels, nor is a recession forecast during the period. It was observed that a recession would lower even this conservative forecast because TOFC/COFC growth has historically been quite sensitive to recessions (2).

The medium-growth scenario, which assumed significant 300-400 percent increases in fuel prices but no significant increases in piggyback service, projects annual TOFC/COFC growth rates of nearly 5 percent for a 1990 volume of 5.3-5.5 million trailer loads. The most optimistic scenario projects annual growth rates of 11-13 percent and 1990 volumes of 10-12 million trailer loads. The study indicated that the main factor driving this high-growth scenario is improvement of currently slow and unreliable service levels, although 300-400 percent increases in fuel prices were also assumed. Specifically, shipper interviews and analysis indicated that the high growth rate would require improving piggyback service levels to approach those of trucks in longer-haul corridors (>500 miles). A survey in one such corridor indicated that current piggyback service averages 7 days for delivery with a 95 percent assurance of delivery within 12 days. Analysis of shipper responses indicated that reducing the average piggyback delivery time to 4 days with 95 percent assurance of delivery within 7 days would cause significant traffic shifts to piggyback from trucks, which have a 3-day average delivery time and a 95 percent assurance of delivery within 5 days (2).

It should be noted that the FRA Intermodal Freight Program has developed several techniques for improving service levels. They are presented here because they represent ways to achieve the service levels assumed in the high-growth scenario. Recommended improvements designed to save time in piggyback terminal operations, where most bottlenecks occur, include

1. Dedicated intermodal yards in which dedicated line-haul piggyback engines originate and terminate (where facility layouts allow);
2. Improved intermodal-yard switching service (dedicated switch engines, if possible);
3. Establishment of yard layouts with separate inbound and outbound traffic lanes to eliminate congestion;
4. Separate lots for parking inbound and outbound trailers and containers;
5. Organized, planned traffic flows in intermodal yards with proper traffic signs to minimize distances traveled by trailers and containers; and
6. Immediate notification to consignees of railcar arrivals, preferably before trailers are grounded, which could allow more pickups at trackside and also reduce congestion and handling costs at terminals (11).

These scenarios to 1990 are presented to provide data that can be compared with the Argonne National Laboratory forecasts discussed below.

Argonne National Laboratory

The Argonne National Laboratory (ANL) projections of piggyback market potentials, market penetrations, and energy savings presented in this paper are an outgrowth of ongoing work for DOE. These forecasts are based on an analysis of intercity truck-market data instead of the 10 percent of the overall intercity market used to develop the Transamerica Interway scenarios. The truck market was used as the starting point for two reasons: (a) It was easier to focus on traffic that had packaging characteristics amenable to piggyback, and (b) bulk commodities were excluded more easily.

Definition of Two Potential Piggyback Markets

The ANL forecasts of the potential TOFC/COFC markets were developed by using projections of motor-carrier activity (i.e., ton miles) by commodity sector and truck size [taken from work in progress by Knorr and Millar to update their 1979 report (12)]. Two estimates were developed for use in the market-penetration scenarios. The pessimistic or constrained market estimate (market A) represents the core of traffic that piggyback might reasonably expect to penetrate given current service levels and moderate increases in fuel prices. The optimistic market estimate (market B) reflects the universe of traffic that TOFC/COFC could technically penetrate, given significantly improved service levels and large increases in fuel prices. However, the probability of achieving market level B is virtually zero. Only in an extreme case in which the gross national product, and thus freight traffic, were significantly greater than in the projected baseline could market level B be achieved.

Market A is based on the assumption that piggyback service is most feasible for commodities that tend to be transported in "dry vans" (i.e., conventional enclosed truck trailers). This market was projected by using data on dry-van shares of total shipments (in tons) by commodity sector from the 1967 and 1972 Commodity Transportation Surveys (13). Dry vans transport a significant share (20-70 percent or more) of total shipments of food, chemicals, stone, clay and glass, pulp and paper, and fabricated metals. These sectors do not represent the actual TOFC/COFC market because some shipments in these sectors are not applicable to piggyback service and some shipments in other sectors are applicable. However, they do represent a significant enough share of that market to be indicative of its current and future magnitude. Thus, market A should be viewed as an estimate of potential market size and not an estimate of market composition.

Market B is based on the assumption that piggyback service is applicable to all intercity heavy-heavy (i.e., class 7 and 8) truck traffic. By limiting this market estimate to intercity ton miles, market B excludes most short-haul, obviously inapplicable, traffic. Although it may include some shorter-haul traffic, this is assumed to be a relatively small portion of the total, since the market is defined in terms of ton miles, not tons. Similarly, it may include small amounts of some bulky, not easily containerized movements. For these reasons, market B is considered to be the high estimate of the potential TOFC/COFC market.

These conceptual market definitions were translated into trailer loads by using projections of truck ton miles developed by ANL, by commodity sector in the case of market A and by intercity heavy-heavy trucks in the case of market B. For market A, ANL projections of truck mode shares were also examined. With the exception of fabricated metals and one of the food sectors, truck shares of total ton miles in all sectors are less than 35 percent. This suggests relatively long average lengths of haul, which would tend to make piggyback an attractive alternative.

For both market projections, piggyback potential was estimated as

$$TRM = TMT/(LOH \times LF) \qquad (1)$$

where

TRM = trailer-load market;
TMT = total ton miles projected for the market;
LOH = average piggyback length of haul, assumed to remain constant at 1013 miles (2); and
LF = average load per piggyback trailer, assumed to remain constant at the 1979 level of 15.9 tons (4).

The following table displays the potential trailer-load markets calculated in this manner:

	Market A		Market B	
Year	Ton Miles (billions)	Potential Trailer Loads (millions)	Ton Miles (billions)	Potential Trailer Loads (millions)
1980	138.7	8.6	325.7	21.9
1990	176.7	11.0	507.7	31.5
2000	218.5	13.6	684.6	42.5

Although it may be argued that LOH will decline over time as TOFC/COFC penetrates shorter shipment segments, recent FRA research indicates that the overall LOH for piggyback traffic has increased from 921 miles in 1972 to 1013 miles in 1976. The research found that this increase was due largely to significant increases in traffic traveling over distances greater than 1500 and 2000 miles (4). Until piggyback completes its penetration of these long-distance segments, LOH may be expected to increase. Since a parametric analysis indicated that any net change in LOH over the forecast period is likely to be small, a constant value was assumed.

Piggyback Market-Penetration Scenarios

Scenarios for low, medium, and high market penetration were developed by using the above-defined market estimates. The low and medium scenarios are based on market A. Since market A is a subset of market B, penetrations also occur in market B, although to a much more limited extent than in market A. The high scenario assumes penetration occurs in both market A and the non-A portion of market B. Trailer-load projections by scenario are given below:

Scenario (level of market penetration)	Projected Trailer Loads (billions)			1980-2000 Average Annual Growth (%)
	1980	1990	2000	
Low	3.4	4.4	5.4	2.3
Medium	3.4	5.5	8.1	4.4
High	3.4	8.1	13.8	7.3

In the low scenario, piggyback remains at the 1980 market share of market A--i.e., 40 percent. This assumption results in a piggyback projection of 4.4 million trailer loads in 1990, which grows to 5.4 million by the year 2000.

In the medium scenario, piggyback service is assumed to penetrate an increasing proportion of market A. Growing from 40 percent of market A in 1980 to 50 percent in 1990 and 60 percent in the year 2000, piggyback trailer loads increase to 5.5 million in 1990 and 8.1 million in the year 2000. On an annual basis, this growth rate is 4.4 percent, or slightly higher than the 3 percent growth rate of the 1970s. It is assumed to occur as a result of moderate increases in already high fuel costs and moderate service improvements, including some use of innovative equipment.

In the high scenario, significantly improved service levels, including a high level of use of innovative equipment, coupled with rapidly escalating fuel prices, results in much higher market-penetration rates. Penetration of 55 percent of market A plus 10 percent of the remainder of market B is assumed in 1990. In 2000, 70 percent penetration of market A plus 15 percent of the remainder of market B is assumed. (These penetration rates equate to 26 percent of all of market B in 1990 and 33 percent of it in 2000.) This results in high-scenario projections for piggyback of 8.1 million trailer loads in 1990 and 13.8 million trailer loads in 2000.

Table 5. Potential piggyback energy savings for 1981-2000 estimated by ANL.

Level-of-Growth Scenario	Potential Diesel Fuel Savings (millions of barrels)				
	1990	Cumulative 1981-1990	2000	Cumulative 1991-2000	Cumulative 1981-2000
Low	9.7	86.9	11.9	109.1	196.0
Medium	12.2	98.4	17.9	151.5	249.9
High	18.9	128.9	30.5	242.9	371.8

Piggyback Energy Savings by Scenario

Although these ANL projections give reasonable approximations of potential energy savings, it should be noted that they are preliminary for the reasons cited earlier. The cumulative estimates presented in Table 5 were developed for each scenario by determining annual piggyback energy savings and summing them over the two decades. Annual energy savings were estimated as

$$ES = TRM \times LOH \times LF \times EUA \tag{2}$$

where ES is annual energy savings and EUA is the 800-Btu/ton mile piggyback energy advantage over trucks.

Using this advantage over the 20 years assumes that overall rail and truck energy efficiencies will both improve over the period but that the difference between them will remain constant. Over the two decades, piggyback energy savings are estimated at about 200 million bbl of diesel fuel under the low scenario; this increases to 250 and 370 million bbl under the medium and high scenarios, respectively. Annual levels of savings range from about 10 million bbl in 1990 under the low scenario to 30 million bbl in the year 2000 under the high scenario.

Applying the nondefinitive 800-Btu/ton mile advantage of conventional dedicated piggyback trains to all TOFC/COFC traffic provides an expeditious method of approximating the energy savings that can be expected under different scenarios without implying false levels of accuracy. However, it does not relate energy savings to the level of service provided. Therefore, a sensitivity analysis was conducted in which two different service levels--high and low--were assumed (i.e., different traffic shares for piggyback movements in mixed consists, conventional dedicated consists, and dedicated consists using innovative equipment).

The low-service-level scenario involves little change from current service levels and only minor decreases in the share of traffic traveling in less energy-efficient mixed consists. It also assumes low penetration of more energy-efficient innovative equipment into the relatively static dedicated train share. The high-service-level scenario projects more significant decreases in mixed-consist piggyback movements and greater penetration of the growing dedicated train share by innovative equipment. It also assumes more modest improvements in service time than those postulated in the Transamerica Interway high-growth scenario. Table 6 presents these service scenarios.

Different energy advantages were assumed and applied to the different forms of piggyback trains. These were (a) zero mixed consists (see the discussion at the beginning of this paper on piggyback cars in conventional trains), (b) 800 Btu/ton mile for conventional dedicated trains, and (c) 880 Btu/ton mile for dedicated trains with innovative equipment (Table 4). These assumptions had the effect of projecting higher estimated energy savings as the level of service increased. They also offset

Table 6. Sensitivity assumptions of shares of piggyback traffic by type of train for two level-of-service scenarios.

Level-of-Service Scenario	Traffic Share by Type of Train (%)					
	1990			2000		
	Mixed	Conventional Dedicated	Innovative Dedicated	Mixed	Conventional Dedicated	Innovative Dedicated
Low	15	80	5	10	85	5
High	10	75	15	5	75	20

the higher energy savings of innovative equipment versus the lack of savings achieved by piggyback cars in mixed consists.

The sensitivity analysis resulted in slightly lower energy-savings estimates than those given in Table 5. For the low-service-level and low-growth scenario, the savings between 1980 and 2000 were 12 percent lower than those for the low-growth scenario given in Table 5. For the high-service-level and high-growth scenario, the energy savings over the two decades were 6 percent lower. However, these findings, like those in Table 5, are strongly dependent on nondefinitive (though reasonable) estimates of piggyback energy advantages. They should, therefore, be considered strictly as a sensitivity analysis and not a refinement of Table 5 estimates.

SUMMARY AND CONCLUSIONS

Based on the limited research results available, this paper has developed reasonable approximations of the energy advantages of piggyback traffic over trucks. It has also presented scenarios of projected TOFC/COFC growth that were developed independently by Transamerica Interway, Inc., and ANL. The ANL scenarios have been used to estimate potential piggyback energy savings through the year 2000.

The ANL energy-savings estimates are significant but not overwhelming, even in a high-growth scenario. For example, the highest annual savings are 30 million bbl in the year 2000 high-growth scenario. This amounts to less than two days' supply (less than 0.5 percent of annual needs) at the current U.S. oil-consumption rate of about 16 million bbl/day. Nevertheless, these savings are definitely worthwhile, especially since they are in petroleum, where U.S. energy scarcity problems are the most pressing.

In addition, it is important to realize that, although potential energy savings are generally smaller in freight than in passenger transportation, they do add up and should be pursued. Even at the current oil price of $35/bbl, which is likely to rise faster than inflation, the value in 1980 constant dollars of the cumulative energy savings projected here range from $7 billion in the low scenario to $13 billion in the high scenario. The main conclusion of this paper, therefore, is that shifting traffic from trucks to piggyback is definitely an attractive energy-conservation option worth considerable effort.

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Use of Density Function and Monte Carlo Simulation Techniques to Evaluate Policy Impacts on Travel Demand

FRED L. MANNERING AND IAN E. HARRINGTON

A modeling system is presented that is designed to evaluate the travel-related impacts of various energy contingency plans. The proposed modeling system uses constructed probability density functions and Monte Carlo simulation techniques in an effort to reduce overall data requirements and allow for ready adaptability to a number of alternative geographic areas. The resulting computer model provides for both an acceptable degree of accuracy and an inherent flexibility and thus represents a general improvement over comparable existing modeling techniques that possess the capability to forecast the impacts of energy contingency plans. To demonstrate the applicability of the computer model, a number of energy contingency alternatives were evaluated at the national level. These alternatives included speed-limit enforcement and reduction, a four-day work week, vehicle modifications, and plans involving household-based vehicle stickers and vehicle-based stickers. Model applications reveal that a relatively wide range of results, including potential reductions in fuel consumption, modal shifts, and income effects, is indicated by the enactment of these alternatives. The results presented in the study are intended for use only as guidelines in the selection of an appropriate contingency plan, and organizational, institutional, and implementation factors not explicitly addressed must also be considered. However, in terms of forecasting capability, the research indicates that travel demand forecasts can, in fact, be made with very modest data requirements.

Recent national concerns relating to the uncertainty of future energy supplies have generated the need to develop standby energy contingency plans in an effort to ease the consequences of potential fuel-supply interruptions. The primary objective of such plans is to equitably reduce the demand for fuel, thereby preventing or limiting the formation of queues at gasoline stations and other undesirable effects that result from a fuel shortage. Regrettably, analytic tools currently available for forecasting the reductions in fuel demand induced by alternative energy contingency plans are highly restrictive in terms of their data requirements and their regional transferability. Furthermore, existing analytic techniques often have methodological approaches that limit their applicability in evaluating the impacts of various energy contingency policies.

The purpose of this study is to develop a sound analytic framework specifically designed to address the issue of the evaluation of energy contingency plans. The proposed framework is designed to overcome the deficiencies of previous analytic efforts in this area and to provide a process that is readily adaptable to a variety of possible contingency planning applications.

This paper first presents a summary of the problem addressed in the study. The discussion is then directed toward the development of the modeling system, and the analytic techniques used are emphasized. The balance of the paper provides a number of sample applications of the modeling system in which the impacts of several energy contingency planning options are estimated.

THE PROBLEM

As shown in Figure 1, a fuel-supply shortage occurs when the available supply of gasoline falls below the current level of consumption (from Q_1 to Q_2). Because consumers thus wish to purchase more gasoline than is available, according to the basic economic laws of a competitive market, the value consumers place on the remaining supply will be increased (from P_1 to P_3) in order to distribute the scarce good.

Since price controls prevent the retail price of gasoline from rising freely to its shortage equilibrium level (P_3), the demand for gasoline at the preshortage pump price remains greater than the available supply, and consumers form queues at service stations in an attempt to obtain their desired share of the constrained supply. Thus, the cost to consumers of waiting in line replaces the increase in the retail price of gasoline in raising the price to its shortage equilibrium level. A major objective of contingency plans is to reduce the shortage equilibrium price and service-station queues by lowering the demand for gasoline at price P_1 from Q_1 toward Q_2.

Such a measure causes a shift in demand from D_1 to D_2, thus reducing the shortage equilibrium price of gasoline (the price at which consumers will want to purchase the Q_2 gal of gasoline that are available) from P_3 to P_2, and the net effect of the contingency measure is thus to move the point of market equilibrium from point D to point C.

MODEL OBJECTIVES

The primary objectives of the proposed modeling process can be classified into five broad categories:

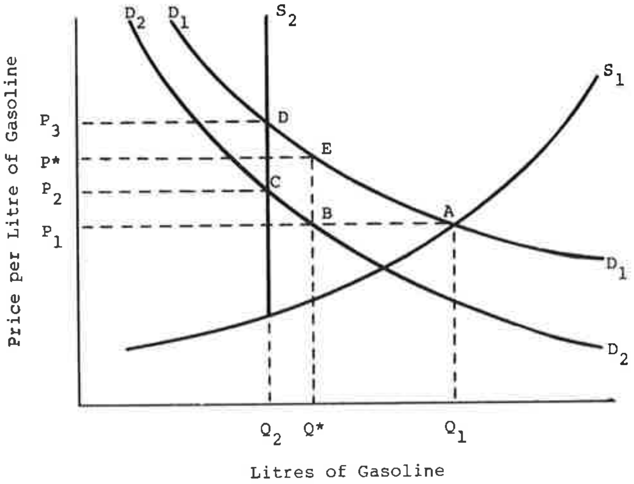
1. To develop a policy-sensitive model that is consistent with the supply-shortage framework presented above;
2. To provide the capability to forecast a wide range of travel demand information, including such factors as modal split, fuel consumption, vehicle miles of travel (VMT), and trip length;
3. To achieve an acceptable level of accuracy with minimal data requirements;
4. To incorporate an inherent flexibility so that the model can be easily adapted to a number of alternate geographic areas; and
5. To minimize model-run computer costs and generalize the program so that it can be implemented on most large-scale computational facilities.

Several existing modeling systems, most of which are discussed in some detail in an NCHRP report (1), were found to satisfy some of the objectives listed above. These models were generally judged to be inadequate for the intended application purposes of this study because they have relatively large data requirements, produce many related outputs that are of little interest in relation to the problem at hand, and use modeling components that are highly time and place specific.

Once the shortcomings of existing modeling approaches were considered, it was decided to develop a modeling procedure that would incorporate the applicable features of existing models and/or be based on newly calibrated models. The disaggregate approach, which includes the application of behavioral choice modeling techniques, was found to be most suitable.

Several problems do arise, however, in the use of disaggregate models. The large amounts of data needed for the calibration of disaggregate models

Figure 1. Effects of fuel-supply shortages and contingency measures on gasoline price and demand.



are not readily available. This implies that the use of existing calibrated models is necessary, and hence the results are subject to errors because of limits in model transferability. In addition, the problem of possible bias in aggregating resultant disaggregate forecasts arises.

After consideration of these arguments, it was decided to construct a modeling system based on a series of existing calibrated disaggregate models. This paper discusses the handling of the aforementioned problems with disaggregate models and explains precisely how these selected disaggregate models are incorporated into the overall modeling system.

MODELING APPROACH

The entire modeling approach is structured so as to be compatible with simulated data. The use of simulated data, derived from constructed probability density functions, offers several advantages over the use of collected data, including (a) easy adaptation to different geographic areas (i.e., a major data-collection effort is generally not needed when the modeling system is transferred), (b) less expense in terms of possible data collection and eventual computer-related costs, and (c) greatly reduced model implementation times.

Unfortunately, a number of disadvantages are associated with the use of simulated data, such as the fact that the assumed density functions are only approximations of actual density functions and the covariances between variables are difficult to account for. Despite these disadvantages, it was felt that the attractive features of the simulation approach provided a strong basis for its use. Furthermore, with the implementation of techniques directed toward limiting the impacts of the inherent disadvantages of the simulation approach, the overall accuracy of such an approach could be greatly enhanced.

Once the capabilities and limitations of disaggregate models and data simulation techniques were considered, the overall modeling system was designed to forecast policy-induced changes in factors such as (a) trip modal shares by trip type (work, shopping, and social-recreational), (b) VMT by trip type, (c) trip generation rates and trip lengths, (d) fuel consumption, and (e) effective fuel "shadow prices", defined here as the fuel pump price needed to clear the market under given shortfall and contingency plan combinations.

In addition to providing total "regional" values for the above factors, the model was designed to have the capacity to determine values for any arbitrary subset of the population (e.g., low-, middle-, and high-income groups). An overview of the resulting modeling system is shown in Figure 2.

As Figure 2 indicates, the system includes models for (a) carpool size, (b) work-trip modal choice, (c) shopping-trip generation, (d) social-recreational trip generation, (e) social-recreational trip destination and modal choice, and (f) shopping-trip destination and modal choice. All of the models, with the exception of the model for work-trip modal choice, were developed by Cambridge Systematics, Inc., for the Metropolitan Transportation Commission (MTC), by using data from a 1968 San Francisco home-interview travel survey (2,3). The work-trip modal-choice model was developed by Ben-Akiva and Atherton by using data from a 1968 Washington, D.C., travel survey. A more detailed explanation of these models is given elsewhere (2,4).

The models for work-trip modal choice, shopping-trip destination and modal choice, and social-recreational trip destination and modal choice are all random utility models of the multinomial logit form. Information relating to the calibration techniques and general properties of such logit models is well documented in several sources, most notably by Domencich and McFadden (5).

In addition, the model for carpool size is of a conventional linear regression form, whereas the trip-generation models assume a nonlinear regression form. The models for both shopping and social-recreational trip generation provide for an interaction with transportation level of service by including the natural logarithm of the denominator of the respective destination/modal-choice model as an independent variable. The variable is referred to as the log sum of a logit model and represents the expected value of the maximum utility of the destination/modal-choice set.

SIMULATION TECHNIQUES

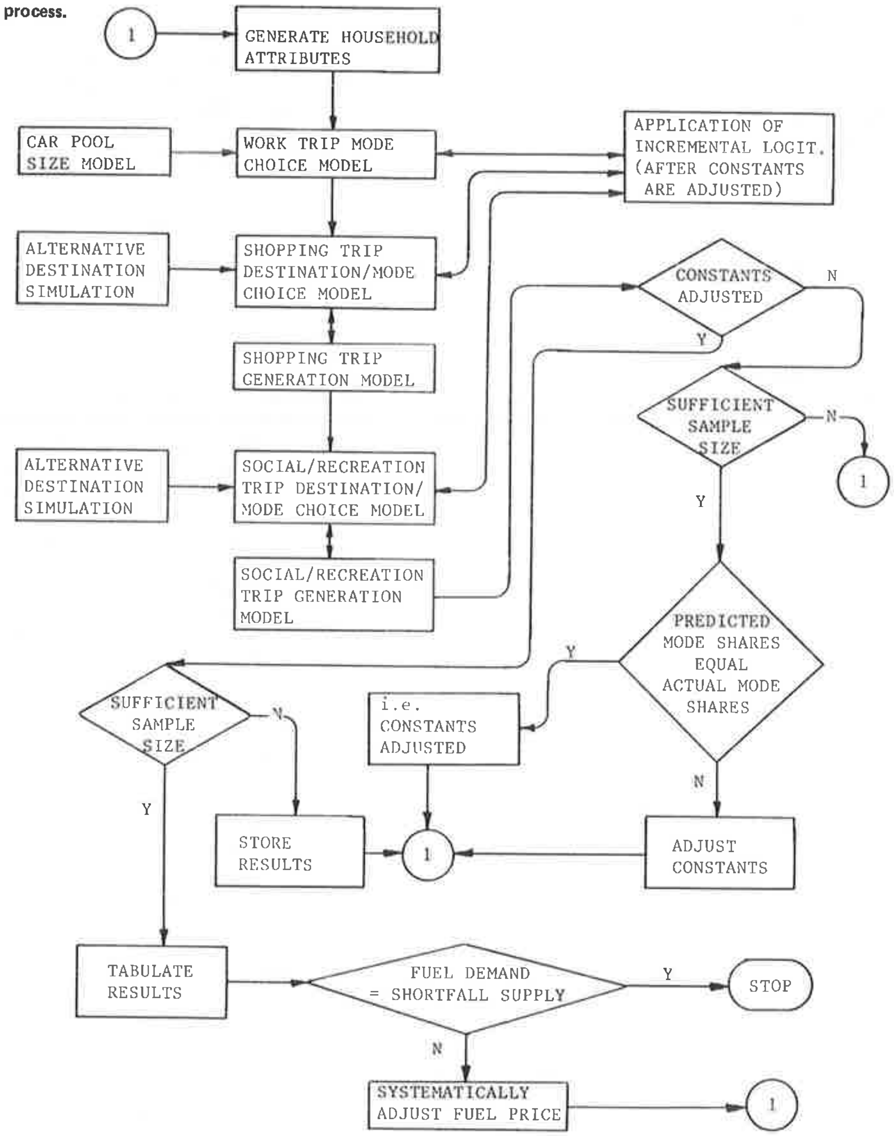
The use of simulation techniques serves two basic purposes: (a) to reduce aggregation bias and (b) to provide the desired level of forecasting detail. A summary of the simulation techniques developed for use in this study is presented in the following sections.

Aggregation Bias

Since disaggregate models provide information only on household-level decisions, the issue of expanding the results to represent aggregate values must be addressed. The potential for aggregation bias arises from two sources: (a) the nonhomogeneity of the population and (b) the fact that the choice probabilities in disaggregate logit models are nonlinear. Aggregation bias can be completely eliminated by simply summing or averaging the individual choice probabilities of the entire population being considered. Unfortunately, the data requirements for such an approach are unrealistically large, since the complete multivariate distribution of explanatory variables is required. To overcome this problem, a number of techniques have been proposed as a means of approximating the true distribution of explanatory variables in the population. These distribution estimation techniques include (a) enumeration, (b) density functions, (c) distribution moments, and (d) classification. More information on distribution estimation techniques is given by Koppelman (6) and Reid (7).

In view of the objectives of this study, it was

Figure 2. Overview of modeling process.



determined that a hybrid technique of distribution estimation would be most suitable. The estimation technique eventually developed relies heavily on the density-function approach and uses classification techniques as a means of approximating the joint distributions of key variables. It is assumed that the variables have multivariate normal distributions. Unfortunately, the number of data needed to construct the necessary distribution, which requires an approximation of the true variance-covariance matrix, tends to be prohibitively large. To overcome this problem, and thereby satisfy the study objective of minimal data requirements, univariate normal distributions were used along with a classification procedure that provides for a covariance between critical variables.

The data needed to construct univariate normal distributions are generally readily available to local and state agencies, since all that is needed is the appropriate means and variances. When the necessary data are obtained, the issue of continuous variables (such as income and residential density) and discrete variables (such as automobile ownership and licensed drivers per household) must be addressed. In the current study, all variables are initially assumed to be continuous, and discrete values are determined, where appropriate, from the constructed continuous distributions by transforming the distribution to provide only integer values. The univariate normal distributions are often truncated to eliminate the possibility of negative or "unrealistic" values.

The classification procedure used to approximate the covariance between critical variables comprises two steps: (a) separating the population into nearly homogeneous subsets by using influential variables, such as income, as a basis, and (b) constructing univariate normal distributions of critical variables for each subset of the population. The use of this procedure provides an approximation of the true multivariate distribution through the application of a number of univariate distributions. The finer the classifications used, the more accurate is the approximation of the underlying multivariate distribution. Regrettably, since fineness of classification greatly increases data requirements, a trade-off must be made between accuracy and data needs.

The application of the classification technique generates a multicentered multivariate normal distribution, which cannot be illustrated here because of space requirements. This resulting distribution can, however, provide an efficient approximation to the true multivariate distribution depending on the level of classification and the number of univariate distributions constructed from such classifications.

In addition to the type of density functions described above, some dummy variables (taking values of zero or one), such as government worker and central-business-district destination, were estimated simply by assuming a uniform distribution and an appropriate probability.

In the current study, the distributions were constructed on the basis of national data provided in a number of sources (8-11). These distributions are presented elsewhere (12).

Aggregation Procedure

The constructed distribution of explanatory variables can now be used in conjunction with the disaggregate models described earlier to provide aggregate forecasts. As mentioned previously, aggregate predictions can be obtained directly by summing or averaging the choice probabilities for all individuals in the population (i.e., complete enumeration). This procedure can be represented in integral form as follows:

$$C_i = \int_x g^i(x)\, h(x)\, dx \qquad (1)$$

where

C_i = share of the population selecting alternative i,
$g^i(x)$ = representation of the specification of the choice model, and
$h(x)$ = distribution of model variables for the total population.

When the exact distribution of model variables is known, the above integration produces the same results as complete enumeration. However, since the distribution of variables in this study is only an approximation of the true distribution, the results are likely to differ from the complete enumeration case, although this difference can be expected to be tolerably small.

With the specification of the choice models known and the distribution of variables constructed, it now becomes necessary to evaluate the above integral to obtain aggregate results. The procedure used for this evaluation is a Monte Carlo integration technique. This technique uses the constructed density functions to generate pseudo households and the results of subsequent applications of the disaggregate models are summed to approximate the actual integral value. Such an explicit integration technique can be readily applied on many computer systems. The accuracy to which the actual integral is approximated is obviously directly related to the number of pseudo households generated. Experience with the model has shown that 500-1000 households are generally sufficient to provide an acceptable level of accuracy.

In summary, the aggregation technique presented above provides (a) efficient use of available data, (b) an acceptable level of forecasting accuracy, (c) an inexpensive and theoretically sound approach, (d) easy adaptability to different geographic areas, and (e) the ability to predict separate results for selected population subsets (e.g., change in VMT for low-, middle-, and high-income groups).

Alternative Destination Simulation

The destination/modal-choice models for shopping trips and social-recreational trips estimate the probabilities of selecting a specified mode for trips to a number of alternative destinations. The available modes in these models are automobile and transit, and in the analysis 10 alternative destinations are provided for each pseudo household (i.e., the total number of choice alternatives is 20). Each alternative destination has specific characteristics assigned to it, such as distance from trip origin and retail employment density. These characteristics are assigned by using density functions (constructed from the data sources referred to above) and the Monte Carlo procedure. Such an assignment permits the determination of the expected change in trip length induced by an applied policy option. The technique accounts for the ability of households to satisfy shopping and social-recreational trip demands at a number of alternate locations.

It should be noted that, since the modeling system used in this study considers only short-term effects, possible changes in residential and workplace location are not considered. Hence, trip distances to alternative shopping and social-recreational destinations and work-trip lengths remain constant.

Model Transferability

The disaggregate models used in this analysis were calibrated by using various data sources; hence, the issue of applying these models to different geographic areas must be considered. A number of studies have been undertaken to evaluate the potential transferability of disaggregate models, most notably the study by Atherton and Ben-Akiva (13). That study concluded that the transferability of model coefficients relating to variables such as income and travel time was justified on theoretical grounds and empirical evidence. However, no theoretical basis was found to exist for the transferring of model constant terms, since by definition such terms capture a wide range of miscellaneous factors that affect the choice process and that can be expected to vary considerably between geographic areas.

In light of these findings, a procedure was used to systematically adjust the model constant terms before the application of the disaggregate models to the study region (the remaining nonconstant model coefficients are assumed to be perfectly transferable). This procedure consists of two steps: (a) generating a sample of pseudo households from the constructed density functions and applying the Monte Carlo integration procedure to estimate aggregate values and (b) comparison of the aggregate values calculated above with the actual observed regional values. (If differences in these values exist, appropriately revise the constant terms and repeat the process.) The application of this process provides a basis for minimizing errors that result from the transferability assumption and provides for ready adaptability of the overall modeling system to alternate geographic areas. In addition, to limit computer memory costs, the impacts of alternative policy options are evaluated for each pseudo household during the Monte Carlo aggregation procedure by applying the incremental logit model (14). This avoids the reapplication of the complete logit model, since subsequent recalculation of systematic utilities is not necessary.

Shadow Price

The model also has provisions for calculating the "shadow price" of gasoline for any combination of supply shortage and contingency measures. The procedure used to estimate this price, which is illustrated in Figure 1, can be described as follows.

First, determine the change in the demand for fuel at price P_1 that results from implementing the contingency measure ($Q_1 - Q^*$). Then, compare the estimated drop in fuel demand at price P_1 with the extent of the supply reduction ($Q_1 - Q_2$). If they are equal, P_2 equals P_1. However, if, as in most instances, the demand reduction does not equal the cut in supply, P_2 will not equal P_1. In this case, the price of gasoline is thus systematically adjusted from P_1 (using an iterative procedure) until the postmeasure demand for gasoline (on curve D_2) is equal to the constrained supply (Q_2). The price at this point is P_2, which is defined as the gasoline shadow price.

MODEL APPLICATIONS

The model described in this paper has been applied to several contingency-measure and supply-shortage scenarios in order to illustrate some of its capabilities and to evaluate the effectiveness of various contingency measures. In addition to estimating the reduction in demand expected from the measures, their net effects on travel and fuel consumption are also evaluated, all at the national level.

Since the net effect of a contingency measure is estimated by comparing the changes it produces in the equilibrium price of gasoline and the distribution of consumption and travel with those changes produced by a supply shortage, the characteristics of points C and D in Figure 1 should be compared to obtain an estimate of a measure's net effect. However, still referring to Figure 1, although the changes occurring between points A and D are readily estimated by the computer model (by increasing the fuel price from P_1 to P_3), estimating the changes between points A and C is costly because of the high computational requirements. As a result, a more cost-effective proportionality technique that does not significantly sacrifice accuracy is developed and used to measure the net effects.

Assuming that the price elasticities of demand curves D_1 and D_2 are equal, it can be shown that the proportional changes in desired fuel consumption and travel between points B and C would equal the proportional changes between points E and D. Therefore, the proportional differences between the characteristics of points C and D are equal to the proportional differences between the characteristics of points B and E. Since the changes produced by the measures discussed here are relatively small, the price elasticity of demand is not likely to change significantly; so the net effect of a contingency measure is thus estimated by comparing the changes between points A and B with the changes between points A and E.

While the changes between points A and B are estimated by the model, the price of fuel at point $E(P^*)$ must be estimated so that the model can estimate the changes between points A and E. Thus, again assuming curves D_1 and D_2 have equivalent price elasticities, P^* can be estimated as follows:

$$P^* = (P_3/P_2)P_1 \qquad (2)$$

Following is a discussion of the application of the model to five contingency measures and the results obtained. However, this discussion must be prefaced by a brief review of the expected impacts of a supply shortage if no contingency measures are implemented.

Fuel-Supply Shortage

A fuel-supply shortage of 7 percent is represented by determining the shortfall equilibrium price (P_3 in Figure 1) through an iterative procedure that consists of changing the price of gasoline until the amount of gasoline normally consumed at that price equals the constrained supply. Assuming a 7 percent shortage in supply and an initial price (P_1) of $0.32/L, P_3 is estimated to be $0.46. This permits the estimation of P^* for each contingency-measure scenario under these assumptions, once the shadow price (P_2) resulting from the measure's implementation has been estimated (Equation 2).

Using the increase in price of gasoline from P_1 to P_3 to represent the supply shortage, the model indicates larger impacts on shopping and social-recreational trips than on work trips, since households desire to maintain their normal commuting practices. The majority of the reduction in shopping-trip VMT results from changes in trip length as households satisfy trip demands by selecting closer alternative destinations. A much smaller portion of the reduction in shopping-trip VMT is attributable to modal shifts and trip generation rates. The induced modal shifts and decreases in trip generation rates for social-recreational trips have a much larger effect on VMT reduction than was observed with the reduction in shopping-trip VMT. This results from the fact that the social-recreational trips generally have a greater sensitivity to utility function cost components.

Contingency Measures

Reduction of Travel Speed

In the first scenario, two speed-limit plan alternatives are analyzed. These alternatives can be summarized as follows: (a) Compliance with the 55-mile/h speed limit is increased from the current 42 percent (based on 1977 Highway Statistics) to 70 percent, and (b) the maximum speed limit is reduced from 55 to 50 miles/h, with a 42 percent compliance level.

The most difficult problem encountered in considering such changes in speed limits and/or compliance is the estimation of future vehicle speed distributions. For the purposes of this analysis, the existing speeds were assumed to have a profile that could be approximated by a truncated normal distribution. On the basis of this normality assumption and existing speed data, an average speed of 56.5 miles/h and a standard deviation of 5.5 were selected as normal speeds on 55-mile/h roads. Under alternative 1, it was assumed that (a) vehicles currently traveling at speeds less than 55 miles/h will be unaffected and (b) those vehicles currently traveling at speeds in excess of 55 miles/h will not reduce their speeds to less than 55 miles/h. An appropriate "mean average speed drop" was selected to ensure that 70 percent of the simulated vehicle-speed observations had speeds at or less than 55 miles/h. For alternative 2, it was assumed that (a) vehicles currently traveling at speeds less than 50 miles/h would not be affected, (b) vehicles traveling at speeds between 50 and 55 miles/h would reduce their speeds to 50 miles/h, and (c) vehicles traveling at speeds in excess of 55 miles/h would reduce their speed by an average of 5 miles/h.

It is estimated that 47.2 percent of all automobile VMT is on roads with 55-mile/h speed limits. Unfortunately, the percentage of VMT on 55-mile/h roads by trip type is not readily available. It is unreasonable to suggest, for example, that shopping trips, which have average lengths of about 5 miles,

Table 1. Estimated effects of contingency measures.

		Change (%)				
		Speed Reduction			Household Sticker	
Category	Measure	Alt. 1	Alt. 2	Four-Day Work Week	Weekend	Weekday
Total change	VMT by trip type					
	Work	-[a]	-[a]	-11.6	-2.8	-10.3
	Shopping	-2.0	-5.0	-0.5	-3.0	-3.9
	Social-recreational	-1.0	-2.5	-2.9	-4.6	-1.6
	Work-trip modal share					
	Drive alone	-[a]	-[a]	+1.9	-4.7	-18.0
	Shared ride	-[a]	-[a]	-5.0	+11.3	+43.2
	Transit	-[a]	-[a]	-6.5	+11.0	+39.2
	Average automobile trip length					
	Shopping	-1.7	-4.3	+0.3	-[a]	-[a]
	Social-recreational	-0.4	-0.9	+1.0	-[a]	-[a]
	Total fuel consumption	-1.5	-3.4	-5.9	-3.4	-5.7
Net change[b]	VMT by trip type					
	Work	+0.2	+0.4	-11.0	-2.4	-9.7
	Shopping	-[a]	-1.1	+5.5	+0.9	+4.0
	Social-recreational	+2.2	+3.7	+6.4	+1.6	+5.7
	Work-trip modal share					
	Drive alone	+0.3	+0.6	+2.9	-4.1	-17.0
	Shared ride	-0.5	-1.1	-7.7	+10.2	+41.5
	Transit	-1.6	-3.1	-11.3	+7.9	+34.4
	Shadow price of gasoline	-8.6	-15.1	-21.6	-15.2	-21.4

[a] No change or insignificant change.

[b] In comparison with do-nothing alternative.

will have the same percentage of VMT on 55-mile/h roads as social-recreational trips, which have average trip lengths of about 12 miles, since access to such roads is a fixed distance that will make up a larger portion of the total shopping-trip length than the social-recreational trip length. To account for this fact, the 47.2 percent of VMT on all roads was appropriately adjusted to account for trip type by applying a trip-length proportionality technique. Furthermore, it was assumed that the percentage of VMT on 55-mile/h roads would be normally distributed about the mean for the trip type with a specified standard deviation. This allows a realistic variance among households and trip destination alternatives.

The resulting estimates of the effects of the two alternative measures on normal travel and consumption patterns are given in Table 1. The impact of the two alternatives on work-trip VMT is negligible due to the inflexibility of the work trip in the short- and medium-range time periods. Furthermore, the decrease in automobile operating costs and the increase in travel time essentially offset each other so that no significant modal shift occurs.

Shopping trips were found to be the most sensitive trip type in both of the alternatives tested. This results from the fact that time is a relatively more important consideration on shopping trips than it is on social-recreational trips or work trips. In addition, shopping-trip generation, destination, and modal selection are more responsive to increases in time than to decreases in operating costs and, as a result, significant reductions in VMT occur. The majority of this decrease was attributable to decreases in average trip length as households selected shopping destinations closer to home.

Social-recreational trips also made significant contributions to the overall decrease in VMT. In this case, a much smaller portion of the VMT reduction is attributable to decreases in trip length and, consequently, decreases in trip generation and modal shifts play a more important role.

The total reductions in fuel consumption of 1.5 and 3.4 percent for alternatives 1 and 2, respectively, largely result from a decreased VMT attributable to increased travel times, although increases in vehicle fuel efficiency still make a substantial contribution to these totals. Both of the alternatives tested indicate that high-income groups are invariably more sensitive to speed-limit changes, since they experience significantly greater reductions in VMT.

In summary, the net effects of these measures, given in Table 1, include considerable reductions in the shadow price of gasoline, net increases in VMT for all trip types (particularly social-recreational trips), and a disproportionate effect on high-income households.

Four-Day Work Week

The second scenario evaluates the impacts of the implementation of a four-day work week. To apply this policy option, it is first necessary to estimate the extent of compliance with such a plan. The assumption of 100 percent compliance is clearly unrealistic, since the nature of a number of jobs makes at least a five-day schedule necessary. As a result of such factors, a compliance level of 63 percent was selected, which is consistent with compliance estimates made in a previous study (15). If it is further assumed that the average reduction in weekday work-trip travel will be 20 percent among complying individuals (with a reduction from five- to four-day work weeks), then a 12.6 percent reduction in work travel would be expected (with 63 percent compliance), providing that no modal shifts occur.

Representation of the four-day-work-week plan in the modeling system was achieved by appropriately adjusting (a) the automobile-availability variables; (b) the employment-density variable in the models for work, shopping, and social-recreational trips; and (c) the number-of-worker variables. The adjustment procedure for the automobile-availability variable was to randomly select 12.6 percent of the household sample to represent those household individuals who were in compliance with the work plan and were not making work trips on the selected work day. For both shopping and social-recreational trips, the automobile-availability variables of these selected households were increased by the number of vehicles no longer being used for work trips and the number-of-worker variables were adjusted accordingly. A subsample of households was randomly chosen to represent those households that are in compliance with the plan but happen to be making work trips on the selected work day. For these households, the automobile-availability variable of the work-trip model was increased by 20 percent of the vehicles normally available for work trips. This increase reflects the fact that many shopping and social-recreational trip demands are now satisfied during the nonwork days and so such trip types do not compete as much for available automobiles during work days; hence, there is an effective increase in work-trip automobile availability.

Two approaches were used in making the employment-density adjustments:

1. For employment density at the work zone and for the retail and service employment densities in the residential zones, uniform reductions of 12.5 percent [selected on the basis of estimated work-force reductions (14)] were used to approximate the reductions in densities resulting from the closing of retail establishments.
2. For the retail employment densities of alternative shopping and social-recreational trip destinations, a random elimination technique was applied because the uniform adjustment approach would not provide for a realistic variability. The technique used randomly eliminates alternative destinations from the set of available destinations with an elimination probability of 0.125 for each shopping and social-recreational trip generated by the household. This technique attempts to capture the possibility that certain destinations will no longer be able to satisfy the trip demand due to store closings.

The application of the above assumptions resulted in the model outputs summarized in Table 1. The reduction in work-trip VMT is quite large, but it is noticeably less than the 12.6 percent reduction that would be expected on the basis of the compliance assumption described above. This apparent discrepancy results from induced modal shifts that arise from the effective increase in work-trip automobile availability among households with individuals who are in compliance with the plan and the decrease in work-trip-destination employment density, which decreases the attractiveness of the shared-ride option. The resultant modal shift consists of a mild increase in the drive-alone option and subsequent reductions in shared-ride and transit alternatives.

Both shopping and social-recreational trips showed decreases in total VMT. Such decreases are caused by rather large reductions in trip generation rates, since the overall attractiveness of trip making declines with reductions in effective employment densities. In fact, the reductions in trip generation rates were sufficiently large to overcome the effects of factors that tend to increase VMT, such as (a) modal shifts to automobile resulting from the additional automobile availability among households that are in compliance with the shorter work week, (b) an increased propensity to generate trips as the reduction in residential-zone employment densities decreases the probability of satisfying trip demands by making nonvehicle trips, and (c) the increase in average automobile trip lengths as households are forced to drive to different destinations to satisfy trip demands as the result of store closings.

The 5.9 percent overall reduction in fuel consumption indicates that the plan has considerable fuel-saving potential even with the modest compliance estimates used in this analysis. The resulting shadow price of $0.37/L represents only a small increase over the base price of $0.32/L. In addition, the implementation of the four-day work week was found to produce greater reductions in VMT among high-income households. This is due to the fact that lower-income households are more sensitive to changes in automobile availability, so much so that their greater sensitivity to reductions in employment densities is overcome.

In general, the four-day-work-week contingency plan appears to be quite effective in terms of reducing fuel demand. Furthermore, although the plan causes greater VMT reductions among high-income households, the differential impacts across income groups tend to be relatively small. The net effects of the plan (Table 1) are mainly to shift VMT from work trips to shopping and social-recreational travel and to shift work trips to the drive-alone mode.

Household-Sticker Plan

The third scenario evaluates the travel impact of a sticker plan that prohibits the use of all household vehicles for one day of the week. A major potential source of error in evaluating this plan is in estimating the number of households whose members will choose not to drive their vehicles on weekdays as opposed to weekends. Because of the significant differences in travel behavior between weekday and weekend trips, two alternatives were analyzed: One assumed that all households will select weekdays as those days in which their vehicles will not be driven, and the other assumed that all households select weekends. These two extreme cases will provide a range of likely consequences arising from the implementation of such a plan.

The representation of the plan in the modeling system is achieved by reducing the appropriate automobile-availability variable to zero in the models for shopping and social-recreational trips and to eliminate the drive-alone alternative in the work-trip modal-choice model. For the all-weekday alternative, it was assumed that the probability of selecting any given weekday is equal at 0.2, and households that did not have automobiles available on any given day were drawn at random. Furthermore, the fact that 90 percent of all work trips occur during weekdays and only 54 and 26 percent of shopping and social-recreational trips, respectively, occur during such days was also incorporated in the analysis (8,9). As a result, the all-weekday assumption would be expected to have less impact on the demand for shopping and social-recreational types of trips. In the case of the all-weekend alternative, the probability of a household selecting a given day was assumed equal at 0.5, and the amount of travel by trip type was also considered (10 percent of all work trips, 46 percent of shopping trips, and 74 percent of social-recreational trips). The results of model applications are given in Table 1.

The results indicate that substantial modal shifts are induced by the plan, including significant decreases in the use of the drive-alone mode, as would be expected. Naturally, the subsequent reduction in work-trip VMT is much larger for the all-weekday case because of the large proportion of weekday work trips. Changes in shopping and social-recreational trip VMT values result from reductions in trip generation rates and modal shifts. No change in automobile trip lengths is expected, since the representation of the plan by varying the automobile-availability variables does not affect the relative attractiveness of alternative destinations.

The reductions in total fuel consumption of 3.4 and 5.7 percent for the all-weekend and all-weekday alternatives, respectively, reflect the total range of fuel savings that can be expected from the implementation of a household-sticker plan. The VMT reductions of such a plan are fairly uniform for households of all incomes. This uniformity arises partly from the fact that, although lower-income households are more sensitive to changes in levels of automobile availability, such households are likely to own fewer vehicles than higher-income households.

As Table 1 indicates, a household-sticker plan has the potential for inducing substantial reductions in the shadow price of fuel. Furthermore, it is indicated that the distribution of stickers that control weekend and weekday automobile use can have a significant impact on plan effectiveness. The net effects of the plan are generally to shift VMT from work trips to social-recreational trips and to shift work trips away from the drive-alone mode.

SUMMARY AND CONCLUSIONS

This research has developed a modeling system that considers the complex interactions between various travel demand components and proposed energy contingency plan options. Because the modeling system uses a number of Monte Carlo simulation techniques that require minimal amounts of data, it can readily be adapted to the consideration of alternative geographic areas and to test a wide variety of possible policy options. In the current study, the model was applied on the national level in an effort to forecast the likely travel-related impacts induced by various energy contingency plans.

The results of the model applications indicate that a relatively wide range of impacts relating to fuel consumption, income effects, and other factors can be achieved with alternative contingency plans. Of the limited number of plans considered in this study, the household-sticker and four-day-work-week measures produce the largest reductions in the demand for gasoline. In terms of the income impacts of these two plans, the sticker measure provides for an equitable distribution among income groups whereas the shortened work week disproportionately affects higher-income brackets. However, it must be recognized that the evaluation of contingency measures should not be based entirely on the impacts addressed in this study, since the implementability, costs, and enforceability of a measure are also critical factors in the selection of an appropriate plan.

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Direct Energy Consumption for Personal Travel in the Chicago Metropolitan Area

D.E. BOYCE, B.N. JANSON, AND R.W. EASH

A set of calculations of direct energy consumption for the Chicago region is prepared. The methodology for developing the energy accounts is illustrated by using two examples for a transit and an automobile trip. Direct operating energy statistics for personal travel are shown in both tabular and mapped forms. Both absolute energy consumption and rates of energy consumption by areal unit are listed. Tables showing how energy consumption varies with trip origin and destination are discussed, and maps that show the energy consumption contours for travel to the Chicago central business district are presented.

This paper presents estimates of direct energy consumption for peak-period weekday person travel in the Chicago region. The methodology is a logical and marginal extension of the current "state-of-the-art" urban transportation demand models (1). All software is compatible with the widely used Urban Mass Transportation Administration/Federal Highway Administration (UMTA/FHWA) Urban Transportation Planning System (UTPS) (2) and the FHWA PLANPAC battery (3) of computer programs for urban transportation planning. Therefore, the methodology for computing energy consumption, in concert with the standard programs for transportation planning, is applicable to a wide range of planning problems, including evaluation of short-range, low-capital transportation improvement options as well as the more standard long-range, capital-intensive system alternatives.

The accounts or estimates presented in this paper are for direct energy consumption, which primarily consists of energy for vehicle operation. For travel by private mode, specifically not included in the calculations is energy consumed in construction and maintenance of automobiles, garaging of automobiles, and highway construction, maintenance, and operation. In the case of public transportation, energy used in construction and maintenance of public transportation terminals and traveled ways is also excluded from these estimates; energy used in operation of transit stations and other vehicle-related facilities is included.

In general, energy consumption is reported in British thermal units (Btu). The factors used in the calculations to convert from liquid measure to energy units are 125 000 Btu/gal of gasoline and 138 700 Btu/gal of diesel fuel. The same conversion factor is used for all diesel-powered modes regardless of whether they are highway or rail. All estimates given were developed from simulations of morning-peak-period weekday personal travel.

EXAMPLES OF ENERGY CALCULATIONS

The procedures for calculating private and public energy consumption can be applied to an individual trip movement that corresponds to a single cell in a trip table. Individual trip calculations can be carried out easily by hand; two examples are worked in this section to illustrate the methodological approach. All calculations are exactly as they would be completed in the computer programs prepared for the analyses.

The first example considered is a public-mode trip between zone 134, on the south side of Chicago, and the Chicago central business district (CBD). Zone 134 is bounded by 103rd Street on the north, 111th Street on the south, Halsted Street on the west, and Michigan Avenue on the east. The table below gives the minimum-time path by bus and rail transit between zone 134 (south-side Chicago) and zone 64 (the Chicago CBD):

A Node	B Node	Travel Mode	Transit Line Used
134	3476	Walk	
3476	3605	Bus	196, 223
3605	2183	Transfer	
2183	2092	Rail rapid transit	26
2092	4523	Transfer	
4523	64	Walk	

The table is read as follows. Starting at the centroid of zone 134, the patron walks to a bus stop at 103rd and Michigan Avenue (node 3476), boards a northbound Michigan Avenue bus, and rides to the 95th Street Dan Ryan rail transit terminal stop (node 3605). The rider walks from the bus stop to the train platform (node 2183) and boards a northbound Dan Ryan train. After riding to the Loop, the patron alights from the train at the station at State and Lake Streets (node 2092), walks to the intersection of Dearborn and Lake Streets (node 4523), and goes on to the destination zone 64 centroid. It is important to understand that this path is not the minimum-energy-consumption path but the minimum-time (a weighted combination of waiting, walking, and riding time) path between zones.

The portions of this trip that are of interest from an energy-consumption standpoint are the bus and rail transit "legs". Only one bus link is used by the rider (node 3476 to node 3605). The two bus lines that operate over this link carry a total of 2665 riders on 47 trips. The link is 1.3 miles long. Energy consumed per person trip on the link is calculated as follows:

$$\text{(Btu per bus vehicle mile)} \times [(\text{number of bus trips} \times \text{link length}) \div \text{patronage}] = \text{Btu per person trip} \qquad (1)$$

Substituting the actual estimates determined by Boyce and others (1) for bus fuel consumption and ridership into this equation gives 42 000 x [(47 x 1.3)/2665] = 960.

The rail transit calculation is similar except that more than one link is involved. Table 1 lists 12 rail transit links between nodes 2183 and 2092. The computations in Table 1 provide the vehicle miles that are charged against each rider on the listed links. During the morning peak period, 42.4 northbound trips of eight-car trains occur; thus, 342.4 vehicle miles are generated by each mile of track. Dividing vehicle miles on each link by the patronage on the link produces the vehicle miles assignable to each rider.

For the trip in question, approximately 0.21 vehicle mile of rail transit output is consumed by each person trip. At 57 000 Btu/rail transit vehicle mile (4), each person trip consumes 11 980 Btu. Adding this energy to that already used for travel to the station by bus produces a total of 12 940 Btu/person trip.

If access to the 95th Street rail transit station is by private automobile, then the gasoline consumed in driving to the station must be substituted for the energy consumed in gaining access by bus. The average distance to the station (a weighted average determined by location of residences within the zone) from the origin zone is 2.2 miles. If one uses the regional average automobile gasoline consumption of 12.7 miles/gal, each mile driven consumes about 9800 Btu. Multiplying this per-mile energy consumption times distance to the rail transit station shows that 21 560 Btu/trip is needed to gain access to rail by automobile. If the return automobile trip is also charged against the automobile access portion of the entire movement, then 43 120 Btu is required for station access by automobile. These results are summarized below:

	Energy Use (Btu)		
Trip Type	Access	Line-Haul	Total
Public mode only	960	11 980	12 940
Automobile driver access to rail	21 560	11 980	33 540
Automobile passenger access to rail	43 120	11 980	55 100

For private automobile trips, as many as five paths are identified between each pair of zones. In this example, energy consumption along only one of the five paths is investigated. One of the automobile minimum-time paths between zone 134 and zone 64

Table 1. Energy calculations for rail transit.

A Node	B Node	Link Length (miles)	Vehicle Miles	No. of Riders	Vehicle Miles per Rider
2183	2182	1.0	342.4	8 026	0.042 66
2182	2181	1.0	342.4	12 085	0.028 33
2181	2180	1.2	410.9	17 344	0.023 69
2180	2179	0.8	273.9	24 931	0.010 99
2179	2178	1.0	342.4	25 433	0.013 46
2178	2177	1.0	342.4	25 573	0.013 39
2177	2176	1.5	513.6	25 574	0.020 08
2176	2175	1.5	513.6	27 147	0.018 92
2175	2099	2.1	719.0	26 887	0.026 74
2099	2100	0.2	68.5	19 852	0.003 45
2100	2101	0.2	68.5	16 014	0.004 28
2101	2092	0.2	68.5	16 384	0.004 18
Total		11.7	4006.1		0.210 17

Table 2. Warm-engine gasoline use for example path.

Street	A Node	B Node	Length (miles)	Time (min)	Gasoline (gal)
Halsted Street	134	2721	0.50	1.30	0.0366
	2721	2723	0.52	1.20	0.0360
	2723	6603	0.11	0.28	0.0080
Ramp	6603	6602	0.12	0.25	0.0079
Dan Ryan Expressway	6602	3668	0.71	0.99	0.0393
	3668	3662	0.45	0.78	0.0239
	3662	2125	0.47	0.74	0.0256
	2125	10467	0.68	1.16	0.0362
	10467	10463	1.00	1.45	0.0553
	10463	10715	0.49	0.76	0.0268
	10715	10457	0.20	0.38	0.0106
	10457	6607	0.52	0.68	0.0293
	6607	10451	0.29	0.68	0.0153
	10451	10448	0.26	0.69	0.0138
	10448	10447	0.82	1.91	0.0434
	10447	10419	0.50	0.71	0.0277
	10419	10397	1.00	1.48	0.0551
	10397	10389	0.87	1.58	0.0461
	10389	4116	1.75	2.71	0.0957
	4116	10365	0.05	0.99	0.0034
	10365	5697	0.53	0.85	0.0287
	5697	10704	0.41	1.13	0.0218
Cermak Road	10704	9797	0.04	0.55	0.0037
Clark Street	9797	9796	0.14	0.95	0.0129
	9796	3783	0.19	3.19	0.0175
	3783	72	0.67	11.18	0.0617
	72	12132	0.33	5.49	0.0304
Polk Street	12132	3718	0.08	1.65	0.0074
Dearborn Street	3718	3717	0.14	0.69	0.0129
	3717	4042	0.08	0.39	0.0074
	4042	4041	0.06	0.45	0.0055
	4041	4036	0.09	1.37	0.0083
	4036	4037	0.09	1.04	0.0083
	4037	4024	0.09	0.44	0.0083
	4024	4025	0.09	0.44	0.0083
	4025	3967	0.08	0.37	0.0074
	3967	3968	0.10	0.49	0.0092
Randolph Street	3968	5691	0.07	0.18	0.0051
	5691	64	0.08	0.23	0.0062
Total			14.67	51.80	0.9070

Table 3. Peak-period regional direct energy consumption.

Travel Category	Petroleum-Based Fuel (gal)	Petroleum (billions of Btu)	Electric (billions of Btu)
Public travel			
Bus			
Nonaccess	11 800	1.63	
Access	1 600	0.22	
All overhead	1 500	0.21	
Rail rapid transit			2.46
Rail rapid transit overhead			0.04
Commuter rail diesel	14 400	2.00	
Commuter rail diesel overhead	100	0.02	
Commuter rail electric			0.97
Automobile access	14 700	1.84	
Subtotal	44 100	5.92	3.47
Private travel	1 344 500	168.07	
Total	1 388 600	173.99	3.47

begins at 107th and Halsted Streets and continues north on Halsted to the Dan Ryan Expressway. It then proceeds north on the expressway to the Franklin Street extension of the expressway. The path then jogs east on Cermak Road to Clark Street, turns north on Clark to Polk Street, and then turns east on Polk to Dearborn Street. The Chicago Loop is entered by way of Dearborn, and the path finally turns west on Randolph Street to LaSalle Street, where the zone 64 centroid is located.

The links in this path are given in Table 2 along with link travel times and distances. Time and distance plus link type are used with gasoline consumption coefficients developed from several sources (5-8) to obtain the final column of warm-engine gasoline consumption per link for an average automobile. Total warm-engine fuel consumption for the complete path is 0.907 gal.

Excess cold-engine gasoline consumption must be added to the warm-engine consumption. Excess cold-engine consumption occurs only over the first 8.5 miles of a trip; since the path in question is longer than 8.5 miles, a lump sum of 0.125 gal of excess cold-engine consumption is added. Thus, a total of 1.032 gal of gasoline, or 128 750 Btu, is consumed during the trip.

REGIONAL ENERGY CONSUMPTION

Table 3 summarizes the estimates of regional direct energy consumption. These findings are broken down into the two primary modes, public and private. Public transportation is further subdivided into submodes in this table. Automobile access trips to public transportation are included under public travel. Total consumption in the region for the morning peak period is approximately 175 billion Btu. Only about 2 percent of this total represents electrical energy consumption by commuter rail and rail rapid transit. Petroleum-based fuels are the overwhelming source of transportation energy in the region because automobile travel accounts for 95 percent of the total energy listed in the table.

The remaining 5 percent of energy for morning-peak-period person travel is for public transportation. Within public transportation, more than half of the operating energy is taken for commuter rail trips (all commuter rail energy plus almost all automobile and bus access energy). The "overhead" modal energy given in Table 3 is for nonproductive vehicle miles. Here, the term nonproductive refers to vehicles running on links that do not have trips assigned to them; thus, they are nonproductive scheduled service rather than movements to, from, and within garages and storage yards. Vehicle miles traveled for maintenance and storage are not included, nor is the extra fuel consumed during engine idling in both public and private modes.

Figures 1 and 2 show direct energy consumption for private and public transportation by district of trip origin. These plots reflect (a) the number of trips in the district, (b) the spatial distribution of the destinations of these trips, and (c) the operating conditions these trips face. For example, the heavy private energy consumption in the mid-northwest sectors results from the number of trips in the district, the vehicle miles generated by these trips, and the traffic congestion encountered. One cannot infer any relative energy efficiencies from these two maps because they show gross

Figure 1. Peak-period energy consumption by origin district: private transportation.

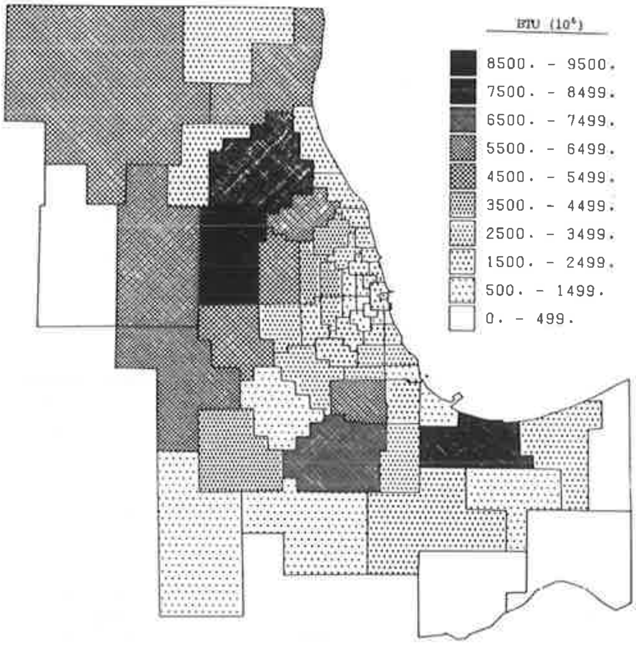
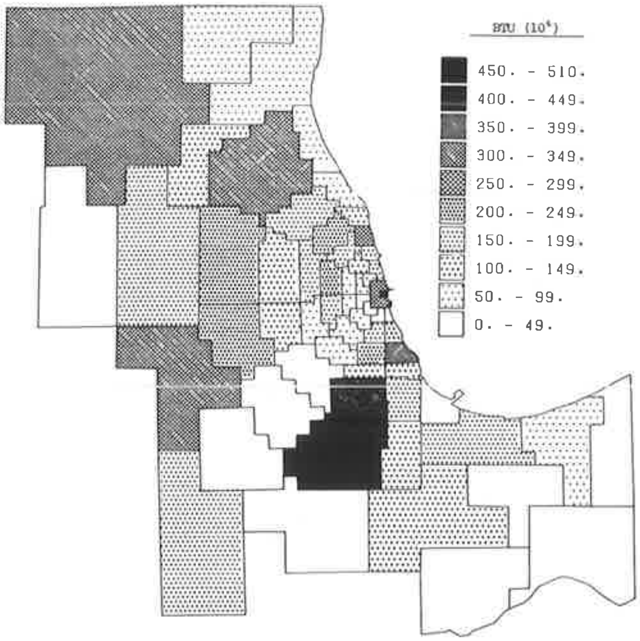


Figure 2. Peak-period energy consumption by origin district: public transportation.



energy consumption instead of rates.

In comparing the two maps, it should be noted that the entire scale of the public-transportation map nearly fits within the lowest rank of the private-transportation map scale. The maximum district energy consumption for public transportation is about 500 million Btu, whereas the largest use in any private-transportation district is around 9 billion Btu. For private transportation, the scale corresponds to a range of gasoline consumption between 0 and 76 000 gal, where each rank interval equals 8000 gal.

There is no clear pattern in the energy consumption for the two primary modes revealed in these two figures. An analyst might anticipate a well-defined concentric pattern of consumption for public transportation due to the proportion of CBD-directed movements in trips by public transportation. But any trend is hard to discern because there are few public-mode trips in the outlying zones. Automobile trips are less focused on any one destination, and private-transportation energy consumption does not exhibit a regular pattern.

Rates of Energy Consumption for the Primary Modes

Rates of energy consumption are far more meaningful than absolute quantities for intermodal comparisons. The following table gives operating energy consumption for the two primary modes in Btu per person trip, Btu per person mile of travel, and Btu per person air mile of travel:

Statistic	Private Travel	Public Travel
Peak-period Btu (billions)	168.07	9.39
Person trips served	2 965 368	511 751
Btu per person trip	56 678	18 349
Person miles traveled	21 106 312	4 818 405
Btu per person mile	7963	1949
Person air miles traveled	17 647 717	4 435 593
Btu per person air mile	9524	2117

The methods for calculating person-trip rates and distance rates differ slightly. All person trips are included in the person-trip rate, but only person trips assigned to the network (interzonal trips) are included in the travel-distance calculations (person trips served include interzonal trips whereas person miles and air miles traveled do not include intrazonal trips).

The per-trip energy consumption for private transportation is about three times the per-trip consumption for public transportation. But this comparison ignores the fact that different trips are served by the two modes. Public transportation is even more efficient when compared on a person-mile basis. If one measures efficiency by using person miles, the ratio is almost four to one in favor of public transportation. This latter comparison, however, ignores the different average trip circuity for the two primary modes. Person miles of travel can also be generated by inefficient indirect routings.

The preferred statistic is the energy consumed per person air mile of travel; that is, energy consumption per mile of point-to-point distance. When consumption is measured as a person-air-mile rate, the ratio between public- and private-mode consumption increases to about 4.5 to 1 in favor of public transportation. Somewhat surprisingly, public-transportation trips in Chicago are, on the average, less circuitous than private-mode trips.

Figures 3 and 4 show two maps that plot the public- and private-mode morning-peak-period average energy consumption per person air mile by district of trip origin. These two maps are clearly different: The public-transportation map is almost a negative of the private-transportation map. Districts that have high rates of consumption on the public-mode map have low rates on the private-mode map and vice versa. Energy consumption rates for private transportation are highest in the urban developed districts, whereas rates for public transportation are highest in the far suburban districts.

Like the scales in Figures 1 and 2, the scales in Figures 3 and 4 are quite different. The highest district average rate for public transportation is less than the lowest district average rate for private transportation. The maximum district average rate of energy consumption per person air mile is 11 100 Btu for private transportation. About 6500 Btu/person air mile is the maximum consumption rate for public transportation.

The rates shown in these two maps and in the table on page 19 are valid only for the existing pattern of regional travel and the existing split of these trips between private and public modes. Any shift of mode choice or redistribution of trip destinations will affect these rates of energy consumption. Strictly speaking, modal energy rates should not be directly compared except when the productive output (the number of persons moved between each origin-destination pair) is the same for the two modes.

The public-transportation energy consumption rates reflect that public-mode trips are heavily focused on the CBD and can be efficiently carried by radial high-capacity line-haul services. Trip desire lines for public transportation are limited compared with the travel pattern of private mode trips. The less well-defined desire lines of private transportation are much less suitable for service by high-capacity public modes.

The difference between existing public- and private-mode travel and the relation between modal travel patterns and energy consumption are further clarified by the data in Table 4, which gives rates of energy consumption and average trip lengths by ring of trip origin. Trip lengths for CBD-originating trips by private mode are much shorter than those for CBD-originating trips by public transportation. Away from the downtown, trip lengths by private mode are fairly constant across the region whereas trip lengths by public mode regularly increase with distance from the CBD. Again, this points out the different character of the two trip populations served by the two primary modes.

These average trip lengths explain why private-mode energy consumption per trip is nearly constant across the region compared with public-mode consumption per trip. Average energy consumption per person trip is roughly the same for private-mode origins in rings 2-8. Slightly longer trip lengths for trips from the outer rings are balanced by more efficient automobile operation due to less traffic congestion in these rings. The energy required for public-mode trips increases with distance from the CBD because of longer trip lengths and also because of less efficient vehicle use at the ends of transit lines where vehicle occupancy levels are lower.

Table 5 repeats the information in Table 4 but tabulates the data by trip destination. Private-mode trip lengths and energy consumption are practically the same as those in Table 4 except for the innermost rings. In the outlying rings, the pri-

Figure 3. Peak-period energy consumption per person air mile by origin district: private transportation.

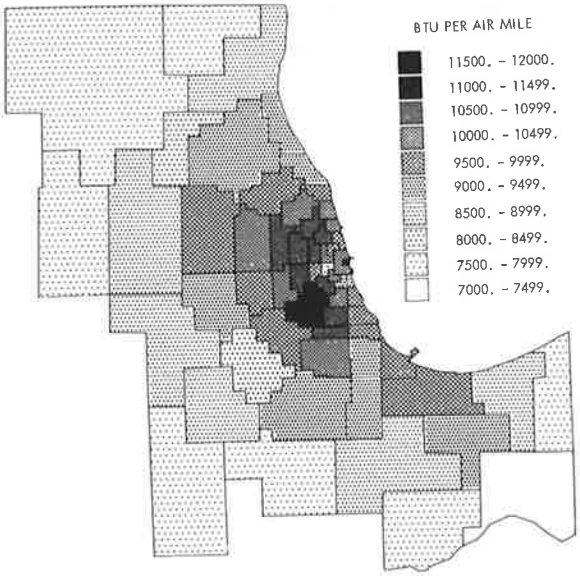


Figure 4. Peak-period energy consumption per person air mile by origin district: public transportation.

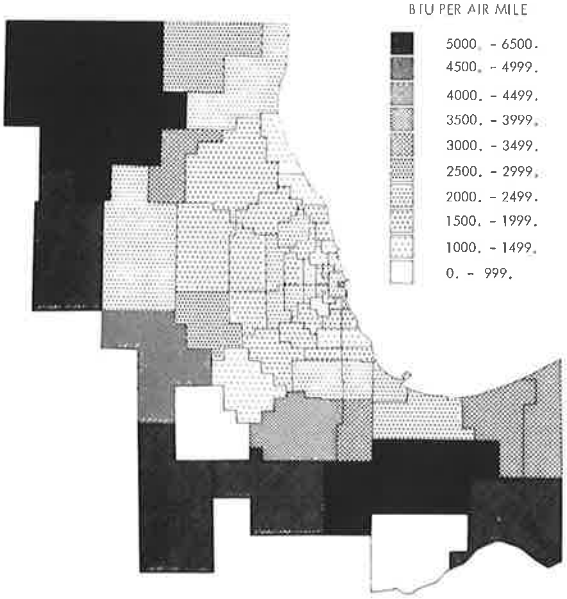


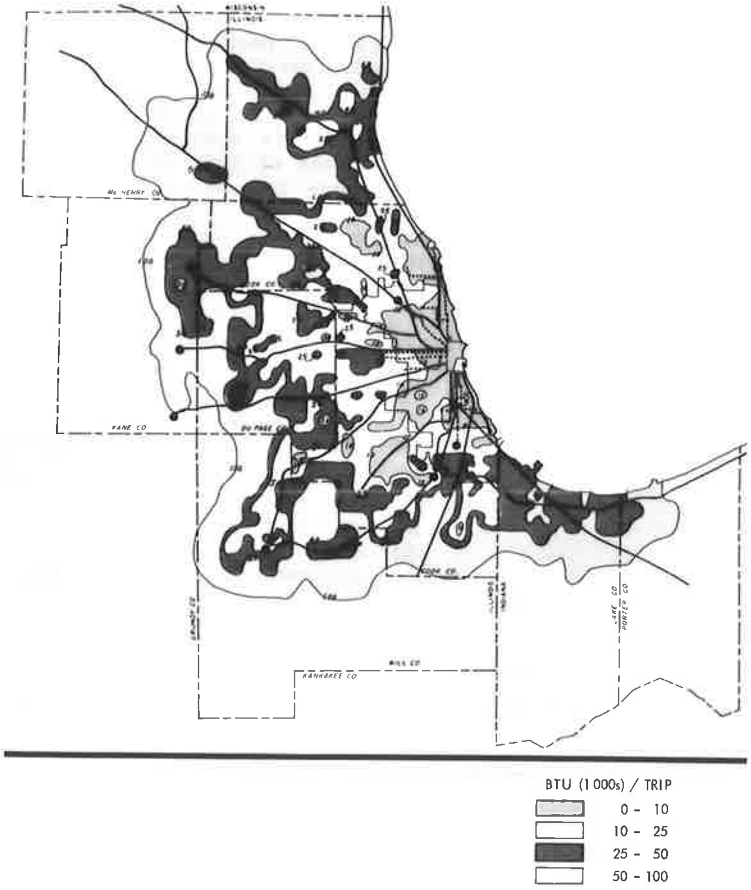
Table 4. Morning-peak-period energy consumption by ring of origin.

	Private Mode			Public Mode		
Ring of Origin	Avg Trip Length (miles)	Btu per Trip	Btu per Person Air Mile	Avg Trip Length (miles)	Btu per Trip	Btu per Person Air Mile
0	1.8	18 800	10 700	8.3	27 800	3300
1	3.5	35 200	10 200	5.7	12 700	2200
2	6.0	57 800	9 600	4.4	7 300	1700
3	5.6	57 800	10 400	5.8	8 400	1500
4	5.6	59 200	10 700	7.1	11 000	1600
5	5.2	54 800	10 400	8.7	16 600	1900
6	5.4	53 700	9 900	12.7	23 500	1900
7	6.2	58 400	9 400	18.7	46 100	2500
8	6.6	58 100	8 700	23.8	72 600	3100

Table 5. Morning-peak-period energy consumption by ring of destination.

	Private Mode			Public Mode		
Ring of Destination	Avg Trip Length (miles)	Btu per Trip	Btu per Person Air Mile	Avg Trip Length (miles)	Btu per Trip	Btu per Person Air Mile
0	7.8	76 600	9 800	10.8	19 600	1800
1	9.6	91 000	9 500	9.7	18 700	1900
2	6.6	66 800	10 100	5.7	10 500	1900
3	5.7	61 000	10 700	4.7	10 900	2300
4	5.0	53 500	10 600	5.1	15 000	2900
5	5.5	56 300	10 300	6.4	20 900	3200
6	6.1	59 300	9 800	9.6	24 400	2500
7	5.8	52 300	9 100	15.2	28 900	1900
8	5.9	51 400	8 600	18.1	34 800	1900

Figure 5. Energy consumption to the Chicago CBD: public transportation.



vate-mode trip lengths calculated by trip origin and trip destination are fairly close, which indicates little directional imbalance in these trips. The two most central Chicago rings do have longer destination trip lengths than origin trip lengths because employment in these rings is drawn from residences far outside the central area.

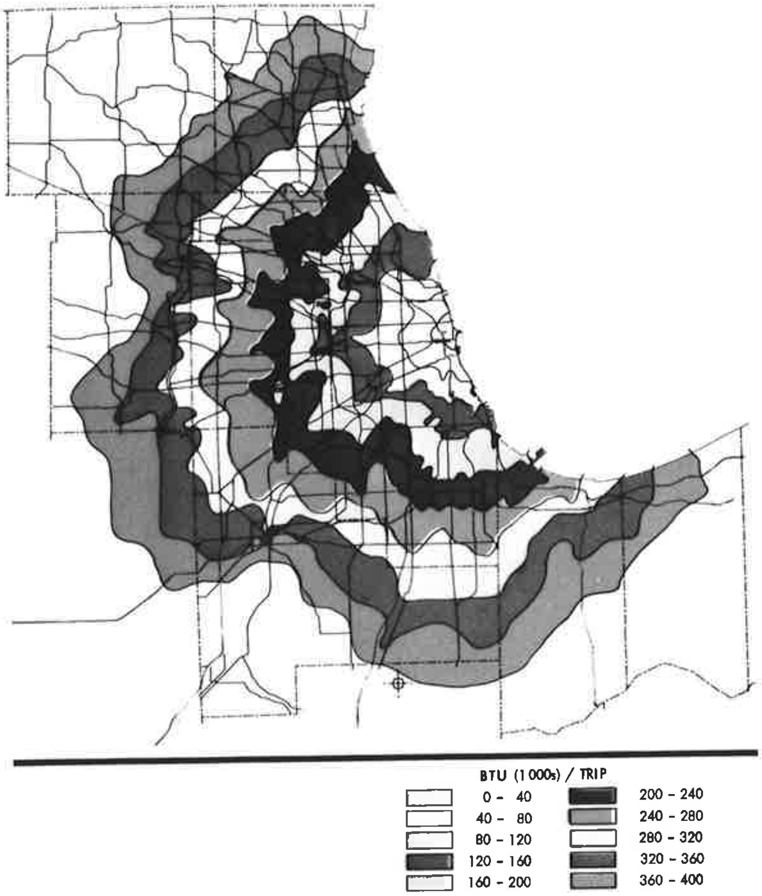
Public-transportation trip lengths exhibit the same pattern regardless of whether they are tabulated by origin or destination. The longest public-mode trips are those that begin or end in the innermost and outermost rings, and the shortest trips belong to the middle rings. Energy consumed per trip follows this same pattern. It should be noted, however, that the relation between energy and trip length does vary.

Energy consumption per person air mile for public transportation is more difficult to explain. Energy consumption efficiency for public modes for trips destined for rings farther away from the Chicago CBD decreases until ring 6; then, public-mode efficiency improves. Apparently, the capacity offered by public transportation (chiefly commuter rail) more closely matches patronage for trips to outlying destinations than it does for trips to rings closer to the downtown. The reverse-direction trips to these inner rings are carried generally by rail rapid transit and bus lines that offer nearly the same capacity in the peak and reverse-peak directions.

Energy Consumption for Travel to the CBD

The final two maps in this section show the energy required by the two primary modes to reach the Chicago CBD. Contours for public-transportation energy consumption are shown in Figure 5, and a similar map for private transportation is shown in Figure 6.

Figure 6. Energy consumption to the Chicago CBD: private transportation.



These maps show how accessible, in terms of energy consumption, the Chicago CBD is from all points in the region.

The two maps are very different, both in the appearance of the energy contours and in the contour values. The private-mode contours are more regular in shape and cover a wider range of values than the public-mode contours. The contours of the two maps are not set at the same values.

In the public-mode map, the contours are not uniformly spaced because the rate of public-mode energy consumption per unit of distance increases substantially as one moves away from the area covered by the regular grid of Chicago Transit Authority lines. Almost all of the city of Chicago is contained within the initial 10 000 Btu contour. But in the outer suburbs, contours 10 000 Btu apart would only be separated by approximately a mile when the automobile is used as an access mode.

Contours in the public transportation map tend to extend out along the commuter rail lines so that almost every point in the region that has direct public service lies within the 50 000-Btu contour. As soon as automobile access is required to reach public modes, the energy consumed quickly rises. There are also a number of "dimples" that lie between contours. These arise because some zones within an area of service still do not have direct public-mode service or because service is provided only by a lightly patronized line. Automobile access to rail transit energy consumption is computed by assuming single-occupancy one-way trips.

Contours on the private-mode map reach much higher values than those on the public-mode map. The 50 000-Btu contour for private transportation covers only a portion of the city of Chicago. Maximum private-mode contours are in excess of 300 000 Btu. Automobile occupancy levels are not incorporated in this map. The contours show average automobile energy consumption to reach the Chicago CBD and not person-trip energy consumption.

CONCLUSIONS

Many earlier studies have published data on the energy-intensiveness of different modes as measured by energy consumed per passenger mile, vehicle mile, ton mile, seat mile, or similar output measure. It is hoped that the reader understands that intermodal comparisons made on the basis of these figures are often misleading. Such comparisons ignore that passenger-mile and ton-mile outputs can be generated by grossly inefficient transportation services. For example, heavily laden vehicles that travel indirect routes can have low energy-intensiveness per ton mile and still be energy inefficient.

Comparisons of modal energy-intensiveness also ignore that low-energy-intensive line-haul modes may depend on high-energy-intensive modes for access and distribution from line-haul terminals. One has only to note that public-mode energy consumption should include energy consumption for automobile station access. For similar reasons, this paper does not compare rail transit with bus. A large portion of rail transit trips in the Chicago region cannot be completed without also using a bus for a portion of the trip.

The results of these analyses for the two primary modes can be summarized as follows. The direct energy consumption estimate of approximately 2000 Btu/person air mile for public transportation in the peak period can essentially be regarded as the maximum efficiency attainable by public transportation. The circumstances are ideal for efficient mode use, the market served has well-defined travel desire lines, and vehicles are operated near capacity. Private modes, in contrast, are operated with much lower vehicle occupancies and serve a relatively dispersed travel market.

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Short-Term Forecasting of Gasoline Demand

JOHN W. HARTMANN, FRANK E. HOPKINS, AND DERRIEL B. CATO

Techniques used recently by the U.S. Department of Energy to forecast short-term demand for motor-vehicle gasoline are reviewed. Techniques used during and before 1979 are discussed briefly, and the rationale for the development of new methods during 1980 is also presented. Because the forecasting effort is an ongoing one, the procedures evolve over time. Only the techniques developed during 1980 are treated in detail, but a brief discussion and summary of the older methods are provided for comparison purposes. The current forecasting technique relies on predetermined parameter values rather than econometrically estimated values. This is the result of an evaluation of the econometric estimates. The new procedures have resulted in improved forecast accuracy and have anticipated the downturn in motor-vehicle gasoline demand that occurred in 1980. The current model computes annual demand for 1980 within 1.0 percent of actual demand, and the average error for the monthly demand estimates during 1980 is less than 2.5 percent of actual demand. The current techniques can be used to project the effects of various policy options, such as improved mileage requirements or gasoline tax levies.

The Short-Term Analysis Division (STAD) in the Energy Information Administration (EIA) of the U.S. Department of Energy is responsible for projecting demands, supplies, and prices of all energy products on a monthly basis, nationally. To do this, STAD uses the Short-Term Integrated Forecasting System (STIFS) (1), which is an iterative balancing procedure, and several "satellite" demand models, one of which is the Motor Gasoline Demand Model. This paper describes the activities that STAD has undertaken in its search for a credible procedure for forecasting the demand for gasoline for use in STIFS.

There are several reasons for undertaking the development of a new short-term forecasting model for motor gasoline demand for STIFS:

1. Several past studies have examined the demand for motor-vehicle gasoline on the Petroleum Administration for Defense Districts (PADD) level. STIFS requires a national basis. STAD felt that one national model could replace the five separate PADD models previously developed.
2. Gasoline prices were relatively constant over the estimation period of the earlier models. However, changes in gasoline price have recently become volatile. This volatility has led to the notion that perhaps a shift in demand is taking place.
3. Several regional price elasticities in the PADD-level model used for the EIA 1978 Annual Report (2) were estimated to be insignificantly different from zero. The rapid increases in price and the effect on demand belie this finding.
4. The linear structure of the gasoline model used in the EIA February 1980 Short-Term Energy Outlook (3) led to large elasticities when faced with the rapid price increases in 1979 and 1980 following the Iranian revolution. The February report used both an econometric methodology and, in the appendix, a simple parametric procedure.

These considerations led to the development of the current gasoline demand model, which underlies the demand projections for the EIA 1979 Annual Report to Congress (4) and subsequent Short-Term Energy Outlooks following the February 1980 report. The parameters of the current model are specified rather than econometrically estimated. This is an interim methodology until a behavioral model that uses household data currently being collected by EIA can be estimated.

EIA's early gasoline models were typically linear regression models. Demand for gasoline was the dependent variable, and real price, real disposable

Table 1. Short-term gasoline demand models: 1975-1980.

Model Formulators	Estimation Date	Dependent Variable			Structure
		Frequency	Level	Time Period	
Alt-Lady	1975	Monthly	National	1969-1973	Regressed demand for motor-vehicle gasoline on 11 monthly dummy variables and real price of motor-vehicle gasoline
Alt-Bopp	1976	Monthly	National	1968-1975	Log linear, regressed demand on relative price of gasoline, real income, 12-month lag demand, embargo dummy
Gaynor-Donnelly	1977-1978	Quarterly	PADD level	Third quarter 1975-second quarter 1976	Linearly regressed demand on quarterly prices, income, and population
Klemm-Bopp	1978	Monthly	National	1968-1977	Log linear, regressed demand on income, retail price index for gasoline, 12-month lag demand
Atkinson-Borg[a]	1978	Quarterly	PADD level	First quarter 1975-fourth quarter 1976	Pooled cross-section data, regressed gasoline use on price, income, and heating-degree days for quarters 1 and 4
Hartmann-Hopkins	1979	Monthly	National	June 1975-August 1979	Regressed gasoline use on two cyclic variables, rapidly changing real prices, steady real prices, real income, and four dummy variables for January, June, August, and December
Rodekohr	1980	Monthly	National	1968-1978	Log linear, regressed per capita consumption on real per capita income, real price, per capita consumption lagged 12 months, and an embargo dummy
Hartmann-Cato[b]	1980	Monthly	National	1975-1979	Assumed price and income elasticity values taken from literature; lagged consumption, lagged real price, and lagged income included as predicting variables

[a] Gasoline use is defined as demand x (efficiency/stock).
[b] This model was used for the 1979 Annual Report to Congress (4) and the Short-Term Energy Outlook (3) of May, August, and November 1980 and February 1981.

personal income, fleet fuel efficiency, and fleet size were the typical independent variables. In some early models, other factors, such as a weather variable, also appeared as independent variables. The seasonal variations were "explained" by a weather variable, monthly dummy variables for various months, or cyclic variables such as the sine and cosine functions over time.

Later EIA models estimated demand in logarithmic terms--that is, regressed log of demand on the logged values of the independent variables. This led to constant monthly elasticities. The introduction of lagged variables on the right-hand side of the equation made the model estimates more theoretically palatable, but the usual problem of serial correlation required the use of appropriate statistical estimation techniques.

The short-term models proposed between 1975 and 1980 are described briefly in Table 1. The models were reestimated by using monthly data for July 1975 through August 1979. Table 2 gives the results of the reestimations, and Table 3 shows the results for the Atkinson-Borg demand model [1978 Annual Report model (5)].

An examination of the significance and the signs and magnitudes of the coefficient estimates shows the deficiencies and the strengths of the models. Table 2 also gives estimations of the reduced-form linear-elasticity and constant-elasticity models for purposes of comparison. Both of these results are poor: The R^2 is only 0.31 in both cases. The signs on the income, automobile efficiency, and fleet-size parameter estimates are inconsistent with their theoretically expected signs. These reduced-form models are therefore inadequate.

In models in which a 12-month lagged dependent variable appears on the right-hand side, R^2 improves considerably, but unusual behavior in a month of the last year is perpetuated in simulations 12 months later.

The Hartmann-Hopkins model was developed in December 1979 as a synthesis of previous efforts. The dependent variable is a proxy for vehicle miles. This is consumption per automobile divided by average miles per gallon. The independent variables include (a) the seasonal sine and cosine and (b) dummy variables, which were found useful in the Alt-Lady demand model. Both income and prices are statistically significant and of the expected sign. The price variable has been divided into two periods: One price variable records prices during a period of stable real prices from March 1976 through December 1978, and the other covers the periods of rapidly changing real prices from July 1975 through February 1976 and from January 1979 through August 1979. This was done in the belief that responses to price are different for these time periods.

A comparison of Federal Highway Administration (FHWA) data (monthly gasoline demand data reported by the states) and Joint Petroleum Reporting System (JPRS) data shows that a difference exists and that it is growing. This is a result of the different points of data collection. The FHWA data are derived from state gasoline drawdowns of primary stocks at refineries and bulk terminals. There is evidence that additional gasoline imports and recycled petrochemical byproducts are blended into the gasoline supplies between the refiner and the wholesale stages. In STIFS, the estimation of gasoline demand has two primary functions. The first is to measure the consumption of gasoline by automobiles, which corresponds to an FHWA measurement concept. The second is to estimate the crude-oil imports needed in refineries to produce gasoline, which corresponds to a JPRS concept.

The FHWA annual data have been found to be more accurate than the JPRS data for measuring gasoline consumption. The monthly pattern of the JPRS data series best captures the refinery production cycle required by STIFS. EIA is currently in the process of revising its data collection form to include the production of gasoline at blending stations, which will bring the JPRS series closer to the FHWA series.

The following three-step methodology was used to forecast monthly gasoline demand in the February 1980 Short-Term Energy Outlook (3):

1. Specify the annual relation between gasoline demand and exogenous variables: national income, price of motor gasoline, automobile fleet efficiency, and stock of motor vehicles.
2. Calculate the annual level of gasoline demand for 1980 based on the FHWA 1979 estimate. Assumptions about price, stock, and efficiency were entered into the relation as specified in the first step.
3. Forecast a monthly distribution of gasoline demand. This was done by using a regression equation based on JPRS data.

This methodology gave an annual estimate of gasoline demand that was consistent with FHWA data and that used the seasonal patterns associated with JPRS information.

An estimate of gasoline demand was made by using the structural relation given below [a proxy for vehicle miles traveled per car (use) was calculated as a function of seasonal factors, monthly adjustments, price, and income]:

Table 2. Results of demand model reestimations.

Model	Dependent Variable	Independent Variable	Estimated Coefficient	t-Statistic	R^2 of Regression	Number of Observations	Standard Error of Regression	Procedure
Alt-Lady	Demand for motor-vehicle gasoline	Constant	9.93	14.46	0.59	50	0.27	Ordinary least squares estimation
		January dummy	-0.61	-3.26				
		February dummy	-0.40	-2.12				
		March dummy	-0.15	-0.79				
		April dummy	0.00	0.02				
		May dummy	0.00	0.32				
		June dummy	0.46	2.41				
		July dummy	0.21	1.15				
		August dummy	0.34	1.86				
		September dummy	-0.18	-0.10				
		October dummy	-0.10	-0.51				
		November dummy	-0.15	-0.81				
		Real price	-0.08	-4.06				
Alt-Bopp	Demand for motor-vehicle gasoline	Constant	5.75	6.04	0.74	50	0.19	Ordinary least squares estimation
		Real income	-0.00	-1.12				
		Real price	-0.09	-6.40				
		Demand lagged 12 months	0.83	8.98				
Klemm-Bopp		Constant	3.12	3.23	0.75	50	0.03	Ordinary least squares estimation
		Log of real income	-0.16	-1.14				
		Log of real price	-0.46	-6.14				
		Log of demand lagged 12 months	0.81	9.03				
Hartmann-Hopkins	Use = (efficiency/demand x stock of vehicles)	Constant	67.11	5.79	0.84	49	2.12	Cochrane-Orcutt interative procedure, final value of RHO = -0.28
		Sine function	1.86	4.15				
		Cosine function	3.15	4.93				
		Real income per capita	0.02	6.75				
		Rapidly changing real price	-0.90	-5.32				
		Steady real price	-0.84	-4.62				
		January dummy	-4.00	-2.98				
		June dummy	3.46	2.37				
		August dummy	2.68	1.98				
		December dummy	4.36	3.26				
Rodekohr[a]	Log of per capita demand	Constant	1.15	2.92	0.90	113	0.03	Cochrane-Orcutt interative procedure, final value of RHO = -0.08
		Log of real income per capita	0.30	4.48				
		Log of real price	-0.13	-4.01				
		Log of per capita demand lagged 12 months	0.79	17.22				
		Embargo dummy	-0.07	-5.99				
Basic Reduced-Form	Demand for motor-vehicle gasoline	Constant	-4.07	-0.56	0.31	50	0.31	Ordinary least squares estimation, linear elasticity
		Real income per capita	0.00	-0.46				
		Real price	-0.06	-1.53				
		Fleet efficiency	0.02	1.01				
		Fleet size	-0.09	-0.60				
Basic Reduced-Form	Log of demand for motor-vehicle gasoline	Constant	-12.60	-0.97	0.31	49	0.40	Ordinary least squares estimation, constant elasticity
		Log of real income per capita	-0.60	-0.48				
		Log of real price	-0.29	-1.50				
		Log of fleet efficiency	3.53	0.94				
		Log of fleet size	-1.14	-0.53				

[a] Estimation period = January 1969 through June 1978.

Table 3. Atkinson-Borg demand model.

	PADD 1		PADD 2		PADD 3		PADD 4		PADD 5	
Coefficient	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error	Coefficient	Standard Error
Intercept	-5.911	0.433	-6.202	0.539	-6.445	0.277	-6.445	0.722	-6.636	0.275
Price	-0.240	0.873	-0.240	0.873	-0.130	0.061 5	-0.130	0.061 5	-0.130	0.061 5
Income	0.620	0.169	0.869	0.344	0.622	0.153	0.730	0.441	0.845	0.087 7
Winter heating degree days	-0.007 72	0.00 803	-0.0107	0.001 73	-0.008 32	0.001 50	-0.0232	0.002 61	-0.0104	0.006 40
R^2[a]	0.935		0.768		0.778		0.866		0.975	
Durbin-Watson statistic[a]	0.910		1.930		2.130		1.800		1.200	

Note: Dependent variable = vehicle use; estimation period = first quarter 1975 to fourth quarter 1976.

[a] Generated by using generalized least squares estimation with one iteration on the data after full-information-maximum-likelihood estimation resulted in convergence. The statistics are therefore representative but not exact.

$$\text{Gasoline demand} = [(\text{miles traveled/vehicle}) \times \text{number of vehicles}] \div \text{fuel efficiency} \qquad (1)$$

or, in units,

$$[(\text{miles/vehicle}) \times \text{vehicles}]/(\text{miles/gallon}) = (\text{miles/vehicle}) \times \text{vehicles} \times (\text{gallons/mile}) = \text{gallons} \qquad (2)$$

The model used in the 1979 Annual Report (4) specifies gasoline use more fully than the February 1980 Short-Term Energy Outlook model (3) by recognizing that consumer reactions to price changes are characterized by rigidities that arise from habit, lack of substitutes (alternative modes of travel), and information delays. Thus, the total impact of a price change on demand will not be realized within a one-month period and may require several months. The current model also attempts to separate total use into automobile use and other use, which includes light trucks, school buses, and nonhighway equipment. Efficiency improvements and vehicle stock changes are exogenous, as in the previous model. Monthly seasonal factors are now derived by decomposing the demand series into trend, seasonal, and irregular components.

The equations of the 1979 Annual Report model are as follows: For automobile trend demand,

$$\begin{aligned}\text{USE} = \text{EXP}[&\text{CONSTANT} - 0.11\,\text{LN}(\text{RPMG/MPG}) \\ &+ (0.11)(0.50)^{12}\,\text{LN}(\text{RPMG/MPG})_{-12} + (0.79)\text{LN}(\text{RY}) \\ &- (0.79)(0.50)\text{LN}(\text{RY})_{-1} + (0.50)\text{LN}(\text{USE})_{-1}]\end{aligned} \qquad (3)$$

$$\text{AUTO} = \text{USE} \times \text{KCARS}/(365 \times 42 \times \text{MPG}) \qquad (4)$$

For nonautomobile trend demand,

$$\text{USE} = \text{EXP}[\text{CONSTANT} - 0.10\,\text{LN}(\text{RPMG/MPG})_{-12} + 0.79\,\text{LN}(\text{RY})] \qquad (5)$$

$$\text{OTHER} = \text{USE} \times (1 + \%\text{KCARS})/(365 \times 42 \times (1 \times \%\text{MPG})) \qquad (6)$$

For total demand,

$$\text{TOTAL} = \text{SEASONAL FACTOR} \times (\text{AUTO} + \text{OTHER}) \qquad (7)$$

where

EXP = exponential,
LN = natural logarithm,
-1 = 1-month lag,
-12 = 12-month lag,
% = percentage change,
AUTO = automobile gasoline demand,
OTHER = nonautomobile gasoline demand,
RY = real income,
RPMG = real price,
MPG = efficiency, and
KCARS = fleet size.

Seasonal factors are as given below:

Month	Factor
January	0.9218
February	0.9685
March	0.9870
April	1.0139
May	0.9973
June	1.0576
July	1.0208
August	1.0366
September	1.0002
October	0.9880
November	0.9964
December	1.0073

The forecasting methodology consists of the following procedures:

1. Specify the parameters of the automobile gasoline model and other gasoline model by using estimates from the literature. Table 4 summarizes the literature search.
2. Forecast the monthly trend in automobile gasoline use as a dynamic function of cost per mile of travel and disposable income; then forecast monthly automobile gasoline demand as the product of automobile fleet size, efficiency improvements, and seasonal factors.
3. Forecast monthly nonautomotive gasoline demand as a function of the cost per mile of travel lagged one year, disposable income, nonautomobile fleet size, efficiency improvements, and seasonal factors.

Gasoline consumption is separated into automobile consumption (private plus commercial) and other consumption, based on 1976 FHWA data. The automobile demand component of personal vehicles plus single-unit trucks is approximately 75 percent, which is used to estimate automobile and nonautomobile demand for gasoline.

Consumers respond to increases in gasoline prices by decreasing miles traveled and increasing vehicle efficiency by purchasing new, more efficient vehicles and retiring older, less efficient vehicles. However, the full impacts of these two effects take time to be realized.

Vehicle efficiency improvements for the fleet are limited by the efficiency of new cars and by the purchase of new cars. The full impact of efficiency improvements in the stock of vehicles requires several years to take effect. Changes in miles driven may be fully realized within one year in response to price change. Significant changes in vehicle travel, however, may not be realized in one month and may take several months.

Short-term monthly forecasts may not be affected by efficiency improvements except those that have been set in motion by previous price changes. Monthly forecasts can be affected significantly by rigidities in the adjustment of gasoline use rates.

The size of the one-month elasticity, as well as the length of the lag, is highly speculative. The procedure described below assumes that

1. The adjustment process is geometric,
2. The adjustment takes place within one year following a price change,
3. The real income effect has an immediate impact on the use of gasoline due to a decrease in purchasing power, and
4. The price and substitution effects have a slow impact because of habit, information delays, carpool formation, search time for alternatives, and the switch to diesel.

Figure 1 shows the geometric adjustment process. The top panel shows a step increase in the cost per mile of travel (price of gasoline divided by efficiency). The middle panel shows the cumulative elasticity (in absolute value) due to decreases in use (the first impact) and efficiency improvements (the longer-term impact). The lower panel shows the corresponding decrease in gasoline demand.

The EIA Midrange Energy Forecasting System (MEFS) transportation demand model (14) estimate of a one-year elasticity of the cost per mile of travel is -0.25. A recent review of the literature gives a range of -0.1 to -0.25 (Table 4).

The price elasticity for "other" consumption was obtained from the EIA-MEFS truck model. The truck

Table 4. Summary of literature survey.

Source	Price Elasticity			Model Type	Sample Information			
	Type	Elasticity	Standard Error		Frequency	Level	Period	Type of Data
Cato (5)	One year	-0.25	0.070	Random coefficient, flow-adjustment regression model, log linear specification; demand expressed as function of price and income and lagged one year	Annual	Sixteen OECD countries, including United States	1962-1977	Temporal cross section
Data Resources, Inc. (6)	One quarter	-0.10^a	0.070	Gasoline demand per capita estimated as function of real price, income, and automobile stock; log linear specification; past behavior captured in four-quarter lag structure for price and income	Quarterly	United States		Time series, retail prices, excluding taxes
Fainer (7)	One year	-0.181	0.039	Demand expressed as log linear function of price and income and lagged one year; dummy variable for each country variant	Annual	Four major European countries	1960	Temporal cross section
Houthakker and others (8)	One quarter	-0.075^b	0.013	Dynamic flow-adjustment model, log linear specification, demand a function of price and income and lagged one quarter	Quarterly	United States (48 states)	1963-1972	Temporal cross section
Houthakker and Kennedy (8)	One year	-0.465	0.105	Same as Houthakker and others, except annual specification	Annual	Twelve OECD countries, including United States	1960-1972	Temporal cross section
Rodekohr (9)	One to 12 months^c	-0.128	0.032	Log linear, demand regressed on price and income and lagged 12 months; embargo dummy	Monthly	United States	Jan. 1968-Dec. 1978	Time series
Rodekohr (10)	One year	-0.163	0.034	Random coefficient, flow-adjustment regression model, log linear specification; demand expressed as function of price and income and lagged one year	Annual	Major European OECD countries	1962-1976	Temporal cross section
Sweeney (11)	One year	-0.227^d -0.232^e -0.300^f	0.060^d 0.050^e 0.050^f	Vintage capital-adjustment model; vehicle miles per capita a function of fleet efficiency, automobile stock, price, income, and the specified exogenous variables	Annual	United States	1957-1977	Time series
Wildhorn and others (12)	One year	-0.370	0.110	Five-equation recursive system, containing three equations that estimate automobile ownership as function of car price, income, and gasoline price and two equations describing VMT and efficiency	Annual	United States	1954-1972	Time series

Note: OECD = Organization for Economic Cooperation and Development.

[a] Four-quarter price elasticity = -0.28.

[b] Four-quarter price elasticity = -0.2.

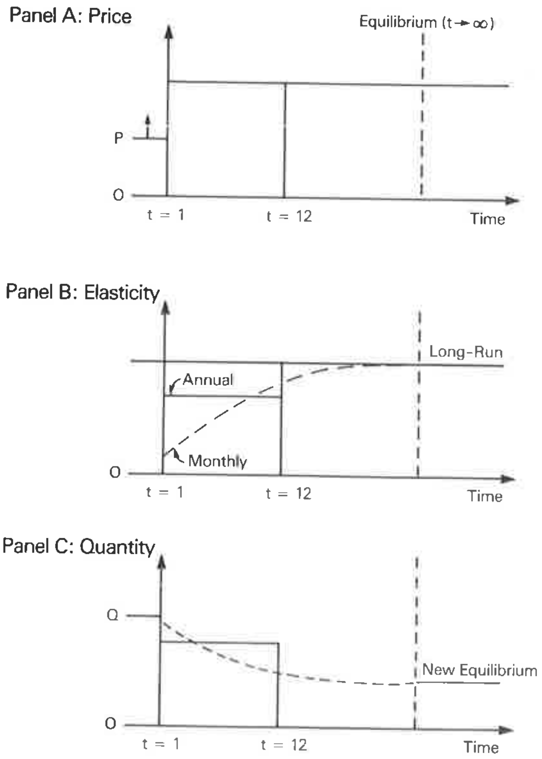
[c] Elasticity constant over 12-month period.

[d] Person-hours included as exogenous variable.

[e] Person-hours and unemployment rate included as exogenous variables.

[f] Person-hours, unemployment rate, and new-car registrations per capita included as exogenous variables.

Figure 1. Geometric flow-adjustment process.



model contains a one-year delay in the response of truck travel to changes in average fuel costs (the average price of diesel and gasoline), which yields a zero elasticity in the first year and a second-year elasticity of average cost of -0.5.

There is little or no reliable information concerning the short-term effect following income changes. A reasonable assumption is that the effect is constant throughout the year. The EIA-MEFS annual automobile model estimate of the income elasticity is 0.79. The range of income elasticity in the literature is between 0.6 and 1.0 in those annual models that do not force the elasticity to increase over time.

Seasonal factors estimated for the 1979 Annual Report (4) are based on the decomposition of a monthly time series into trend, seasonal, and irregular components. In general, any monthly time series (Q) can be assumed to be the product of the trend of the series (T), a seasonal component (S), and an irregular component (I), or Q = T x S x I. The Bureau of the Census X-11MULT Seasonal Adjustment Program (15) was used to derive the seasonal factors.

Automobile use (USE) is specified as a geometric function of the logarithm of the real cost per mile [real price of gasoline (RPMG) divided by the average efficiency of the automobile stock], real personal disposable income (RYD), and USE lagged 1 month. Also included in Equation 3 are a 1-month lag on income, which has the effect of keeping the income elasticity constant, and a 12-month lag in the cost per mile, which assumes that all adjust-

Table 5. Comparison of recent model backcasts of gasoline demand for 1979.

	Gasoline Demand (000 000 bbl/day)						
		Rodekohr Model		Hartmann-Hopkins Model		1979 Annual Report Model	
Month	Actual	Backcast	Error	Backcast	Error	Backcast	Error
January	6.830	7.292	0.462	6.913	0.083	7.159	0.329
February	7.254	7.198	-0.056	7.185	-0.069	7.604	0.350
March	7.229	7.574	0.345	7.194	-0.035	7.646	0.417
April	7.055	7.674	0.619	7.151	0.096	7.521	0.466
May	7.213	7.449	0.236	7.144	-0.069	7.693	0.480
June	7.191	7.714	0.523	7.327	0.136	7.670	0.479
July	6.902	7.619	0.717	6.886	-0.016	7.432	0.530
August	7.330	7.505	0.175	6.909	-0.421	7.882	0.552
September	6.881	7.440	0.559	6.529	-0.352	7.332	0.451
October	7.020	7.392	0.372	6.386	-0.634	7.426	0.406
November	6.791	7.477	0.686	6.264	-0.527	7.197	0.406
December	6.730	7.535	0.805	6.413	-0.317	7.181	0.451
1979 average	7.034	7.489	NA	6.858	NA	7.479	NA

Table 6. Comparison of February 1981 model backcast with actual data for 1980.

	Gasoline Demand (000 000 bbl/day)			
Month	Actual[a]	Model	Difference	Difference (%)
January	6.335	6.273	-0.062	-0.98
February	6.594	6.552	-0.042	-0.64
March	6.411	6.523	0.112	1.75
April	6.799	6.535	-0.264	-3.88
May	6.726	6.523	-0.203	-3.02
June	6.661	6.914	0.253	3.80
July	6.735	6.711	-0.024	-0.36
August	6.646	6.891	0.245	3.69
September	6.515	6.640	0.125	1.92
October	6.621	6.627	0.006	0.00
November	6.344	6.674	0.330	5.20
December	6.616	6.701	0.085	1.29
Average	6.583	6.631	0.146[b]	2.21

[a] From Monthly Energy Review, March 1981; last three months are preliminary.

[b] Average of absolute values.

ments in the use rate occur within a 12-month period.

The one-month real price elasticity is assumed to equal -0.11, which, because of the assumed speed-of-adjustment coefficient, yields a 12-month price elasticity of -0.22 [i.e., $-0.11 \times 1/(1 - 0.5) = -0.22$]. The income elasticity is assumed to equal 0.79, which is the value from the MEFS automobile model.

Equation 4 yields the monthly trend of gasoline demand as the product of the stock component and the efficiency component. Forecasts for the growth of automobile stock and the average efficiency of the stock are based on forecasts contained in the February 28, 1980, control solution put out by Data Resources, Inc.

Nonautomobile gasoline demand is forecast more simply than automobile demand. Based on the MEFS truck model, it is assumed that there is a 12-month lag in the response of truck miles to a price change. Equation 6 incorporates an assumed increase in truck stocks and efficiency increases equal to those assumed for automobiles. The price elasticity is assumed to equal -0.10 and the income elasticity to equal 0.79. Automobile and nonautomobile gasoline demand are added, and the seasonal factors are applied to estimate monthly total demand.

Table 5 gives a comparison of actual demand data and predicted values from three of the models recently developed: the Rodekohr, Hartmann-Hopkins, and EIA 1979 Annual Report models. These "backcasts" are calculations made by estimating model parameters over the 1977-1978 period and then using these estimates and actual independent variable values to predict the 1979 monthly gasoline demand. It should be noted that 1979 was a difficult year to predict because of unusual shortages, which caused supply constraints on demand during the summer months. The Rodekohr and 1979 Annual Report models overstate yearly demand by about 6.4 percent, and the Hartmann-Hopkins model understates by about 2.5 percent. The significance of these results is that all of the models predict the downturn in demand, especially late in 1979, after the summer shortage. The mean square error (MSE) and percentage MSE for each model are given below:

Error	Rodekohr Model	Hartmann-Hopkins Model	1979 Annual Report Model
Mean square	0.264	0.094	0.200
Percentage mean square	3.75	1.34	2.84

The results of the performance of the current model for 1980 are given in Table 6. The accuracy of the model can be seen in this backcast. The last three months of "actual" data are preliminary data from the March 1981 issue of EIA's Monthly Energy Review. As the table indicates, the model performs reasonably well. Sources of error include price, income, and fuel-efficiency forecasting errors. Another source of error, of course, arises from the unpredictable nature of consumers' monthly demands. The monthly pattern is monitored continually to reduce error from this source.

The process of model development for short-term prediction of demand for motor-vehicle gasoline has led to a reasonably accurate formulation. In these times of rapid price increases and income fluctuations, the current model is a valuable tool by which to evaluate consumers' responses. It can be used to evaluate the short-term effects on consumption of price controls or gasoline taxes or of mandated fuel-efficiency standards. In addition, given a reasonable projection of pricing decisions by the Organization of Petroleum Exporting Countries and refiners' and distributors' margins, the current model can be used to project gasoline demand. The model, in conjunction with supply information and a balancing system such as STIFS, can be used to signal a surplus or a shortage of gasoline for the nation.

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Issues for Developing State Energy Emergency Conservation Plans

MICHAEL A. KOCIS, RONALD H. BIXBY, AND DAVID T. HARTGEN

The key components of the process of developing a state-level energy emergency conservation plan and concomitant issues critical to responding effectively to future fuel-supply emergencies are described. In the event of a declared energy emergency, every state will be expected to consume a certain percentage of fuel below some predetermined base-period volume. The primary concern of the states then is to propose actions to meet the targets during a specified time frame and to achieve objectives such as minimizing market disruptions in geographic subareas and price monitoring. Also of prime concern to the states is maintaining the mobility of the traveling population. Equally important are the equitable distribution of the hardship that results from any shortfall, the ease of implementation of plans in advance of a major fuel-supply interruption, and the reliance on voluntary rather than mandatory conservation by the public. Efforts by the states should assist the public response by emphasizing alternative mobility options and encouraging consumers to find and use those alternatives in their own self-interest.

Since the 1973-1974 oil embargo, both the U.S. Department of Transportation and the U.S. Department of Energy have been increasingly active in transportation energy conservation and contingency planning at the federal, state, and local levels. A clear understanding of the guidelines that have been established and promoted by these agencies during the past years is essential to successful plan development and implementation. Although the effort has accelerated since 1979, the development of adequate plans for energy emergencies has been of great concern only at the local and state levels. In general, these plans can be characterized as a compendium of options that have been inadequately evaluated with respect to their probable effectiveness, their impact on various market segments, and their feasibility of implementation. Furthermore, they are generally not well coordinated with recent federal directives and guidelines on energy contingencies. In an effort to avoid such problems in its own work, the New York State Department of Transportation (NYSDOT) recently contracted with System Design Concepts, Inc., to conduct a fairly extensive study of transportation energy contingency planning. This paper discusses the key components of a planning process and issues critical to an effective response during future energy shortfalls.

BACKGROUND OF TRANSPORTATION ENERGY EMERGENCY PLANNING

U.S. Department of Transportation

The Federal Highway Administration (FHWA) and the Urban Mass Transportation Administration (UMTA) have been promoting a wide range of transportation energy conservation and contingency planning, research, demonstration projects, workshops, and conferences (1). These activities have been conducted pursuant to national transportation legislation, the Emergency Highway Energy Conservation Act of 1974, which provides for such programs as ridesharing, the 55-mile/h speed limit, and park-and-ride development as well as financial assistance for transit authorities and transportation system management. In early 1979, FHWA and UMTA issued a joint directive that requested that all regional administrators "actively promote energy contingency planning among the states and metropolitan planning organizations and strongly recommend inclusion of contingency plan development in each MPO's Unified Planning Work Program" (2). As a follow-up, the U.S. Department of Transportation (DOT) issued a document listing the kinds of actions some local entities had taken in preparing to deal with energy shortages (3). A three-part report was prepared for DOT to be used as a guide by the many actors involved in the planning and implementation of transit, paratransit, and ridesharing initiatives (4).

FHWA issued a directive encouraging the preparation of energy contingency plans by state and substate agencies as a preparatory response to an energy emergency (5). Each state highway agency is encouraged to work cooperatively with state energy officials in preparing the transportation element of statewide, substate, and metropolitan-area energy conservation plans and emergency energy conservation plans.

U.S. Department of Energy

In November 1979, Congress passed the Emergency Energy Conservation Act (EECA), which directed the establishment of a federal gas rationing plan and a standby federal emergency energy conservation plan. States are required to prepare and submit a state emergency conservation plan (SECP) within 45 days of the establishment of a mandatory energy conservation target by the President. If a state does not submit a plan, or if the plan does not meet federal criteria, a federal backup, or "standby", plan consisting of mandatory measures may be imposed on the state (6). So far, only voluntary gasoline-reduction targets have been issued.

The requirements for state plans under the legislation are fairly broad. A plan must demonstrate the capability of meeting the target, equity, and consistency with state and federal law and must include appropriate public participation. State plans may contain measures suggested by the federal plan, coupled with other proven measures or measures uniquely appropriate to the state or local area.

If the President projects that fuel supplies may be reduced, possibly due to federal policy decisions, political events, international petroleum agreements, or diversion of supplies to the Strategic Petroleum Reserve, he can make the current state voluntary fuel-reduction targets mandatory at any time. Once the mandatory target was established (assumed to be in the range of 7-8 percent), the state would begin to implement its emergency conservation plan. The target would probably not have to be reached for at least 3-5 months. However, monthly monitoring of movement toward compliance is expected from the U.S. Department of Energy (DOE). If the state plan was not meeting the specified target, the federal government could mandate other measures. For the first half of 1980, most states were meeting their targets.

In order to assist state energy and transportation officials to develop policies and programs for SECPs, DOE distributed information on state-level actions and the range of options available, including the context for conducting state-level planning (7). DOE also published an Energy Emergency Handbook (8), designed as a reference document for use by those with responsibilities for energy emergency management at the state and local levels. A conference on contingency planning in the transportation sector was sponsored by DOE and UMTA for the purpose of providing a forum for examining issues related to transportation energy contingency planning and to provide a basis for more coherent and effective public and private planning (9).

Local Efforts and State-Level Roles and Responsibilities

Prior to the requirements of the EECA, transit authorities and metropolitan planning organizations (MPOs) took the most initiatives and had the primary responsibility for transportation contingency planning in most states (10-12). Although states control many of the key powers that govern short-term actions such as pricing, restrictions on fuel purchase, rationing, and fuel set-aside, few state transportation or energy agencies have developed programs for exercising these powers in support of local or statewide objectives. As a result of EECA, however, local efforts are now being paralleled by statewide planning efforts. The current emphasis has been to encourage state government to assume more responsibility in conservation and contingency planning and to pay particular attention to the present targets established by DOE as a guide (13).

Depending on the state, it is either the state energy office or the state transportation office that has prepared or is preparing these plans. In most states, however, the energy office has the primary lead but is working closely with the transportation department. Some of the important responsibilities that must be clarified at this level are the following:

1. Definition of fuel savings and/or mobility maintenance objectives for conservation and contingency planning (for example, how, where, and to what extent different areas of a state should comply in meeting a mandatory demand-reduction target),
2. The analytic framework for assessing the potential for statewide and local-area actions,
3. Criteria for plan content, and
4. The role of the statewide plan in relation to local-area plans in terms of an ongoing planning process, plan implementation, emergency management, and funding.

A key issue facing state-level planners is the integration of existing fuel-supply-related powers and actions, controlled by state energy offices, with actions to reduce demand and maintain mobility, which are largely the responsibility of transportation agencies and operators at the local level.

Several organizations have followed the progress of EECA plan development, including the National Conference of State Legislatures, the National Governors Association, the U.S. Congress, and, more recently, the Planning Research Unit of NYSDOT. Our survey found that more than half the states have plans in draft form. Yet, on review, it should be noted that there has been a lack of evaluation of the energy savings attributable to the plan, the economic impacts of the actions, and the lost mobility implied by the shortage. These plans are oriented to reducing gasoline lines and preventing panic at the pump. The third, equally important, goal--maintaining the mobility of the traveling population--is often ignored. Particularly disturbing in many plans is the lack of awareness of the expected effectiveness of government-imposed actions in relation to the effects of changes in the driving habits of individuals without government intervention and improvements in fleet fuel efficiency.

ANALYTIC ELEMENTS OF STATE EECA PLANNING PROCESS

To assist in the plan development process, we suggest here a number of practical considerations that should be incorporated into such plans and suggest a systematic approach for evaluating possible strategies.

The exact format of any statewide EECA planning process depends on the objectives, roles, and responsibilities of the agencies and actors involved (14). However, certain analytic procedures should be followed in order to (a) systematically evaluate all actions and strategies contained in the statewide plan as to their probable effectiveness, interrelations, and impacts on various affected groups and geographic areas and (b) ensure their consistency with existing conservation behavior and local contingency plans. This planning process comprises five analytic elements, which are described below.

Transportation Inventory

The development of emergency transportation energy plans must consider the specifics of a state's transportation systems, the demographic and travel characteristics of its residents, and their willingness and ability to further conserve transportation energy or cope with temporary fuel shortages. An energy planning data base is required that will provide consistent levels of information and emphasis on

1. Transportation modes (automobile, bus, truck, rail, and air),
2. Transportation sectors (local and intercity),
3. Types and time of travel (work, nonwork, weekday, and weekend),
4. Geographic areas (urban, suburban, and rural) and subareas (agricultural and recreational), and
5. Past and current patterns of public response.

This data base forms an essential control mechanism for measuring the impacts and effectiveness of potential actions on a statewide and disaggregate basis.

Scenarios

State plans should define and consider likely future conservation and contingency scenarios in order to anticipate statewide impacts, measure projected public response, and determine appropriate public and private actions. These scenarios should be specified in terms of the following characteristics at the statewide level (it should be recognized that significant variations will occur at the local level):

1. Price of fuel,
2. Type and level of fuel shortfall,
3. Public perception,
4. Geographic distribution,
5. Lead time and immediate history, and
6. Type of fuel allocation.

If scenarios defined by the state were used as the basis for local energy planning and development, a strong element of consistency would be added to the overall planning process. Currently, most local areas use independent, often arbitrary assumptions about the future, especially regarding the level of fuel shortage or travel demand. In addition, inconsistent scenarios can result in a breakdown in emergency management of a crisis situation by different levels of government if the scenarios are used as a basis for "triggering" predetermined response actions. Parallel analyses can be developed for urban-level plans.

Impacts of Scenarios

States should have a clear understanding of the public response, travel demand, and economic consequences of future scenarios--assuming no government action--in order to determine when, where, and to what extent different types of government or private-sector actions may be appropriate. Some of the most important impacts of scenarios for purposes of emergency energy planning are

1. Energy savings due to efficiency improvements (i.e., fleet turnover and speed reduction);
2. Reduction in travel [in vehicle miles of travel (VMT)] for local, intercity, work, nonwork, weekday, and weekend travel;
3. Reduction in travel (VMT) due to diversion from automobile to other modes (local transit, commuter rail, and intercity bus, rail, and air) and increases in demand for these modes; and
4. Economic impacts of scenarios, including expenditures for gasoline and revenue losses to government and travel-related industries.

By examining the impacts in item 2 above, it is possible to determine the level of unmet travel needs associated with various types of travel for different scenarios. Disaggregation of these data by socioeconomic and demographic characteristics, combined with public response survey data, will provide a profile of who suffers most during fuel shortfalls. These unmet travel needs act as a barometer for identifying conservation behavior and selecting possible actions to reinforce that behavior while maintaining mobility and reducing negative economic impacts.

Candidate Actions

Existing state and local contingency plans contain a wide range of actions and strategies (15,16). Thus, a sufficient base of possible actions is readily available from which candidate actions suited to the unmet travel needs of and impacts on each state and local area for different scenarios can be drawn.

In order to initiate the sorting process necessary to evaluate and select those actions that are most appropriate for each state, selection criteria for the candidate actions must be defined. The following criteria should serve as a guide:

1. Geographic variation--Because of the differences between urban and rural areas of the state with respect to price and fuel shortfall levels, existing transit services, socioeconomic characteristics, existing actions already planned and/or implemented, the appropriateness of some actions is likely to vary significantly.
2. Feasibility--The feasibility criterion covers a range of possible considerations, including (a) time required to implement or remove an action; (b) anticipated acceptance by and/or compliance with the action by consumers, business and industry, and government; and (c) implementation constraints and opportunities, including financial, political, institutional, legal, technical, operational, and environmental, as well as the degree of flexibility required for optimum implementation of an action.

3. Government involvement--Consideration must be given to the degree to which the success of an action depends on direct government participation in planning, implementation, or enforcement as opposed to actions that the public or various groups can take themselves, with minimum government intervention or assistance, to save energy and maintain mobility. This criterion would include the administrative costs of government involvement.
4. Fuel savings--In considering the estimated transportation fuel savings for different types of fuels directly attributable to an action, it must be recognized that some actions will have greater fuel-saving potential when combined with other actions.
5. Mobility effects--The mobility-effects criterion considers the direct and indirect effect that an action may have on maintaining mobility (work, personal business, and social-recreational travel) and essential transportation services (public, commercial, police, fire, public health, and social service transportation).
6. Equity--Actions taken should not pose an unreasonably disproportionate share of the burden of restricted energy use on any region or any specific type of industry, business, commercial enterprise, or group of consumers.
7. Cost-effectiveness--The cost-effectiveness of an action should be high in terms of (a) the primary objectives of the scenario, (b) the relative importance of the action in terms of other alternative actions, (c) the relative importance of the action to other scenarios and objectives over the long and short term, and (d) the importance of the action to the success of interrelated strategies and actions.

Impact of Actions

The effectiveness of candidate actions in meeting the unmet travel needs, negative impacts, and objectives associated with each scenario should be determined. Evaluation of the probable effectiveness of actions has been relatively weak in most existing contingency plans and nonexistent in others. Some useful assessment techniques have been compiled, but no comprehensive "cookbook" of proven methodologies is currently available for use by contingency planners (17,18).

Reliance on VMT control totals established as part of the contingency-planning data base and scenario framework can greatly assist the evaluation process. These control totals can be used to help define specific market segments relevant to individual actions or combinations of actions and thus determine an upper bound on the potential for each action. The VMT control totals are categorized as follows:

1. Area--Statewide, urban (standard metropolitan statistical area), and rural;
2. Sector--Local and intercity;
3. Type--Work and nonwork; and
4. Period--Weekday and weekend.

Market segments for actions include the following:

1. Major--Consumers, private industry, and government; and
2. Submarkets--Employees by employer size, shoppers, business travelers, vacationers, recreation travelers, and gasoline purchasers.

PRINCIPLES FOR PLAN CONTENT

The following basic points serve as guiding principles that should be considered before a decision is made on a package of actions or strategies to be considered in a state emergency conservation plan.

Focus on Markets and Substate Areas

The plan should focus on easily identifiable segments of society whose transportation fuel needs can be identified and for which the savings potential from major actions can be assessed. The following markets or segments are necessarily quite broad so that no single group is unfairly burdened: (a) consumers, (b) business and industry, (c) freight and goods movement, (d) recreation and vacation travelers, and (e) government.

The overwhelming negative reaction to the proposed, and subsequently dismissed, weekend boating ban in the federal standby plan can attest to the need for careful assessment of energy savings potential. Broad packages of actions should be developed for each market and region that are internally consistent, are tailored to regional demographics and transportation options, and stress conservation while maintaining mobility.

Incentive-Based Program

The plan should emphasize actions that help each market or region to deal with shortages by expanding alternative mobility options, providing information, or providing assistance, either technical, managerial, or financial. Coercive actions should be stressed only as a last resort in the event of a very clear, immediate, and massive need. When coerced, people will respond only to the minimum extent necessary, violations will be extensive, and enforcement will be difficult and burdensome, if possible at all. When the crisis passes, behavior will revert to precrisis patterns; thus, attainment of ongoing conservation goals over the long run will be hindered.

Emergency Versus Conservation

The plan should clearly distinguish between actions appropriate for true emergencies that require immediate actions and less immediate conservation efforts. The state may have to develop two different emergency response approaches for two different situations: (a) meeting supply shortages or perturbations, a situation that requires measures to alleviate market disruptions as evidenced by long queues at retail service stations, and (b) meeting a conservation target, voluntary or mandatory, in the absence of a clear supply shortage externally imposed on the state, a situation that requires measures to help people cope with less fuel.

In the first case, the public's willingness to conserve is greater since its perception of the reality of the "crisis" is sharper. In the second case, consumers are likely to be skeptical, generally unwilling to act on their own, and more resentful of coercive actions.

Clear Lines of Government Responsibility

The plan should integrate and build on the various planning efforts and established responsibilities of public and private groups in transportation. Key groups that should be included, both in the planning process and in plan implementation, are federal, state, and local governments; transportation providers; fuel suppliers; business; and other interested parties. Otherwise, in the event of a future energy emergency, a situation may occur in which part of a local plan may conflict with the state plan.

Generally, the state plan is far more likely to be activated before either federal rationing, for which a 20 percent shortfall and congressional approval are required, or local contingency plans, for which an emergency declared by the Governor would probably be required. At this point, the implementation of many elements of a state plan will require the cooperation of local officials, probably MPOs.

MPOs in urbanized areas can be particularly valuable in employer-oriented plan development. In many areas, these organizations are already working with employers and transit operators to institute carpooling, vanpooling, transit promotion, and flex-time programs. They can also assist companies in preparing ridesharing and other conservation and contingency plans by providing instruction and methods for data collection and analysis, impact identification, and implementation mechanics and can assist conservation plan actions generally by coordinating and promoting conservation and mobility actions and serving as a regional clearinghouse and multiagency "spokesperson".

Existing Communication Channels

Where communication with the public (or with various markets) is necessary, maximum use should be made of already existing contact systems--MPOs, for example--or reregistration notices from the state department of motor vehicles, which can be augmented (at very low cost) with additional material on motorists' driving habits and fuel-efficient cars as well as carpooling and use of transit. Existing industry and business groups (e.g., chambers of commerce), organizations of public officials (e.g., county executive associations), transportation providers (e.g., bus and taxi companies), consumer and public interest groups (e.g., the League of Women Voters), and others can provide input and act as secondary promotion resources.

Equity

Equity is a high priority for energy planning. The EECA of 1979 states that, "taken as a whole, the plan should be designed so as not to impose an unreasonably disproportionate share of the burden of restrictions of energy use on any specific class of industry, business, or commercial enterprise or any individual segment thereof." Understandably, the boating interests voiced concern over the proposed restrictions on recreational watercraft presented in the federal standby plan.

Phased and Measured Implementation

The plan should be structured so that elements can be added or subtracted incrementally, or increased or decreased in intensity, according to the level of the emergency and the progress made toward conservation and mobility objectives. Actions that prevent panic, encourage conservation, and are incentive based should come first; only in extreme crises (15-20 percent energy shortfall) should stringent actions be considered. At shortfalls greater than 20 percent, federal rationing systems should be included in the plan's action packages.

Boundaries

The plan should consider what adjacent states and countries (Canada and Mexico) are doing in terms of each scenario and action, especially for those actions that affect intercity vacation travel and fuel availability (e.g., speed-limit enforcement and odd-even gasoline rationing). Interstate coordination, including Canada, is required to mitigate negative impacts on the tourist industry.

SUMMARY AND CONCLUSIONS

It is universally recognized that transportation energy conservation is an essential component of an effective state policy for energy emergencies. The statistics of conservation potential are generally well known and agreed to. Transportation energy must be conserved continually as well as in an emergency, and potential state-level actions to initiate this conservation should be prudently prepared.

Recent federal directives have greatly accelerated the process of emergency plan preparation at all levels of government, by private industry, and by transportation providers. This paper suggests a number of practical considerations that should be incorporated into such plans to improve their effectiveness and relevance.

ACKNOWLEDGMENT

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Analysis of Long-Term Transportation Energy Use

THOMAS J. ADLER AND JOHN W. ISON

The structure of ENTRANS, a DYNAMO-based simulation model of the interactions between energy supply and transportation-related energy use, and some of its policy analysis applications are described. ENTRANS includes representation of the characteristics of transportation supply (public transit, highways, and automobiles) and households' travel-related decisions (car type, travel mode, trip length, and frequency). The model is capable of analyzing a wide range of policies designed to change automobile fuel use. The results of several detailed policy analyses are described. These results indicate that automobile fuel-efficiency standards can be both effective and cost efficient and that fixed additions to the gasoline tax can have substantial short-term, but little long-term, impact on fuel use. Overall, the model is a useful step in the development of a comprehensive tool for the analysis of transportation energy policy. Ongoing development will make ENTRANS more useful for specialized applications.

This paper describes the structure and applications of a model for forecasting transportation energy use at the national level. Development of the model started in September 1978 and over the course of the effort, U.S. gasoline prices doubled and use of gasoline for automobiles became a significant national concern. The original purpose of this research was to develop a better understanding of the long-term effects of transportation energy policy on gasoline use through an explicit representation of all of the important interactions among travel demand, transportation supply, and energy supply. The events of the past two years have both increased the importance of obtaining better understanding in this area and (to an even greater extent) increased the relevance of the research to the current debate on national energy policy. Attempts to reduce U.S. dependence on foreign energy sources have inevitably involved analysis of policies including gasoline pricing and taxation, automobile energy efficiency regulations, and increased support of public transit systems. The long-term effects of such policies are, however, not fully understood.

The model developed in this research effort--Energy Use in Transportation (ENTRANS)--represents a large subset of the factors that have an impact on the effectiveness of alternative policies. The model has been implemented in a way that allows easy access by policy analysts with diverse levels of computer experience. It has already been used in a range of policy analysis tasks and is continually being updated with recent data and improved structural elements. The model version whose results are described here, ENTRANS 4/15, was developed recently for the Solar Energy Research Institute.

WHY ANOTHER TRANSPORTATION ENERGY MODEL?

When this project was originally proposed, in November 1977, a number of completed transportation energy use models were already available. Although a few of these were actively being used for policy analysis, the difference in forecasts among the models was generally quite large. For example, Figure 1 shows the range in estimates of automobile fuel use from a sample of relatively current models (1). One could argue that this range in estimates represents a plausible (and even optimistically small) level of uncertainty about uncontrollable future events. However, our review of the existing models indicated that the differences in model forecasts were explainable not so much by uncertainty in the parameter estimates as by differences in model structure and, in particular, by differences in the factors and interactions that were included in the models. Generally, those models had been "first-generation" efforts. In addition, they had been built to address relatively limited ranges of policy issues. Our approach was to build on these efforts by piecing together a more structurally complete model set and, in addition, to draw more heavily on some of the recent work in transportation demand modeling.

A more structurally complete model is not necessarily a better model. In constructing our model, we wanted, in addition, one that would be easy to use and would be capable of representing, in a realistic way, the effects of a wide range of policies.

MODEL STRUCTURE AND COMPONENTS

The remainder of this paper summarizes the development and applications of ENTRANS. Substantially greater detail on both model structure and applications can be found elsewhere (2-5).

The basic components and relations included in this modeling effort are shown in Figure 2. Energy supply is described by the price and availability of crude oil. These quantities are determined in an externally linked energy supply model, NEP2000 (6). Energy consumption is divided into two end-use categories: transportation and all other uses. Transportation energy use is further split into passenger travel and freight transportation. ENTRANS represents, in detail, only those mechanisms that influence passenger travel. Other uses of crude oil are determined exogenously to the model.

Figure 1. Comparison of fuel-use forecasts of various models of national transportation energy use.

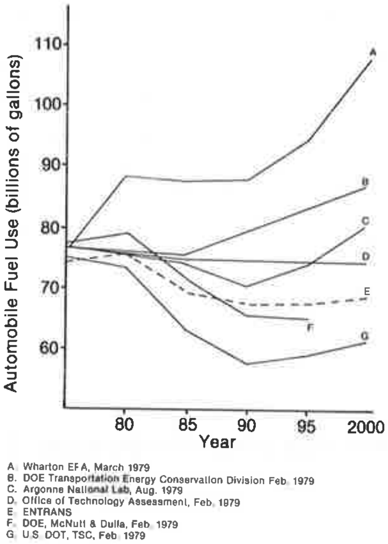
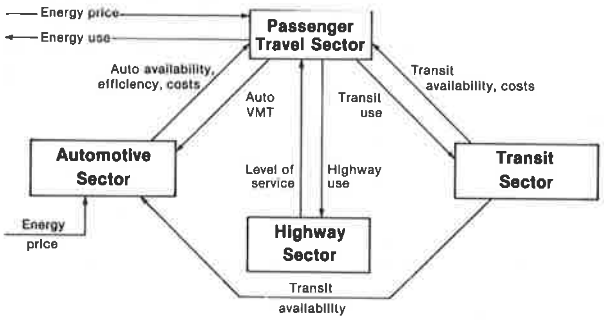


Figure 2. ENTRANS model structure.



The basic factors that influence passenger-travel energy use include individuals' daily travel decisions as represented in the travel sector, the service characteristics of the public transit system (transit sector) and of the highway network (highway sector), and the fuel efficiency of the automobile fleet (automobile sector).

In a general sense, this structure corresponds to the classical economic supply-demand paradigm where, in this case, transportation supply and demand are nested within an energy supply-demand system. The structure must also represent the mechanisms by which supply-demand interactions are affected. Both energy and transportation suppliers are regulated, which means that it may be impossible to increase prices in order to clear the market at given levels of supply. In addition, many of the changes in energy supply (e.g., construction of new production facilities) and in transportation supply (e.g., improvement in fleet fuel efficiency) can be accomplished only over relatively long periods of time. Together, price regulation and significant physical delays to supply change mean that any realistic model of these supply-demand interactions should recognize the time dynamics of response to system changes. Thus, interactions in the structure in Figure 2 must be traced continuously through time. This is accomplished in ENTRANS by implementation in the DYNAMO continuous systems simulation language, which allows explicit representation of physical and information delays.

To fully represent the long-term effects of policies, the model simulates system behavior to the year 2020. Obviously, the quantitative values of forecasts that far in the future involve great uncertainty. The primary benefit of the long forecast horizon of the model lies in tracing, through time, the long-lasting effects of policy change, given fixed assumptions about uncontrollable attributes of the future.

ENTRANS contains seven sectors:

1. Travel--Computes mode-specific travel demand and fuel use;
2. Automobile--Represents the effect, on automobile fuel efficiency, of industry and consumer response to gasoline prices and government policies;
3. Transit--Represents the transit sector response to changes in ridership and to various policies;
4. Carpool--Represents carpool-specific levels of service;
5. Highway--Determines the effect of highway condition and congestion on average network speed;
6. Demographic--Projects economic and population growth; and
7. Cost--Converts crude-oil prices to equivalent gasoline prices.

The seven sectors, their interactions, and information flows are shown in Figure 3.

Passenger Travel and Fuel Cost

The ENTRANS travel model computes travel demand and modal splits. Household-level travel is determined by assuming that households maximize the utility of travel subject to time and money constraints. Utility is measured by travel distance; it is assumed that increased travel distance provides greater utility by increasing the spatial range of opportunities for satisfaction of household needs and desires.

This theory implies that travel decisions for all modes are based on two generic modal characteristics--cost and speed--and two generic demographic characteristics--number of trip makers per household and income. On a household level, trip-making decisions are limited by the binding constraint of the mode with the maximum number of daily miles possible. In general, travel modes are compared on the basis of the maximum number of daily miles possible by each mode. Since the maximum number of daily miles associated with a mode is a measure of the utility of that mode for a household, it can also be used to determine modal splits in a logit formulation.

The question of whether households' travel time and money constraints are stable at the aggregate level, as implied by this model, has recently been the subject of active debate (7). In a sense, the use of constant household travel time and money constraints in ENTRANS could be viewed as a normative assumption. That is, given major increases in the future cost of travel due to expected increases in fuel prices, policymakers should not expect households to spend an increasing fraction of their budget on travel. ENTRANS is not intended to be used to trace short-term responses (0-1 year), which might well include variable expenditures on travel. Rather, the model's focus is on the system's long-term response, in which case the assumption of a constant travel budget seems somewhat more reasonable.

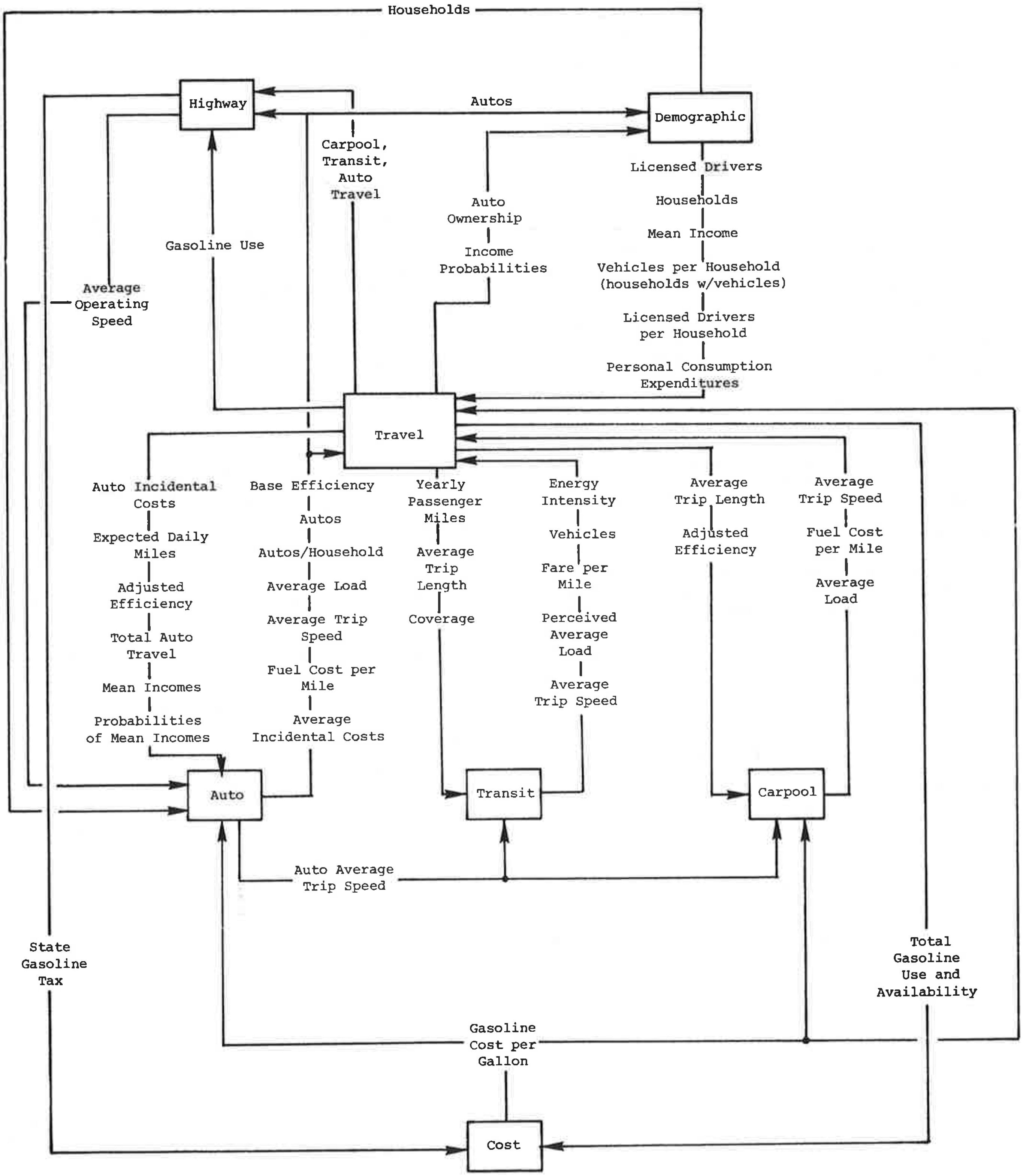
The travel model includes several other components that predict other travel characteristics, such as trip lengths, frequencies, automobile occupancies, and travel speeds, all of which affect automobile fuel efficiencies and, thus, fuel consumption.

Automobile Industry and Consumer Responses

Two parallel structures are used to model the decisions of the automobile industry within ENTRANS. The first computes costs associated with automobile production and outputs price for each of five automobile size classes. The second finds the fuel efficiency within each class that minimizes consumers' life-cycle costs of automobile ownership.

Four cost factors influence the fuel-efficiency decisions of each automobile manufacturer: technology costs, gasoline costs, fines for not meeting government-mandated fuel standards, and government excise taxes. Each of these costs is a direct function of automobile fuel efficiency:

Figure 3. ENTRANS intersector information flows.



1. Technology costs increase as fuel efficiency is increased. These represent nonmonetary costs of small, down-sized automobiles as well as the additional costs of fuel-efficient technologies.
2. Gasoline expenditures expected over the lifetime of an automobile decline with improved efficiency and increase with higher gasoline prices.
3. Penalty fines are imposed for noncompliance with the government standards. Higher efficiency of any automobile will (other things being equal) increase the efficiency of a manufacturer's new-car fleet and reduce noncompliance penalty fines.
4. Excise taxes imposed by the government are directly related to the fuel efficiency of each automobile; as the efficiency of an automobile increases, excise taxes are reduced (in some cases, up to a specified fuel efficiency).

Lifetime fuel cost savings are offset by technology costs as fuel efficiencies increase. It is assumed that, within an automobile size class, the lowest life-cycle costs will always be the most attractive to consumers. It is further assumed that manufacturers provide the least-cost combination of technology costs, fuel-economy increases, penalty costs, and excise taxes to the consumer in an attempt to maximize automobile attractiveness, sales, and, hence, profits.

The second parallel structure used to represent the automobile industry is virtually identical to the first. The only major difference is that it computes incremental price and fuel-economy changes by using the derivatives of gasoline, technology, marginal penalty cost, and excise-tax functions. The minimum life-cycle cost is found when a selected fuel economy drives the sum of the four component derivative cost functions to zero. Since the life-cycle-cost function used in this model is analytically intractable (3), a numerical solution technique, first derivative search, is used to find the optimum value.

The factors that influence the utility of an automobile class, and therefore its market share, include operating costs, new-car prices, class-specific attributes, and household attributes. A multinomial logit model that represents the trade-offs among these factors is used to determine this market share (8).

A conceptually simple, though important, component of the model is a vintaging sector that traces the composition of the national automobile fleet. New automobiles enter the fleet each year with given fuel efficiencies, and old automobiles are scrapped or otherwise removed from the fleet, so that aggregate fleet efficiency changes over time. Actual fleet efficiencies are computed on a use-weighted basis; older cars have lower use weights than newer cars.

Other Transportation Supply Sectors

The transit, carpool, and highway sectors compute levels of service by mode given modal characteristics and travel volumes. These levels of service are used by the travel sector to determine travel patterns. The highway sector determines the impact of highway-specific policies on automobile operating speeds. Vehicle travel distance affects levels of congestion and rates of road deterioration.

Other Model Sectors

The demographic and cost sectors of the model consist of several exogenously determined factors. The demographic sector computes household characteristics such as number of households, mean household income, number of licensed drivers per household, and number of automobiles per household for households that own automobiles. Inputs include the total number of automobiles, from the automobile sector, and the distribution of automobiles across income classes, from the travel sector. The cost sector uses a wellhead crude-oil cost predicted by NEP2000 (6) and intermediate conversions and costs to compute the price of gasoline. One intermediate cost is the average state fuel tax, which is computed in the highway revenues subsector. Values for fuel use and fuel availability from the travel sector are used to compute a price multiplier resulting from fuel shortfall.

Use of the Model

ENTRANS is built with a user's interface that allows direct, interactive, English-language policy testing. Policies can be tested individually or in packages. A sample session is shown in Figure 4. Responses after question marks are given by the user. Results from this particular run are not included here but would follow immediately after the listing in Figure 4. Model runs cost approximately $3 on Dartmouth's Honeywell 6180 computer. Policies not included in the list of options can be specified interactively by changing equations, parameter values, or values of variables in "rerun" mode.

MODEL BEHAVIOR

Base Model Run: Historical Behavior

The validity of any model rests on both the reasonableness of its individual assumptions and the ability of these assumptions to produce reasonable aggregate behavior. The structure of ENTRANS is based on clearly defined economic theory that describes how the automobile industry responds to economic pressures (such as gasoline prices and government policy) and how consumers make travel decisions and select automobiles. Model parameters have not been chosen, nor has a structure been selected, solely in order to obtain a "good fit" with historical data. This is important, since a comparison of model output with history provides a good test of the reasonableness of its structure and assumptions.

In a system in which precise prediction is not desired or is not possible, it is important to compare the model variables with actual historical values. The model should be required to reproduce the historical behavior mode, though not necessarily the exact historical values. ENTRANS is not meant to predict exact numerical values but to illustrate the long-term dynamics of the system's structure and how various policies will change those dynamics. The model is valuable primarily as a tool for evaluating relative differences in system behavior due to different policies or alternative exogenous assumptions.

Since the concern of this study is the effect of energy price and availability on transportation-related energy demand, four variables are traced historically to check the consistency of the model with actual behavior: fuel use, automobile vehicle miles of travel (VMT), automobile price, and fuel efficiency.

Historically, automobile fuel use increased over the last 25 years. In the 1950-1975 period, actual use increased from 30.9 to 76.0 billion gal/year. As shown in Figure 5, the model closely replicates this behavior, starting out with 27 billion gal/year in 1950 and ending in 1975 with about 73 billion gal/year.

Figure 4. Sample ENTRANS run.

```
ENTRANS Interface here!
Foreground or Background?  foreground

End-Year? 2020

Plot/Print options (press return for available options) ?

Available options are:
   1)   PLOT Standard Plot
   2)   PLOT Extended Standard Package
   3)   PLOT Auto Prices
   4)   PLOT Passenger Miles by Mode
   5)   PLOT Daily mileage by income class
   6)   PLOT New car market shares
   7)   PLOT Trip Characteristics
   8)   PLOT Demographics
   9)   PLOT New car on-the-road economies
  10)   PLOT New car EPA economies
  11)   PLOT Generalized new car prices
  12)   PLOT Penalty costs
  13)   PLOT Technology costs
  14)   PLOT Transit Sector Response
  15)   PLOT Auto Vehicle Miles
  16)   PLOT Auto Fuel Use
  17)   PLOT Auto Maximum Daily Miles
  18)   PLOT Transit Maximum Daily Miles
  19)   PLOT Highway Sector Response
  20)   PRINT Standard Printout
  21)   PRINT Auto Prices
  22)   PRINT Passenger Miles by Mode
  23)   PRINT New car market shares
  24)   PRINT Trip Characteristics
  25)   PRINT Demographics
  26)   PRINT Transit Sector Response
  27)   PRINT Auto Vehicle Miles
  28)   PRINT Auto Fuel Use
  29)   PRINT Auto Maximum Daily Miles
  30)   PRINT Transit Maximum Daily Miles
  31)   PRINT Highway Sector Response
  32)   PRINT New car on-the-road economies
  33)   PRINT New car EPA economies
  34)   PRINT Technology costs
  35)   PRINT Penalty costs
  36)   PRINT Excise tax costs
  37)   PRINT Generalized new car prices
  38)   PRINT Lifetime gasoline costs
  39)   PRINT Auto stock
  40)   PRINT Fleet economies

Plot/Print options (press return for available options) ? 1,3

Enter policies.  Press an extra 'RETURN' when done.
Type LIST for options.
Policies?  list

Available policies are:

Code   Title
 NMAN   No mandated fuel economies
 HMAN   High mandated fuel economies after 1985
 LPEN   Low Penalty rates ($ 25)
 HPEN   High Penalty rates ($ 100)
 LTAX   Low gasoline tax ($ .30) in 1985
 MTAX   Medium gasoline tax ($ .60) in 1985
 HTAX   High gasoline tax ($ 1.00) in 1985
 TAX80  Gasoline tax in 1980
 EXT    Excise tax on gas guzzlers (no rebate
 RATD   Driver Based Rationing (1985)
 RATV   Vehicle Based Rationing (1985)
 CPPI   Carpool Parking Incentives (5 minute savings 1985)
 CPSL   Carpool Special Lanes (1.3 times avg. auto speed in 1985)
 UMTA   Increased UMTA Capital Expenditures (extra $ 500 mil. beyond 1985)
 HCL    Increased Highway Construction Levels (30% increase in 1985)
 HRL    Increased Highway Reconstruction Levels
 HML    Increased Highway Maintenance Levels (30% increase in 1985)
 TFAR   Decreased Transit Fares ($.05 decrease in 1985 and beyond)
 NEP1   National Energy Plan 1
 NEP2   National Energy Plan 1 & 2
 N2000  NEP2000 World Price Scenario (default)
 OPEC1  Low OPEC Price Scenario
 OPEC2  Medium OPEC Price Scenario
 OPEC3  High OPEC Price Scenario
 HGNP   High GNP Growth Rates
 MGNP   Medium GNP Growth Rates
 ZMIG   Zero Mean Income Growth after 1980
 HPOP   High Population Growth Rates
 LPOP   Low Population Growth Rates

Policies?  hman
Policies?  hpen
Policies?  run high mandates and penalties
*RUN HIGH MANDATES AND PENALTIES
```

Figure 5. ENTRANS simulation of historical values.

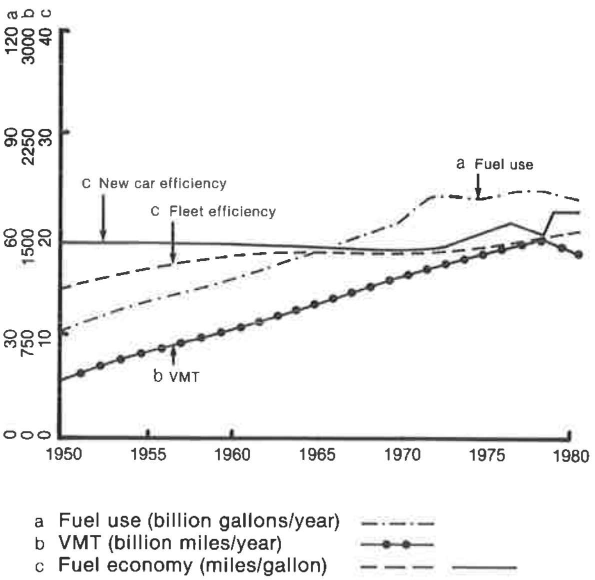
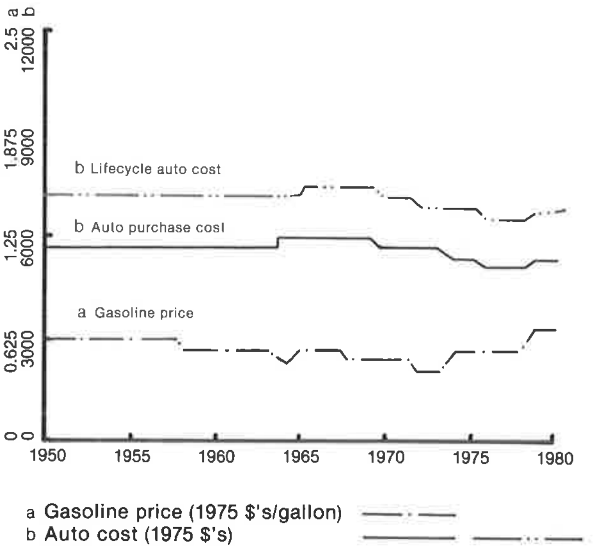


Figure 6. ENTRANS simulation of historical costs.



During the 1953-1973 period, ENTRANS shows automobile fuel use to be consistently higher than the historical value (Figure 5). This is mainly due to consistent underestimation of automobile fuel efficiency. Unfortunately, Federal Highway Administration (FHWA) Highway Statistics (9), which provides data for past fuel consumption, VMT, and fuel efficiency, does not provide efficiency measures on a model-year or size-class basis. Thus, ENTRANS (which traces fuel efficiency for five automobile type classes) uses historical efficiencies developed for the Wharton econometric model (10), which are lower than those cited in Highway Statistics.

Historical and predicted automobile VMT both rise steadily between 1950 and 1973 and exhibit a slight decrease between 1973 and 1975. During the growth period, both household income and population, the prime determinants of gross travel demand, rise steadily. Increased income makes it possible for a larger portion of the population to own automobiles, thus increasing the availability of cars and, thereby, VMT. Income growth also increases household transportation budgets. This budget increase, coupled with steadily declining operating costs resulting from gasoline prices falling more rapidly than car efficiency, allows each household to travel farther. Population growth during this period also makes an important contribution to total VMT.

As pointed out earlier, the historical automobile fuel-economy data were extracted from Highway Statistics (9) so as to be consistent with data plots for automobile VMT and fuel use. ENTRANS, however, has been designed around the lower on-the-road fuel efficiencies used in the Wharton model. During the entire period, fleetwide fuel efficiency steadily declines. This correlates well with the decline in gasoline prices seen over the same period (Figure 5). As gasoline price and operating costs fall, household incomes rise and operating costs assume secondary importance; consumers shift their emphasis from automobile cost to comfort, size, and performance considerations; the efficiency of cars decreases as consumers' tastes change; and the efficiency of the American automobile fleet declines.

As the model is specified, only changes in fuel efficiency affect the costs of automobile production and, thus, retail price. Prior to the implementation of government fuel-standards programs in 1978, only the price of gasoline affected the efficiency of cars manufactured in the United States. Fuel economy fell with gasoline price and automobile prices dropped, particularly between 1969 and 1975. ENTRANS produces prices that, on the average, accurately track the observed values (see Figure 6). Deviations can be seen during the 1950s, but they are primarily due to consumer shifts between automobile size classes and not to price differences within each size class.

Base-Case Assumptions

The values of a number of exogenous variables are specified in each model run. These values are included but are not computed within ENTRANS and therefore may be changed for purposes of investigating alternative future scenarios. Since the output of the model is directly tied to its exogenous assumptions, it is important to list these assumptions.

Specifically, four sets of exogenously determined variables are used in ENTRANS:

1. Population growth rates [base = 1.7 percent/year (11)],
2. Gross-national-product growth rates [base = 3 percent/year, declining to 1.25 percent by the year 2020 (12)],
3. Fuel prices and production rates (6), and
4. Highway construction and reconstruction rates (9).

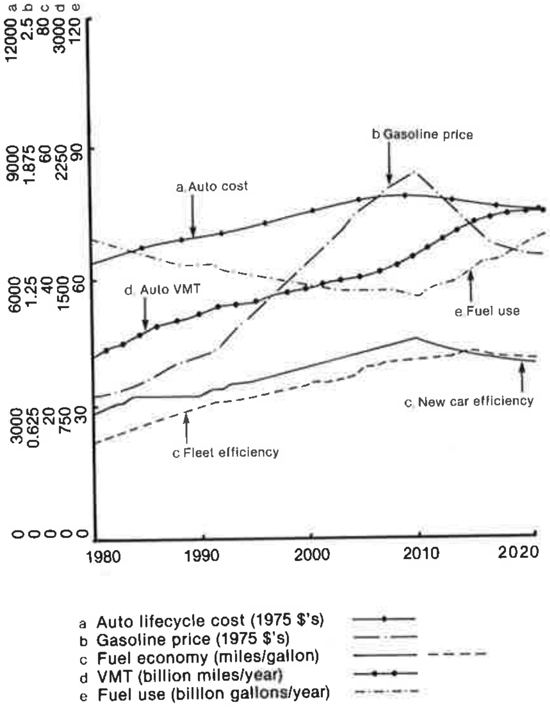
The model version whose results are described here, ENTRANS 4/15, differs from earlier versions primarily in its use of updated gasoline price projections and in the use of "optimistic" technology cost curves. These new cost curves, developed in consultation with the Transportation Task Force of the Solar Energy Research Institute (SERI), assume lower costs for implementing fuel-efficiency improvements than were assumed in the earlier model versions.

Base Case: 1980-2020 ENTRANS Projections

Fuel Use

Figure 7 shows that between 1980 and 2010, automo-

Figure 7. ENTRANS base case.



bile fuel use declines from 70 billion to 57 billion gal/year. Despite the fact that VMT increases over this period, increases in fleetwide fuel efficiency more than compensate, and the result is a net decrease in fuel use.

Between 2010 and 2020, VMT continues its upward growth but is not offset by increases in fleetwide fuel efficiency. This produces an increase in total automobile fuel use over this period, from 57 billion to 66 billion gal/year.

Automobile VMT

Over the entire period, 1980-2020, VMT increases, primarily because of population and income growth. Between 1980 and 1990, VMT increases relatively quickly but, beyond 1990, this rate declines because of high prices and, later, gasoline shortages. Despite rising gasoline costs between 1980 and 1990, automobile operating costs do not rise significantly because of increases in new-car and fleetwide fuel efficiencies brought about by federal fuel-economy programs. After 1990, fuel economy ceases its growth and operating cost begins to grow along with gasoline price, and thus the growth in VMT is less than what might be expected from population and income influences.

Automobile Fuel Economy

Between 1980 and 1985, increases in the price of gasoline force new-car fuel efficiency to increase at a rate greater than federally legislated fuel-economy improvement programs [Energy Policy and Conservation Act of 1975 (EPCA)]. This is shown as an increase in new-car fuel economy from 19.4 miles/gal in 1980 to 22.4 miles/gal in 1985 [these are on-the-road fuel efficiencies and are therefore below Environmental Protection Agency (EPA) ratings]. However, these improve automobile fleet efficiency only as inefficient models are replaced by the new, more fuel-efficient ones. Thus, fleet efficiency increases slowly during the simulation, lagging behind the improvements in the new-car fleet by about 10 years.

Automobile Prices

From 1980 until the end of the simulation in 2020, the average automobile retail price increases. This is a result of three factors:

1. As fuel efficiency is improved to meet federal regulations, cars become more expensive to manufacture and retail prices increase.
2. At the same time, the automobile industry offers incentives to purchase smaller, cheaper, more fuel-efficient cars and disincentives for the purchase of large ones.
3. Market shares shift toward the less expensive cars, and the average retail price does not increase as much as the technical costs would indicate.

The generalized new-car price (Figure 7) increases continually from 1980 to 2020. From 1980 to 1985, increases in generalized new-car price are caused primarily by increases in purchase price, but beyond 1985 they are caused by continuing increases in the lifetime gasoline cost.

General Model Price Elasticities

The elasticity of fuel use in relation to changes in gasoline price is not a direct input to ENTRANS but an output that results from the interaction of several model components. There are three primary determinants of gasoline price/fuel use elasticity: household travel patterns, production decisions by the automobile industry regarding new-car fuel efficiency, and consumers' automobile-type choices. Changes in automobile fleet composition are necessary before fleet efficiency equals a given year's new-car fuel efficiencies. The ENTRANS gasoline price elasticities are reduced in absolute value by traffic congestion effects. Increased prices cause automobile travel reductions that, in congested areas, increase highway operating speeds. This increase in speed is an incentive to travel that in part offsets the effect of the price increase.

To determine the price elasticity of fuel use in ENTRANS, it is necessary to construct a base run with fixed gasoline price beyond a certain year (chosen here as 1979) and compare outputs from a run with a small (1 percent) increment added to the fixed gasoline price in a particular year. In the runs described here, automobile fuel-efficiency regulations were removed so that a pure price response could be observed. The elasticities vary through time, ultimately reaching the long-term value, and they are also different at different base gasoline prices.

The elasticities computed at two base gasoline prices are shown in Figures 8 and 9. These figures indicate the model's general behavior. At a gasoline price of $1/gal (Figure 8), automobile fuel efficiencies have not yet improved to near their maximum potential. Thus, incremental price increases can easily be offset by improved automobile efficiency. In fact, the long-term elasticity value of -0.5 is composed of a -0.1 elasticity for VMT and a -0.4 elasticity for automobile fuel-efficiency improvements. New-car fuel efficiencies are not reflected in the fleet efficiency until approximately 10 years after the gasoline price change, when older cars have "vintaged out" of the stock.

At a gasoline price of $2/gal (Figure 9), the long-run elasticity is lower in absolute value than at $1/gal: -0.3 versus -0.5. In fact, the relative contributions of travel reductions and efficiency

Figure 8. Elasticities of gasoline price and fuel consumption at $1/gal.

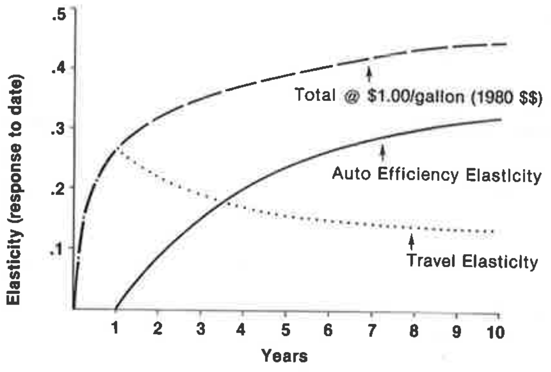
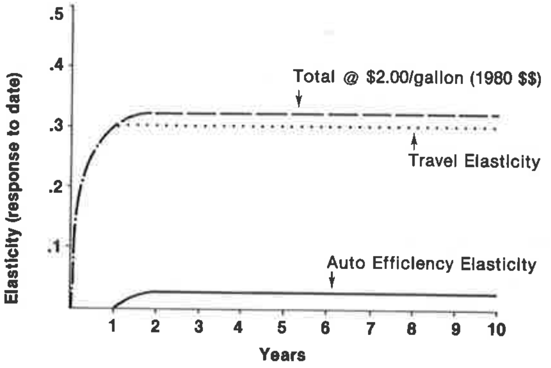


Figure 9. Elasticities of gasoline price and fuel consumption at $2/gal.



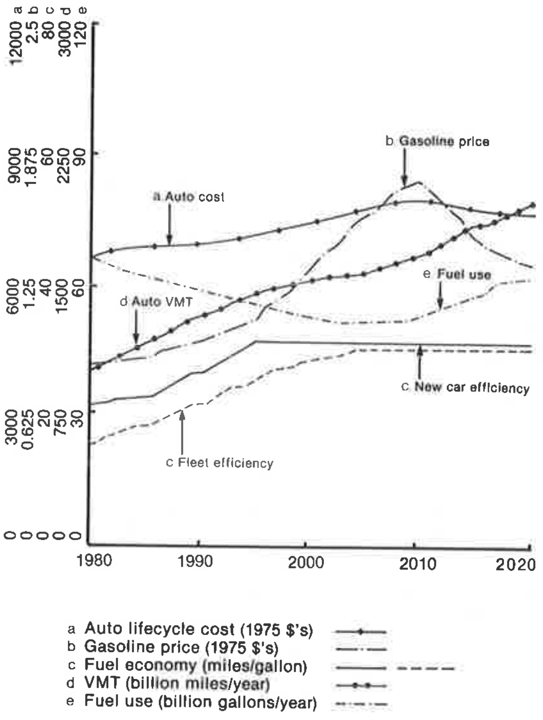
improvements also change substantially. At $2/gal, automobile fuel efficiencies have already increased substantially and further improvements are progressively more difficult and, thus, more expensive. The result is that the fuel-efficiency elasticity is less than -0.05. By contrast, as gasoline prices increase, more households become constrained by travel costs, and thus the elasticity of travel with respect to price increases. At $2/gal, the elasticity of total travel is -0.25 as compared with -0.1 at $1/gal. Because the travel elasticity dominates at high gasoline price and because travel patterns can be shifted with little delay, the long-run equilibrium response is essentially achieved within two years. The behavior illustrated in these elasticity plots clearly indicates the inadequacy of conventional fixed-elasticity assumptions; fuel-use elasticities vary not only over time but also across different prices.

POLICY ANALYSIS

Mandated 40-Mile/Gal Fuel Efficiency

Under a scenario that calls for 40-mile/gal mandated automobile fuel efficiency, government standards are extended beyond 1985. The standards increase from their 1985 value of 27.5 miles/gal (EPA-rated) to 40 miles/gal by 1995. Given the gasoline prices used in these ENTRANS runs, this target fuel efficiency would not be reached without regulation. After-tax penalty fines for noncompliance are doubled to $100 for each mile per gallon that a manufacturer's fleet is below the standard. This ensures that the standards are met by the manufacturers. The results are shown in Figure 10.

Figure 10. Results of policy involving mandated 40-mile/gal fuel efficiency by 1995.



Fuel Use

Under these extended mandates, total fuel use declines over the 1980-2005 period, from 65 billion gal/year in 1980 to 51 billion gal/year in 2005 (as compared with 57 billion gal in 2005 in the base case). Increases in VMT are more than offset by increases in fleetwide fuel economy over this period. Later, fuel use increases to about 62 billion gal/year in 2020, compared with the base-case value of 68 billion gal, a 9 percent decrease.

Automobile VMT

Total VMT increases faster between 1990 and 2020 than in the base case. Increasing fleetwide fuel economy produces a lower operating cost, which allows a higher growth rate in VMT. In addition, the gasoline price declines during the years 2010-2020 with the assumed introduction of synthetic fuels. This further reduces operating costs and increases total mobility.

Automobile Fuel Economy

The higher noncompliance fines provide manufacturers with sufficient incentive to meet the higher fuel-economy standards. Beyond the year 2000, average new-car fuel efficiency is 31 miles/gal compared with the base-case value of 27 miles/gal in the year 2000.

Automobile Prices

Improved efficiencies increase the automobile's manufacturing costs, and hence the retail price increases. This, however, is more than offset by gasoline savings, and the life-cycle costs are slightly lower than in the base case: $7600 versus $7700 in 2020. Thus, the extended fuel mandate policy reduces both fuel consumption and automobile

Figure 11. Results of policy involving mandated 50-mile/gal fuel efficiency by 1995.

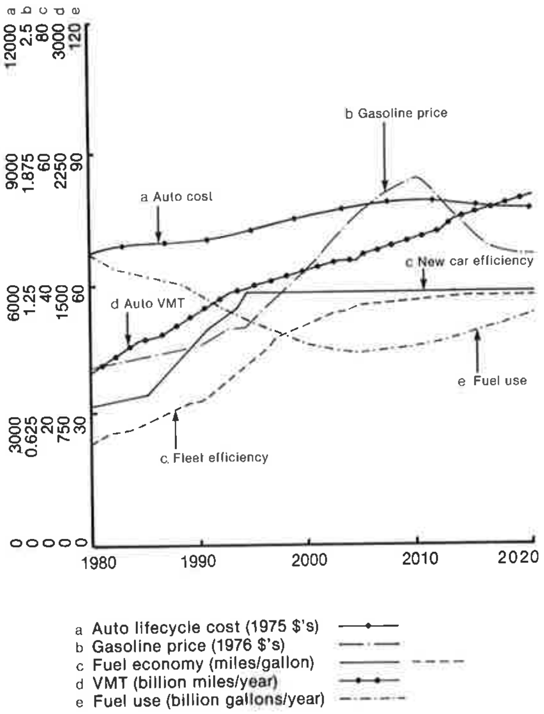
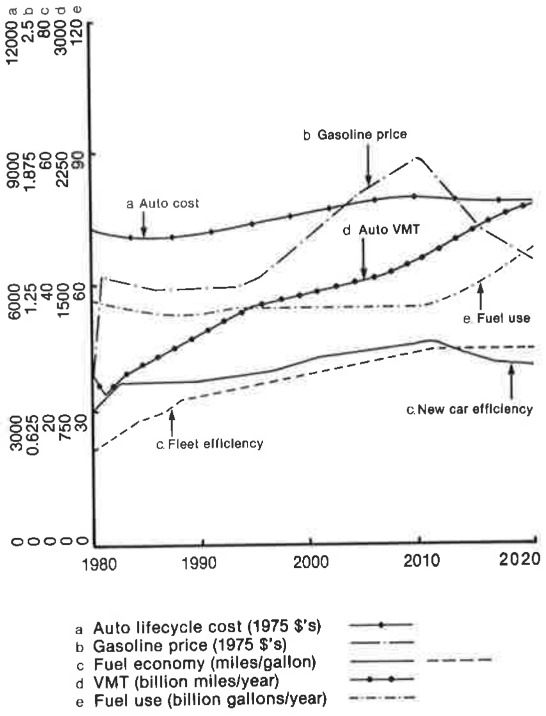


Figure 12. Results of policy involving $0.50 current-dollar gasoline tax.



ownership costs below those of the base case.

Mandated 50-Mile/Gal Fuel Efficiency

Figure 11 shows the results when government standards for fuel efficiency are increased to 50 miles/gal (EPA-rated) by 1995 from the 1985 target of 27.5 miles/gal.

Fuel Use

Under the 50-mile/gal mandates, total fuel use declines substantially to 44 billion gal/year by 2005 as compared with 51 billion gal in the 40-mile/gal mandate policy. This decrease comes despite continuing increases in automobile VMT. Automobile VMT continues to grow beyond the year 2005, but automobile fleet efficiencies catch up to new-car efficiencies by 2005. This causes fuel use to begin increasing to 50 billion gal/year by 2020.

Automobile VMT

Because of the lower operating costs of more fuel-efficient vehicles, automobile travel is increased over the base case by about 5 percent and over the 40-mile/gal mandate policy by about 3 percent.

Automobile Fuel Economy

New-car EPA-rated efficiencies increase, along the mandated schedule, to 50 miles/gal by 1995, which corresponds to 30 miles/gal on the road. Gasoline prices are not sufficiently high to increase vehicle efficiencies beyond that value through the year 2000.

Automobile Prices

Technical improvements in automobiles necessary to increase efficiencies do increase purchase prices, but these increases are more than offset by reduced life-cycle gasoline costs. Thus, total life-cycle automobile ownership costs are even slightly lower (2 percent) than under the 40-mile/gal mandate policy.

Current-Dollar Gasoline Tax

Figure 12 shows the effect of a $0.50 gasoline tax (in 1975 dollars) implemented in 1980. After its initial introduction, this tax is continually eroded by inflation (averaging only about 5 percent/year), which results in diminished effectiveness in later years.

Fuel Use

Fuel use declines sharply from 65 billion to 54 billion gal/year following the gasoline tax addition in 1980. This is due partly to the increasing fleetwide fuel efficiencies that result from the EPCA fuel-economy standards and partly from a decrease in VMT. Fuel use resumes growth beyond the year 2010, as in the base case.

Automobile VMT

Automobile VMT decreases when the gasoline tax is implemented in 1980, due to the resulting sudden increase in automobile operating cost. This lasts only for two years; afterwards, VMT resumes its growth, sustained by increases in fleetwide efficiency (producing lower operating costs) and growth in population and income.

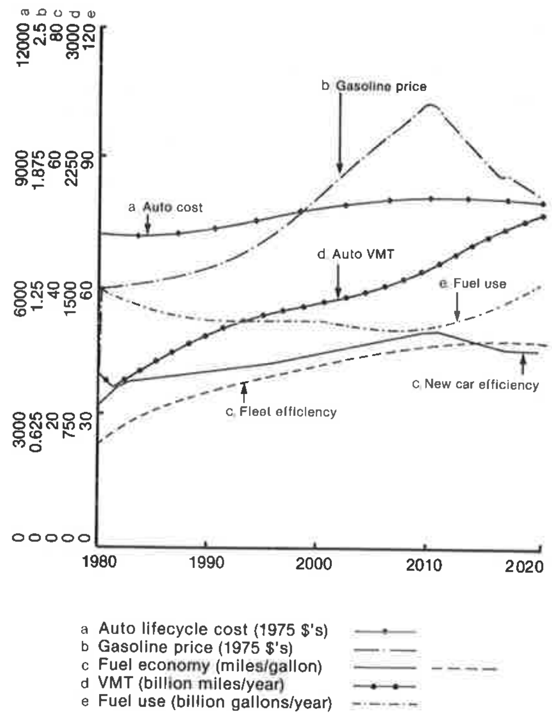
Automobile Fuel Economy

Fuel efficiency exhibits the same behavior as in the base case and for the same reasons.

Automobile Prices

New-car purchase prices do not change from the base case and generalized new-car price is slightly higher (e.g., $6700 versus $7000 in the 1985 base

Figure 13. Results of policy involving $0.50 real-dollar gasoline tax.



case) due to the increase in lifetime gasoline costs caused by the tax. Thus, this policy costs consumers more than the base case.

Real-Dollar Gasoline Tax

A $0.50 real-dollar gasoline tax has the effect of a sustained increase on gasoline price that keeps pace with inflation (see Figure 13). It is similar in principal to the proportional taxes common in Europe, although it is tagged only to general inflation rates, not specifically to energy price inflation.

Fuel Use

The real-dollar tax causes not only an immediate reduction in fuel use to 54 billion gal/year, as with the current-dollar tax, but also sustained reductions as long as the tax remains in effect. This longer-term effect is pronounced by the year 2020, when the current-dollar tax results in the use of 66 billion gal/year versus 60 billion gal under the real-dollar tax.

Automobile VMT

Since the real-dollar tax results in higher gasoline costs, automobile travel is depressed below the base-case level and slightly (1 percent) below levels under the current-dollar tax.

Automobile Fuel Economy

The higher gasoline costs cause on-the-road fuel-efficiency improvements to 31 miles/gal by 2020 versus 29 miles/gal under the current-dollar tax.

Automobile Price

Higher gasoline costs cause increased automobile life-cycle costs of about 2-3 percent over those under the current-dollar tax.

Figure 14. Policy comparisons: fuel use.

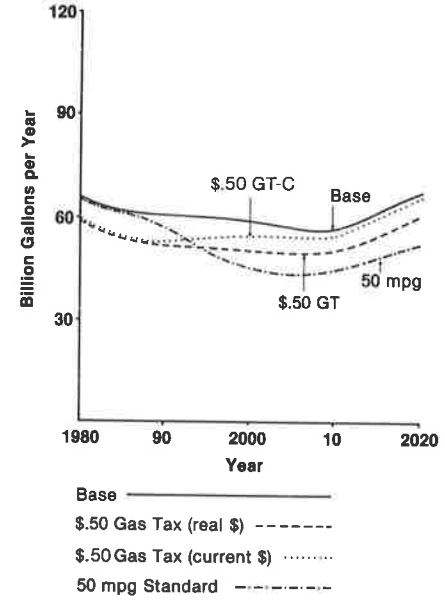
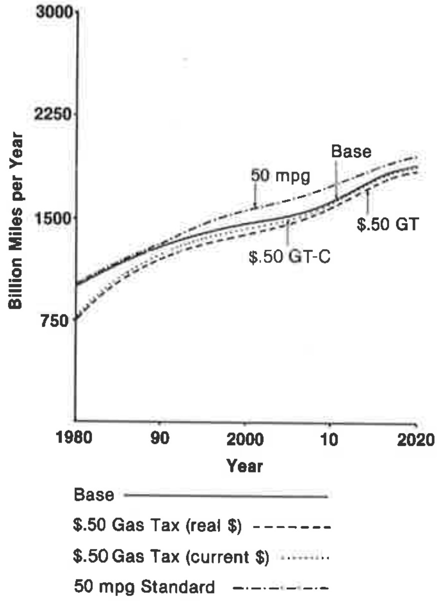


Figure 15. Policy comparisons: automobile VMT.



POLICY COMPARISONS

Four of the ENTRANS policy runs described in the previous sections are summarized in Figures 14-17. In Figure 14, fuel use is compared for each policy. High fuel-economy standards have the greatest impact on long-term patterns of fuel use. A one-time current-value gasoline tax has a large immediate impact on fuel use, but this effect erodes over time in comparison with the effect of a real-dollar tax.

Fuel use is determined by both the amount of automobile travel and automobile fuel efficiencies. The policies are substantially different in their effects on these two factors. Figure 15 shows that the taxation policies achieve fuel savings partly by reducing automobile travel. By contrast, the extended mandates stimulate increased travel because

Figure 16. Policy comparisons: automobile fleet efficiency.

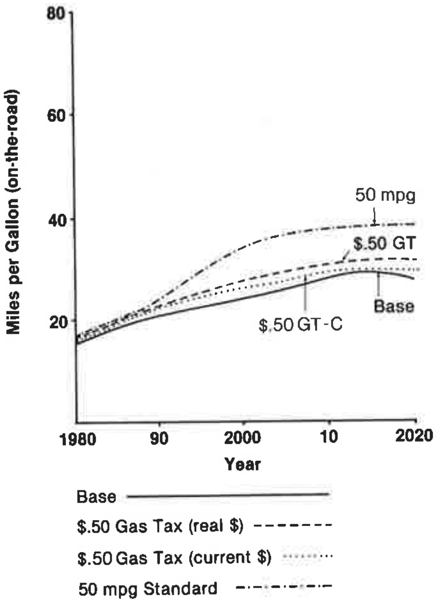
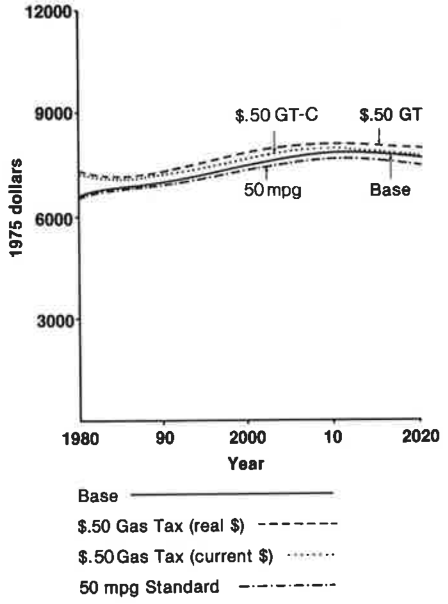


Figure 17. Policy comparisons: automobile life-cycle cost.



of lowered vehicle operating costs. In all cases, changes in automobile travel are diluted somewhat by the congestion effects described earlier. As shown in Figure 16, the mandate policy has a significant effect on automobile fleet fuel efficiency, whereas the taxation policies have noticeable though somewhat smaller effects.

In Figure 17, automobile ownership costs are compared for the alternative policies. Shifts to smaller, more fuel-efficient, less expensive cars cause net reductions in consumers' life-cycle automobile costs under the more stringent mandate programs. Taxation policies cause increased life-cycle costs because of the higher cost of gasoline.

The policies described here represent only a small subset of the ones that have been evaluated by using ENTRANS. Describing the forecast results of the policies does, however, illustrate the structure of the model system. Clearly, an informed evaluation of the relative desirability of alternative fuel-conservation policies must be based on information about the wide range of impacts that will result. Although each of the policies is evaluated here by using only four measures, the model traces and can display many other impact measures, including the incidence of impacts across income groups. A more complete description of these results can be found elsewhere (2).

CONCLUSIONS

The ENTRANS model is one of several existing models of transportation energy use, each of which has unique advantages and a different range of appropriate uses. The advantages of ENTRANS are its relatively complete structural representation of energy use in passenger transportation, its ease of use in analyzing a wide range of different policies, and its flexibility in incorporating alternative structural assumptions, input data, or empirical parameters. Current users of the model include groups within the U.S. Department of Energy and SERI, and the model is continually being updated and expanded. The model, as currently structured, is not useful for short-term prediction, nor does it include the full range of transportation energy uses (e.g., freight movement). It is hoped that efforts elsewhere will complement this research and provide policymakers with a full spectrum of models for analyzing the important issues concerning U.S. gasoline use.

ACKNOWLEDGMENT

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State-Level Stock System Model of Gasoline Demand

DAVID L. GREENE

A summary overview of the specification and econometric estimation of a state-level model of highway gasoline demand is presented. The model, which was developed by Oak Ridge National Laboratory for the Energy Information Administration, was designed for policy- and technology-sensitive forecasting of gasoline use by light-duty highway vehicles over the 1980-2000 period.

This paper provides an overview of a model developed for use by the U.S. Department of Energy (DOE) in conducting policy- and technology-sensitive forecasting over a 5- to 15-year horizon of regional demand for motor fuel for light-duty vehicles. A policy- and technology-sensitive long-range gasoline demand model must integrate three major elements: (a) the demand for travel, (b) the demand for vehicles used to accomplish that travel, and (c) the technology by which those vehicles transform motor fuel into travel. Models by Difiglio and Kulash (1) and Sweeney (2) were the first to incorporate these elements into unified models for long-range forecasting of gasoline demand in the United States. Unlike these models, the model developed here takes as its theoretical basis the household production theory of consumer demand. In this framework, households are viewed as purchasing goods in the marketplace, which they transform, in conjunction with available technology, into commodities whose consumption directly yields utility [as shown, for example, by Pollak and Wachter (3)]. Thus, gasoline, or even travel, is not necessarily desired for its own sake but is rather an input to the production of something else that is.

In household production theory, demand functions exist for goods (e.g., gasoline) and have equal standing with demand functions for produced commodities (e.g., travel). As a result, it is perfectly valid to estimate direct demand equations for gasoline. Furthermore, in the short run, the demand function for gasoline will be conditional on the technology available for producing travel. These concepts form the basis for the model structure shown in Figure 1.

Given exogenous variables that include new-vehicle prices and characteristics, the demand for new vehicles by vehicle class and state is determined. Next, given existing state fleet compositions, new-car prices, and other variables, state used-vehicle holdings are determined by class and vintage. New purchases and used holdings combine to make up the fleet composition. Based on fleet composition, historical and exogenously specified data on vehicle fuel efficiencies, and state characteristics, fleet fuel efficiency is determined. Finally, fleet composition, fuel efficiencies, and other variables such as gasoline price determine the state gasoline demand.

It is not possible in this brief overview to provide full details of the specification or estimation of the model, nor is it possible to characterize the sources and construction of the data base used in its estimation and calibration. The interested reader is referred to the five-volume model documentation prepared for DOE (4), in which these issues are fully addressed.

This paper is divided into two parts: The first describes the theoretical specification of the model, and the second discusses the results of its econometric estimation.

MODEL SPECIFICATION

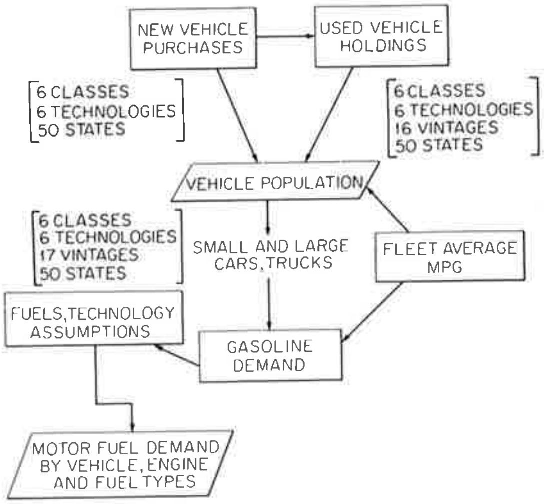
Demand for New Vehicles

The preferred approach to modeling automobile demand has, until recently, been the stock-adjustment model introduced by Chow (5) and Nerlove (6). This model specifies current sales as a function of current prices and income and lagged stock (other variables may be included):

$$q_{jt} = q_j (P_t, y_t, q_{jt-1}) \tag{1}$$

New vehicles are viewed as additions to current stock; i.e., new and used cars are assumed to be aggregatable commodities. Recent work has challenged that view. Wykoff (7) proposed the hypothesis that the services of new cars are considered by consumers to be qualitatively superior to those of used cars. In this perspective, new-car purchases are not merely additions to the existing stock but rather reflect the demand for a unique commodity, new-car services, measured independently of the existing stock of used cars. Both Wykoff and Johnson (8) found the superior-goods hypothesis performed well empirically, and Wykoff found it to be superior to the stock-adjustment approach. The superior-goods hypothesis was adopted in the model, and new and

Figure 1. Structure of state-level gasoline demand model.



used cars are treated as closely substitutable, but distinct, goods.

Another commodity aggregation issue arises with respect to vehicles of different types. The requirements of policy analysis dictate that the model be sensitive to policies aimed at changing both the technical efficiency and the vehicle mix of the fleet. The latter consideration suggests that a typology of vehicles be developed based on vehicle attributes relevant to fuel economy and consumer demand. Previous models have typically used classifications that were based on a measure of vehicle size (1) or on a combination of size and price (9) and whose boundaries were determined by judgment. A less subjective, multidimensional approach to classifying automobiles that used cluster analysis was successfully applied to 1975 model-year cars (10). The essence of this approach is to classify cars into groups that are as much alike as possible based on relevant vehicle characteristics. This approach was applied to automobiles from 1955 to 1977 in order to establish a classification that was consistent over time. Pickup trucks and vans were treated as a separate group.

Most previous models have predicted class shares by using logit-type probabilistic choice models that predict the expected fraction of new-vehicle sales for each class. To obtain sales by class, one obviously needs to have an estimate of total new-car demand. But, if the vehicle types in fact represent distinct goods, the overall demand equation will suffer to some extent from aggregation bias. A preferred approach is to estimate demand equations by vehicle class, treating the classes as close substitutes. This leads to a set of related regressions:

$$A^k = A^k (C_1, \ldots C_k, \ldots C_n, P, W, I, e_k, h, d, b) \qquad (2)$$

where

A^k = demand for new cars of class K,
C_1-C_n = new-car costs of K and all other classes that are assumed exogenous and those of used cars,
P = vector of other goods prices used in the production of travel,
e_k = fuel efficiency of class K vehicles,

and other variables are demographic and environmental. Since vehicles within a class will have (approximately) the same prices, A^k may be expressed simply as number of cars rather than in terms of some numeraire.

Consistent with previous studies, we assume the supply of new cars to be perfectly elastic at a price established by the producers.

Demand for Used Vehicles

In the model used, vehicle supply is represented by means of scrappage functions and used-vehicle demand is represented by equations that determine used-vehicle prices. Vehicle scrappage is determined by a combination of physical deterioration, accident, and market conditions based on Parks' interpretation of scrappage as a stochastic process (11). Following Parks, we make scrappage a logistic function of prices of used cars (p), repairs (r), and age (v):

$$\lambda(P/r,v) = 1/A + \exp\{-[b_1 + b_2 (P/r) + b_3 v]\} \qquad (3)$$

If we evaluate $\partial\lambda/\partial p$ as

$$\partial\lambda/\partial p = (A + \exp\{-[b_1 + b_2(P/r) + b_3 v]\})^{-2} \cdot (b_2/r)\exp[-b_2(P/r)] \qquad (4)$$

it is clear that $b_2 < 0 \rightarrow (\partial\lambda/\partial p) < 0$. That is, if $b_2 < 0$, then scrappage rates go down as prices go up. In this circumstance, λ looks very much like a vintage supply equation. Holding variables other than price constant, we may write

$$(U_t' - U_{t+1})/U_t' = \lambda'(p) \qquad (5)$$

where λ' is now a function of p only and $U_t' = U_t + A_t$ (last year's used stock plus new-car sales). Rearranging gives

$$U_{t+1} = U_t' [1 - \lambda'(p)] \qquad (6)$$

The assertion that the logistic scrappage equation derived by Parks represents the consumer as a supplier of used vehicles can be justified by an examination of the behavioral content of the equation. The consumer bases the decision as to whether to retain (supply) or scrap (not supply) a vehicle solely on the price of the vehicle relative to the cost of repairing (producing) it. If the price is greater than or equal to the cost (the "profit" is nonzero), the vehicle is retained (supplied to the market). If not, it is scrapped (supply is zero). The analogy to the standard producer's problem in microeconomic theory is straightforward. Only the formulation of costs as stochastic is substantially different.

The demand side of the used-car problem is specified in terms of demand relative to last period's stock. Assume that the survival rate of used-car stock (U_{t+1}/U_t) is a function of price (p) and other factors (z). Consumer theory suggests that these other factors would be income and the prices of substitutes (new cars) and complements (such as gasoline). The functional form

$$U_{t+1}/U_t' = 1/\{1 + \exp[-(a_0 + a_1 p + a_2 z)]\} \qquad (7)$$

has the desirable property of being bounded by 0 and 1. Rearranging gives

$$p = -(1/a_1)\{\ln[(U_t'/U_{t+1}) - 1] + a_0 + a_2 z\} \qquad (8)$$

which is the demand equation in terms of price. In contrast to the scrappage equation, this equation includes income and prices of other goods. An advantage of this formulation is that it permits a detailed accounting of the actual number of vehicles by class and vintage within the context of a supply and demand model. By virtue of this, we can also keep track of changes in vehicle efficiencies or even vehicle technologies as they are introduced and penetrate the vehicle fleet.

Conditional Demand for Gasoline

The vehicle demand equations derived above are long-run, static equilibrium equations. They describe the behavior of the consumer when all inputs to the household production process are variable and are thus a function only of goods prices and income. In the short run, the individual consumer may be able to turn over his or her vehicle stock rather quickly. However, the aggregate stock, by virtue of the value embodied in it, remains virtually constant. Thus, both the number of vehicles and their characteristics are essentially fixed, which makes the demand for gasoline conditional on them and independent of vehicle prices. This gives the model a sequential structure in which gasoline demand is conditional on the outputs of the motor-vehicle demand models.

The gasoline demand functions for states as fully specified include gasoline price (p^g), a vector of prices of other inputs (p^o), wage and nonwage income (w, I), a vector of vehicle ownership by efficiency-size classes (Q^v), a vector of vehicle characteristics (X), household size (h), working- and driving-age population (d), and other state characteristics (z):

$$q_{st} = q_s\left(P_{st}{}^g, P_{st}{}^o, w_{st}, I_{st}, Q^v{}_{st}, X_{st}, h_{st}, d_{st}, z_{st}\right) \qquad (9)$$

where the subscripts s and t index state and time period, respectively.

Throughout, we have spoken as if the only highway motor fuel for light-duty vehicles were gasoline; in the future, however, there may be significant fuel substitution. The distribution between gasoline and other fuels is "shared out" according to the distribution of engine technologies in the vehicle fleet.

ESTIMATION OF ECONOMETRIC RELATIONS

This section of the paper first describes the five automobile classes used in modeling new-car demand and then considers the estimation of the six new vehicle demand equations, the results of the estimation of the used-car supply and demand equation, and, finally, the estimation of the gasoline demand model itself. Issues of functional form and regional parameter estimates as well as price and fuel-efficiency elasticities are addressed. Data for all 50 states and the District of Columbia for the 1967-1977 period were used in estimating the model (4).

Vehicle Classification

The five-group vehicle classification used in estimating class demand equations is described in Table 1. Based on their mean or centroidal values on each of eight variables, the groups can be described as follows:

Class	Vehicle Type
M1	High-performance, luxury sports cars
M2	Large luxury cars
M3	Small economy cars
M4	Medium-sized economy cars
M5	Large economy cars

New-Vehicle Demand

The model for new-vehicle demand consists of five automobile classes plus all light trucks with a gross vehicle weight of less than 10 000 lb. Each variable actually included in the estimated equations is described below. Detailed descriptions of primary data and sources are given elsewhere (4).

Table 1. Centroid values for five-group classification.

Variable Group	Group M1	M2	M3	M4	M5
Membership	50	135	251	304	234
Market shares (%)	5.1	13.9	25.8	31.2	24.0
Wheelbase (in)	96.4	123.0	95.6	112.8	120.7
Roominess factor (ft^3)	63.3	124.1	89.7	111.3	147.0
Curb weight (lb)	2780	4740	2308	3517	4410
Manufacturer's list price ($)	8063	7682	3606	4412	5214
Number of passengers	2.56	5.85	4.27	5.52	6.65
Displacement (in^3)	202	438	119	301	365
Price to number of passengers ($)	3115	1323	884	815	789
Horsepower to weight	0.0462	0.0499	0.0336	0.0407	0.0383

After considerable experimentation, annual payments cost was selected as the vehicle price variable. This variable was computed from the manufacturer's list price and the interest rate for loans on new or used automobiles, as appropriate, by using the following formula:

$$C_{it} = MLP_{it} / \sum_{k=1}^{3} (1 + r)^{-k} \qquad (10)$$

where

C_{it} = annual payment for a class i car purchased new in year t,
MLP = manufacturer's list price, and
r = finance rate for new-automobile loans.

Initially, individual prices of new and used vehicle substitutes were tested in the equations. Not surprisingly, multicollinearity problems were horrendous. Therefore, price indices for other new cars and for used cars were constructed by weighting class prices proportionally to their budget shares. The base year used for budget shares was 1967. The formula for the other-new-car price index (CIND) in the class i equation is as follows:

$$CIND_{it} = \sum_{j \neq i} C_{jt} \cdot C_{j67} \cdot A_{j67} / \sum_{j \neq i} C_{j67} \cdot A_{j67} \qquad (11)$$

where A_{j67} is the sales of class j cars in 1967.

Gasoline price was entered as gasoline cost per mile, except in the light-truck equation. Income is simply measured as personal disposable income per household. Unemployment is the unemployment rate (in percent). All monetary variables were deflated to temporally and spatially constant dollars by using the regional cost-of-living index described elsewhere (4). Two demographic variables were included: household size (average number of persons per household) and the number of persons per household between the ages of 18 and 44 inclusive, the prime age group for drivers. Two rather crude measures of state spatial structure were included: (a) gross population density in persons per square mile and (b) urbanization measured as the percentage of population living in standard metropolitan statistical areas (SMSAs).

In theory, three vehicle price variables should appear on the right-hand side of each vehicle demand equation: (a) own price, (b) the price index of other new cars, and (c) the price index of used cars. The problem is that all three variables are strongly correlated as confirmed by simple as well as multiple correlation coefficients.

Solutions to the multicollinearity problem are few and generally "painful" (12). Of the possible solutions, we have resorted to (a) dropping the used-car price variable and (b) using extraneous information about the values of parameters. Extraneous information is used in an innovative way that allows an explicit trade-off of changes in the least-squares parameter estimate toward an a priori more desirable estimate for increases in the mean squared error (MSE) of the model. This was done by mapping the MSE of each regression equation as a function of arbitrarily fixed values of the own-price elasticities.

The equations were estimated in double log form. The coefficient of the log of own price was constrained by transforming the log dependent variable (y) by adding b_1x_1 where $-b_1$ is our first estimate of the price elasticity; $y + b_1x_1$ may then be regressed against the remaining variables in the model (all but x_1). It is relatively easy to show that in an ordinary-least-squares (OLS) regression the value of b_1 that minimizes the error sum of squares for the transformed dependent variable regression is exactly the OLS estimate that would be obtained by performing the OLS regression of y on the full set of explanatory variables. By repeatedly selecting values of b_1, one can describe the relation between b_1 and the error sum of squares.

The equations were estimated in logarithms by using the variance-components procedure of the SAS79 program (TSCSREG) (13). National-level slope coefficients were estimated with state intercept terms computed from the equations' residuals.

Five-year dummy variables were included in the class 3 equation. Foreign cars--in fact, small cars in general--were an innovation during the 1960s in the United States. It was not until 1970 that Ford (Pinto) and General Motors (Vega) began to produce class 3 vehicles. The five dummy variables account for the shift in the demand curve as class 3 vehicles penetrated the U.S. market. By 1972, this penetration appears to have been complete. Time dummies for 1972 and afterward proved to be nonsignificant. A 1977-year dummy variable was also included in the class 4 and class 5 equations. The reason for this is that a significant redesign of large vehicles, called "downsizing", first occurred in 1977.

In general, the results were encouraging. In five out of six cases, the optimal own-price coefficient was negative, as expected. Only in the case of class 4 cars was this not the case. (Although it is not possible to offer a definitive explanation for this, it may well be that the omission of used-car prices had a greater effect on this equation.) This approach includes three criteria for deciding on the "best" value for the own-price elasticity: (a) the cost in increased error sum of squares of deviations from the optimum, (b) the effect of changes in the own-price coefficient on the values of other parameter estimates, and (c) a priori knowledge about parameter values. Based on such considerations, the final equations presented in Table 2 were chosen. There is no doubt that this approach involves subjective judgment as well as a priori knowledge about parameters. However, the technique we have adopted is certainly no less intelligent than ignoring the statistical problems and simply letting the chips fall where they may.

Although standard errors are given in Table 2, they should not be taken literally since they do not take into account that the value of the own-price coefficient was fixed outside of the regression analysis. Strictly speaking, the error of these exogenous estimates (which is unknown) should be taken into account.

Used-Car Demand

Equation 4 was estimated by means of a nonlinear least-squares routine [the SAS79 NLIN procedure was used (13)]. Equations were estimated for all states. Separate scrappage equations were estimated for classes 2, 4, 5, and 6, which are predominantly domestically manufactured vehicles. For classes 1 and 3, the equations for 2 and 4 were substituted, respectively. Individual equations could not be estimated for classes 1 and 3, since these consist primarily of imported cars and only the first seven vintage-year observations were available in the data base for imported cars in operation. Vehicles do not even begin to be scrapped in significant numbers until they are at least five or six years of age. In all, more than 200 separate equations were estimated with satisfactory results.

Prices of one-year-old used cars were estimated as a simple linear function of new-car prices. This simplification of the theoretical used-car demand model was used because of time and resource constraints. Preliminary experimental attempts to estimate the fully specified equation, however, indicated that new-car price was the only statistically significant variable. The used-car price equations were estimated at the national level by means of ordinary least squares [the SAS79 GLM procedure was used (13)]. Prices are purchase prices in 1967 constant dollars. The results are given in Table 3.

Gasoline Demand Equation

The variables used in estimating the gasoline demand equation are as follows:

1. Gasoline price--State prices were derived from data for 55 cities.
2. Income--Wage rate and nonwage income as well as disposable household income were used in alternative estimations. Disposable income was preferred because of its greater usefulness for applications of the model in forecasting. However, the choice of income measure had a minimal effect on the coefficient estimates of other variables. All money variables were converted to constant spatial dollars by means of a state cost-of-living index (4).
3. Persons per household under 18 years of age--Persons per household under 18 years of age accounts for state-to-state differences in the aggregate household composition by individuals not of driving age.
4. Workers per household--Workers per household largely measures a time trend of increasing labor-force participation rates for household members.
5. Urbanization--The urbanization variable is percentage of state population residing in SMSAs.
6. Population density--Population density is measured in persons per square mile.
7. Small cars--Number of small cars, roughly subcompact or smaller (i.e., classes 1 and 3), per household was used.
8. Large cars--Number of large cars per household, roughly compact or larger (i.e., classes 4, 5, and 2), was used.
9. Light trucks--Number of trucks of less than 10 000 lb weight per household was used.
10. Fuel efficiency--The fuel-efficiency measure used is estimated realized fuel economy of the state light-duty-vehicle fleet in miles per gallon.

The dependent variable used in this analysis is the Federal Highway Administration (FHWA) annual series of state highway gasoline use (taken from FHWA Table MF-26). This total includes private and commercial use and use by all types of vehicles. In

Table 2. Variance-components estimates of new-car class demand equations that use transformed dependent variable technique.

Vehicle Class	Intercept		Own Price		Cross Price		Gasoline		Income		Household Size		Age 18-44	
	C	SE	C	SE	C	SE	C	SE	C	SE	C	SE	C	SE
1	-6.370	3.609	-0.7	-	0.289	0.456	0.326	0.196	1.428	0.195	-1.425	0.457	-	-
2	4.035	2.413	-2.5	-	1.406	0.267	-0.094	0.167	0.808	0.136	-	-	-1.903	0.198
3	4.929	2.073	-0.7	-	0.330	0.189	0.209	0.149	0.334	0.153	-0.912	0.435	1.951	0.243
	-1.308[a]	0.078[a]	-1.091[b]	0.076[b]	-0.864[c]	0.073[c]	-0.453[d]	0.065[d]	-0.192[e]	0.620[e]				
4	2.314	2.082	-0.4	-	0.417	0.209	-0.090	0.142	0.060	0.111	0.902	0.264	-	-
	0.306[f]	0.193[f]												
5	-0.658	2.535	-2.5	-	2.226	0.258	-0.162	0.163	0.427	0.142	2.244	0.381	-1.887	0.235
	-0.504[f]	0.156[f]												
6	1.318	2.273	-1.2	-	1.138	0.251	-0.006	0.192	0.332	0.137	-1.300	0.354	0.609	0.224

Note: C = coefficient and SE = standard error.

[a] Year 1967.

[b] Year 1968.

[c] Year 1969.

[d] Year 1970.

[e] Year 1971.

[f] Year 1977.

Table 3. Equations for one-year-old used-car price.

Class	Intercept		New-Car List Price		
	C	SE	C	SE	R^2
1	225.941	270.622	0.650	0.039	0.93
2	506.117	217.476	0.673	0.032	0.96
3	259.668	50.083	0.670	0.018	0.98
4	-43.050	93.082	0.757	0.025	0.98
5	-198.972	14.0185	0.737	0.032	0.96
6	-1115.798	152.819	1.100	0.046	0.96

Notes: C = coefficient and SE = standard error.
Number of observations = 22.

our model we deal explicitly only with passenger cars and light trucks. These together account for well over 90 percent of all use. Heavy trucks, however, use nontrivial amounts of gasoline--on the order of 6.5 percent of total highway use (14, Tables 6.1, 7.2B, 8.1A, and 6.1). This must be borne in mind when one interprets model forecasts.

Since the fuel-efficiency data are the key to the model, they merit some description. The methods used in producing these data are the same procedures embodied in the fuel-efficiency submodel (Figure 1). To obtain the estimates used in this analysis, detailed statistics on state vehicle fleet compositions by vehicle make, model, and vintage were combined with city and highway fuel-economy estimates of the Environmental Protection Agency (EPA) to obtain sales-weighted fleet efficiency measures for each state. By using engineering procedures developed by Rose (15), these values were adjusted for the following factors to obtain estimates of realized fuel efficiency for each state: (a) the average U.S. discrepancy between EPA test and on-the-road fuel economy, (b) state monthly temperature distributions, (c) state trip-length distributions, (d) vehicle travel distribution for state urban versus rural roads, and (e) relations between vehicle use, vehicle age, and vehicle age distributions.

Due to the pooled time-series, cross-sectional nature of the data, a variance-components form of the generalized least-squares model was used in estimating the demand equation (12,13).

FUNCTIONAL FORM

Rather than assume a particular functional form, the Box-Cox transformation procedure was used to determine the "optimal" functional form [as discussed, for example, by Zarembka (16)]. In this procedure, both the dependent and independent variables are altered by the transformation

$$X' = (XK_{-1})/K \quad K \neq 0$$

$$X' = \log(X) \quad K = 0 \qquad (12)$$

Although the maximum likelihood value of K was at 0.15, the approximate confidence interval for K easily included 0.0 (i.e., the double logarithmic transformation). The double log form of the model was therefore accepted.

REGIONAL ELASTICITIES

The error-components model can be construed as implying that intercept terms (the scalar constants in the double log form) vary across states. Perhaps of greater interest is the possibility that slope parameters differ significantly across states and regions. Particular attention has been given to the possibility that gasoline price elasticities vary by state and region (17-20). In general, the conclusions have varied according to the regionalization used and the method of estimation. Greene (21) has suggested that regional gasoline price data may not be of sufficient quality to permit the estimation of regional price elasticities. Income elasticities are also of interest, since substantial income growth in the future is likely to shift regional patterns of consumption. This issue has apparently not been addressed elsewhere.

To test the existence of differing price and income elasticities for the 10 federal regions, all other slope coefficients were assumed constant across states and nine new variables representing the product of the logarithm of price (or income) and a set of regional dummies (d_i) were introduced. The exponent (or elasticity) of price (income) is thus

$$\beta_p = \beta_{10p} + \sum_{i=1}^{9} d_i \beta_{ip} \qquad (13)$$

so that each region will have a different elasticity. The results, based on (asymptotic) F-statistics, indicated that both price (F = 2.45) and income (F = 7.66) elasticities vary significantly across regions. An examination of income elasticities reveals that the range of income elasticities is a mere 0.34-0.40 (see Table 4). For this reason, regional income elasticities were not incorporated in the model equations.

Regional short-run price-elasticity estimates, on

Percentage Population in SMSA		Population Density		Unemployment		Residual Variance (df)	
C	SE	C	SE	C	SE	C	SE
0.237	0.071	0.050	0.030	–0.105	0.045	0.136	542
0.088	0.046	–	–	–0.088	0.033	0.073	543
0.138	0.053	–	–	–0.193	0.034		
–	–	0.055	0.013	–0.157	0.026	0.052	542
–	–	–	–	–0.236	0.034	0.060	542
–0.132	0.047	–0.264	0.018	–0.245	0.032	0.051	541

the other hand, exhibit a larger quantitative variability. The estimates range from a high of +0.02 (which is statistically not different from zero) to a low of -0.20. Three of the 10 regions have elasticity estimates greater than -0.10 (see Table 5). The explanation for the geographic variation of these regional estimates is not obvious. However, at least five factors probably contribute to the pattern: (a) inadequate state-level price data (21); (b) spatial choice constraints limiting the ability to reduce travel in more sparsely settled states; (c) through traffic (in general, smaller states astride major Interstate routes would be most affected); (d) commercial gasoline use, which appears to have considerable geographic variability (22); and, finally, (e) the well-known fact that adding dummy variables to an equation contributes multicollinearity (the problem is not severe in this case, but it is undesirable).

In summary, there are good reasons why one should expect short-run price elasticities to vary geographically. However, there appear to be equally good reasons--most importantly, data shortcomings--why the particular estimates presented here should be treated with caution. As a result, we have not included regional price elasticities in the model.

Table 4. Variance-components estimation of gasoline demand equation with regional income coefficients.

Variable	Estimated Coefficient	t-Statistic	Standard Error
Intercept	6.40	8.13	0.79
Price	–0.13	–3.64	0.04
Income	0.36	12.08	0.03
1	0.01	0.89	0.01
2	–0.02	–1.92	0.01
3	0.02	1.89	0.01
4	0.03	4.11	0.01
5	0.01	0.62	0.01
6	0.03	3.75	0.01
7	0.01	1.07	0.01
8	0.01	1.70	0.01
9	0.01	1.43	0.01
Population under 18	–0.19	–3.79	0.02
Small cars	0.09	7.55	0.01
Large cars	0.05	1.62	0.03
Light trucks	0.03	2.92	0.01
Urbanization	–0.05	–3.08	0.02
Population density	–0.05	–3.31	0.01
Labor force	0.06	5.46	0.01
Fuel efficiency	–1.45	–6.68	0.22

Note: $\sigma_\mu^2 = 0.0083$, $\sigma_\nu^2 = 0.0001$, $\sigma_\gamma^2 = 0.0005$, and df = 530.

FUEL-EFFICIENCY RESPONSIVENESS

A major objective was to empirically estimate the degree to which improvements in the fuel efficiency of the vehicle fleet, as measured by the estimated state fleet realized fuel economy, would be translated into realized fuel savings. The elasticity of state gasoline demand with respect to the estimated realized efficiencies was therefore econometrically estimated. The results are given in Table 6. Once again, since the equation was estimated in double log form, the coefficients may be interpreted as constant elasticities.

A useful interpretation of the fuel-efficiency (MPG) elasticity is obtained by considering the relation between it and the elasticity of fuel cost per mile:

$$P^\alpha \, MPG^\beta = (P/MPG)^\alpha \, MPG^\gamma \tag{14}$$

where $\beta = \gamma - \alpha$. Thus, the estimated elasticity of MPG in Table 6 is, in effect, the fuel-efficiency elasticity minus the gasoline-price elasticity. The point estimate of γ is therefore

$$\gamma = -0.91 + (-0.10) = -1.01 \tag{15}$$

which is about what one would naively expect. In other words, all of the estimated on-the-road fuel-efficiency improvement will be translated into energy savings, but as the vehicle fleet becomes more efficient consumers will face a lower fuel price per mile and travel more. In the context of household production theory, this is interpreted as a change in the travel production function. The estimates suggest that a 10 percent increase in fleet fuel efficiency would result in roughly a 1 percent increase in travel and an overall fuel savings of 9 percent. Assuming that this is accurate, fleet fuel-efficiency improvements should be an extremely effective method of reducing the demand for gasoline. As a caveat, however, one should note that the asymptotic 95 percent confidence interval for the elasticity of fuel efficiency is quite large: $\epsilon_E \doteq -0.91 \pm 0.39$.

SUMMARY

The specification and econometric estimation of a state-level highway gasoline demand model has been described. The model comprises models for new- and used-vehicle demand, vehicle efficiency, and gasoline demand. New-car demand is estimated by state

Table 5. Variance-components estimation of gasoline demand equation with regional price coefficients.

Variable	Estimated Coefficient	t-Statistic	Standard Error
Intercept	5.19	6.73	0.77
Price	–0.13	2.82	0.04
1	–0.00	–0.11	0.04
2	0.12	2.20	0.05
3	–0.00	–0.06	0.04
4	–0.07	–1.79	0.04
6	–0.06	–1.31	0.04
7	–0.02	–0.50	0.04
8	0.04	1.08	0.04
9	–0.00	–0.10	0.05
10	0.14	–3.04	0.05
Income	0.38	12.28	0.03
Population under 18	–0.19	–3.62	0.05
Small cars	0.08	7.36	0.01
Large cars	0.08	2.70	0.03
Light trucks	0.04	3.44	0.01
Urbanization	–0.05	–3.00	0.02
Population density	–0.07	–5.36	0.01
Labor force	0.07	5.82	0.01
Fuel efficiency	–1.14	–5.41	0.21

Note: $\sigma_\mu^2 = 0.0081$, $\sigma_\nu^2 = 0.0001$, $\sigma_\gamma^2 = 0.0006$, and df = 530.

Table 6. Variance-components estimation of gasoline demand equation.

Variable	Estimated Coefficient	t-Statistic	Standard Error
Intercept	4.56	6.24	0.73
Price	−0.10	−2.90	0.04
Income	0.40	12.74	0.03
Small cars	0.07	6.62	0.01
Large cars	0.08	2.55	0.03
Light trucks	0.05	4.33	0.01
Population under 18	−0.18	−3.54	0.05
Urbanization	−0.04	−2.54	0.02
Population density	−0.06	−5.28	0.01
Labor force	0.06	5.07	0.01
Fuel efficiency	−0.91	−4.62	0.20

Note: $\hat{\sigma}_\mu^2 = 0.0096$, $\hat{\sigma}_\nu^2 = 0.0001$, $\hat{\sigma}_\gamma^2 = 0.0006$, and df = 539.

for six vehicle classes. Given last year's used-car fleet composition, current used-car stocks by state, class, and vintage are estimated. Based on state fleet composition as well as historical and exogenously supplied information on vehicle fuel efficiencies, the in-use fuel efficiency of each state's vehicle fleet is estimated. Gasoline demand is estimated conditional on state fleet composition and fuel efficiency. The model also provides the ability to introduce new vehicle technologies by class, keep track of their penetration into state vehicle fleets, and estimate their fuel use according to their proportions in state vehicle fleets. The model thereby provides a capability for policy- and technology-sensitive forecasting of gasoline demand at the state level. The modeling system has been implemented on computer systems at the Energy Information Administration of DOE and at Oak Ridge National Laboratory.

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Fuel Consumption on Congested Freeways

CHRISTO J. BESTER

The effect of interactions between vehicles on freeway fuel consumption is investigated. The relation between energy and fuel consumption during free-flow conditions is established by means of the basic equations of movement. This, together with the acceleration noise due to traffic interaction, is then used to calculate the additional fuel consumption when the smooth flow of vehicles is hampered by the presence of other vehicles. It is found that, for densities less than one-third of the jam density, fuel consumption due to traffic interaction is negligible. For high densities, however, constant-speed fuel consumption can be increased by as much as 50 percent.

As a result of oil shortages, the fuel consumption of vehicles has received increased attention over the past few years. Because of the high traffic volumes on freeways, the effect of traffic interaction on fuel consumption is important for the justification of new facilities or the implementation of different transportation system management strategies. To predict this effect, speed-change cycles have been used (1,2). It is difficult, however, to relate these cycles to traffic volume or density. Capelle (3) hypothesized that "acceleration noise" (the standard deviation of accelerations) on a section of road is equal to the total fuel consumed minus the minimum fuel consumption. In this paper, the effect of acceleration noise on fuel consumption at different speeds will be investigated as a way of predicting additional fuel consumption due to traffic interaction.

This paper first shows how the fuel consumption at constant speed on a constant gradient can be calculated from the basic energy equations. This is then used to predict fuel consumption during acceleration and deceleration. All of these predictions are substantiated by the results of actual field tests with various passenger cars. The fact that accelerations follow a normal distribution is then used to calculate the additional fuel consumption due to acceleration noise.

FUEL CONSUMPTION AT CONSTANT SPEED

To relate fuel consumption to energy, it is first necessary to consider the various forces that act on a vehicle that is being driven at constant speed on a constant gradient. The most important of these are the rolling, air, and gradient resistances. Power is also used to overcome transmission losses and to turn the engine.

Assuming that fuel is directly related to energy, or

$$F = bE \tag{1}$$

the above can be expressed by means of the following formula:

$$F = P_1 + P_2/V + P_3V^2 + P_4G \tag{2}$$

where

F = fuel consumption;
b = a conversion factor;
E = energy;
V = speed;
G = gradient;
P_1, P_3, and P_4 = constants derived from the rolling, air, and gradient resistances; and
P_2 = a constant that is related to idling fuel consumption.

This formula is only valid if the expression $P_1 + P_3V^2 + P_4G$ is positive. If it is negative--e.g., as a result of a negative gradient--then

$$F = P_2/V \tag{3}$$

A fuel flow meter, measuring to the nearest milliliter, was installed in several passenger cars to test the validity of the above equations. A fifth wheel provided accurate measurements of distance and speed. The results for one specific car are given below (each value represents the average of at least four measurements):

Speed (m/s)	Gradient (m/m)	Fuel Consumption (mL/km)
11.11	-0.0065	59.5
11.11	+0.0065	72.5
16.67	-0.0065	55.0
16.67	+0.0065	68.5
22.22	-0.0065	66.5
22.22	+0.0065	79.5
27.78	-0.0065	82.0
27.78	+0.0065	91.5
33.33	-0.0065	108.5
33.33	+0.0065	113.0
36.11	-0.0065	123.0
36.11	+0.0065	130.0
11.11	+0.029	97.5
16.67	+0.029	100.5
22.22	+0.029	109.0
27.78	+0.029	122.5
33.33	+0.029	155.0
16.67	+0.047	115.6
22.22	+0.047	139.6
27.78	+0.047	153.1

By means of a regression analysis on the results, it was found that Equation 2 explains as much as 97.9 percent of the variation ($r^2 = 0.979$) in fuel consumption due to speed and positive and small negative gradients. To test the validity of Equation 3, the fuel consumption for a specific car was predicted for a route of 10 km in rolling terrain (up to 5 percent gradient) for a constant speed of 90 km/h and then actually measured. The predicted amount of 1477 mL, total in both directions, compared well with the measured amount (average of five runs) of 1472 mL. The results for a Continental passenger car with a gross mass of 1400 kg are as follows:

$$F = 14.7 + 440/V + 0.0764V^2 + 1268G \tag{4}$$

where F is in milliliters per kilometer, V is in meters per second, and G is in meters per meter. These values are used in all subsequent calculations.

From Equation 4, the values of the fuel conversion factor b, the air-drag coefficient, the rolling resistance factors, and the idling fuel consumption can be calculated. The frontal projected area of the car is 2.5 m^2, and a 10 percent transmission loss is assumed (1). The coefficient of the V^2 term is made up of the air resistance and the speed-related term of the rolling resistance. I have assumed the latter to be 6.86×10^{-5} m^{-1}, as given by St. John and Kobett (4). The tests were done at an altitude of 1500 m, and therefore the density of the air is 1.059 kg/m^3. This affects the calculation of the air-drag coefficient. The following values are used:

Item	Value
Fuel conversion factor b (L/kW•h)	0.30
Air-drag coefficient	0.552
Rolling resistance (N/kg)	$0.1137 + 6.86 \times 10^{-5}V^2$
Idling fuel consumption (L/h)	1.58

The last three values agree very well with those found in earlier research (2,4). This is proof of the assumption leading to Equation 1. The value b can now be used to predict the additional fuel consumption due to acceleration.

FUEL CONSUMPTION DURING ACCELERATION

Several problems are involved in the measurement of additional fuel consumption due to acceleration:

1. Acceleration is never constant.
2. Acceleration occurs for short periods only.
3. There is a time lag between the moment of measurement in the fuel line and that of actual combustion in the engine. This time lag is also variable and depends on the flow rate of the fuel in the supply line.

For these reasons, it was decided to predict rather than directly measure the additional fuel by means of the theory developed in the previous paragraph. The predictions will then be validated by different means.

From Newton, force = mass x acceleration; thus,

$$E = Mad \tag{5}$$

where

M = mass (kg),
a = acceleration (m/s²), and
d = distance (m).

However, for an accelerating vehicle, the engine, driveline, and wheel inertias also have an effect. This is compensated for by using the effective mass M_e, which is a function of the inertias and the total gear reduction (5,6). For the 1400-kg test vehicle, the effective mass during acceleration in fourth gear is 1532 kg.

Therefore, the additional fuel consumption due to acceleration in top gear is

$$\begin{aligned} F_a &= bM_e ad/\eta \\ &= [(0.3 \times 1532 \times 1000)/3600] \cdot (100/90) \cdot a \\ &= 142\alpha \text{ mL/km} \end{aligned} \tag{6}$$

where η is the driveline efficiency. This can also be calculated for the other gears.

An attempt was made to validate Equation 6 by measuring the fuel consumption during acceleration (see Figure 1). For the reasons mentioned earlier, this attempt was not very successful.

By combining Equations 4 and 5, it was possible to predict the total fuel consumption for each 2-s period during a 30-s trip that included two speed-change cycles. In this case, if the expression $14.7 + 0.0764V^2 + 1268G + 142a$ is negative (while deceleration takes place), Equation 3 is applicable. Figure 2 shows the comparison between the calculated and measured fuel consumption. The variability of the time lag, mentioned earlier, is clearly illustrated. During acceleration it is about 1 s, but during deceleration, when the flow rate is low, it is twice as much. Considering the above, the total calculated consumption of 97.3 mL compares well with the measured 101 mL.

It is clear that the combination of Equations 3, 4, and 6 gives a reasonable estimate of the fuel consumption during acceleration and deceleration. It can now be used to calculate additional fuel consumption due to acceleration noise.

ACCELERATION NOISE

Although a motorist may wish to drive at a constant speed, it is impossible to do so. When high traffic volumes are present on the highway, the motorist is often forced to change speed. The geometric characteristics of the highway may also cause accelerations and decelerations. Even on the perfect roadbed, the driver unconsciously varies the speed of the vehicle. These accelerations approximately follow a normal distribution (7). The standard devia-

Figure 1. Additional fuel consumption due to acceleration.

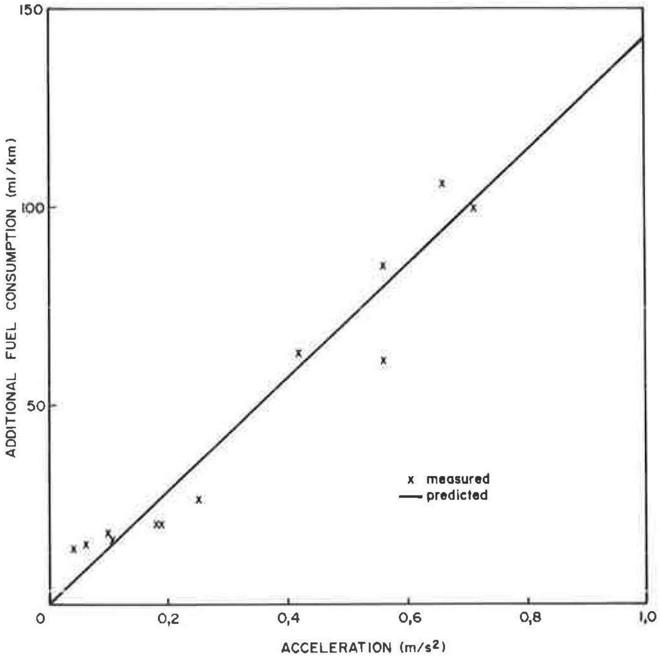
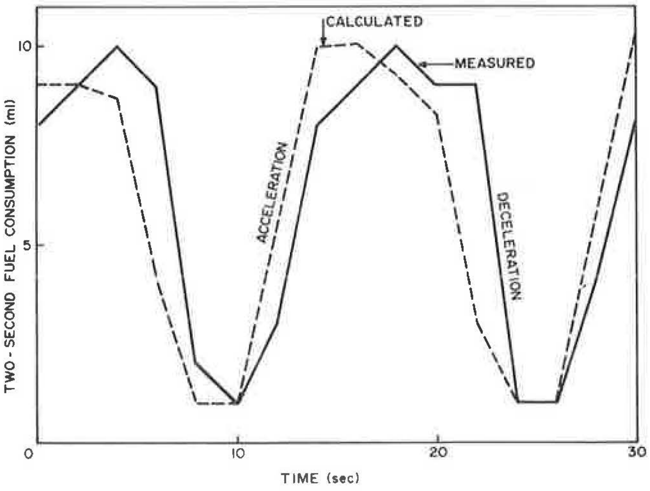


Figure 2. Measured and calculated fuel consumption during acceleration and deceleration.



tion of the accelerations--the acceleration noise--gives an indication of the severity of speed changes.

Acceleration noise has two components: the natural noise (σ_n), which can be ascribed to the driver and the road (8), and the traffic noise ($\sigma\ $), which is generated by traffic interactions. Drew and others (9) showed that

$$\sigma_t = \sigma_{tm} - \alpha k u^2 \tag{7}$$

where

σ_{tm} = maximum noise related to traffic only,
α = $(27\sigma_{tm})/(4u^2{}_f k_j)$,
k = density,
u = speed,
u_f = free-flow speed, and
k_j = jam density.

Assuming a linear relation between speed and density,

$$\sigma_t = \sigma_{tm} - \alpha k[u_f(1 - k/k_j)]^2 \tag{8}$$

This can be written as

$$\sigma_t = \sigma_{tm}[1 - 6.75(k/k_j) + 13.5(k/k_j)^2 - 6.75(k/k_j)^3] \tag{9}$$

The total noise is

$$\sigma = \sigma_t + \sigma_n \tag{10}$$

The relation between acceleration noise and density is shown in Figure 3.

FUEL CONSUMPTION DUE TO ACCELERATION NOISE

The fact that acceleration is a random variable, having the normal distribution $N(o,\sigma^2)$, is now used to calculate the additional fuel consumption due to acceleration noise. The method of calculation is explained with the help of Figure 4, which shows the graph of the normal probability density function f(a). The total area under the curve is equal to one. The shaded area A gives an indication of the proportion of time (or distance, if a spe-

Figure 3. Acceleration noise versus relative density.

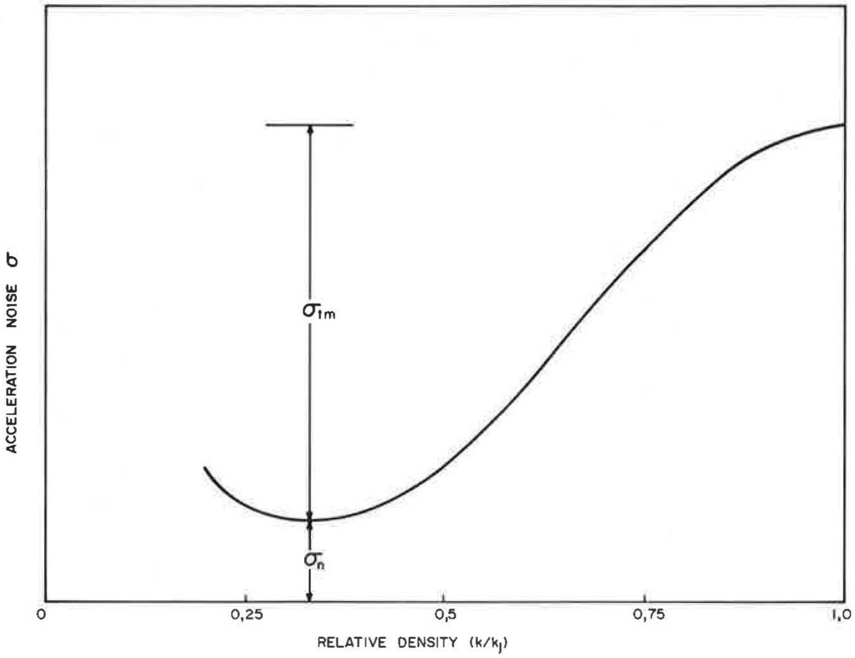


Figure 4. Normal probability density function $f(\alpha)$.

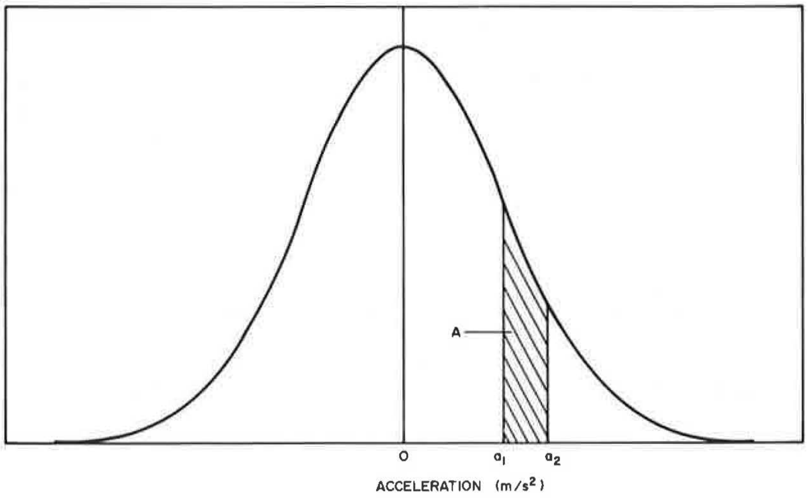
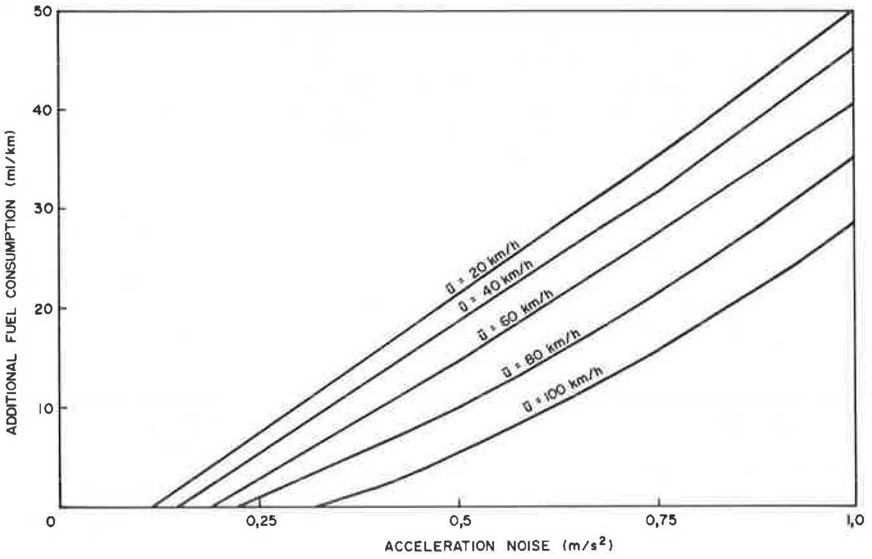


Figure 5. Additional fuel consumption due to acceleration noise.



cific average speed is assumed) during which the acceleration is between a_1 and a_2. With the band sufficiently narrow, it can be said that, for a distance of 1000A meters out of a kilometer, the acceleration is $(a_1 + a_2)/2$. By using Equations 3, 4, and 6 together with numerical integration of f(a), one can calculate the total fuel consumption per kilometer for different average speeds $\bar{u}$. By subtracting constant-speed fuel consumption, the additional fuel consumption due to acceleration noise can be found. The results are shown in Figure 5.

These results can now be used together with Equation 9 to determine the fuel consumption as a result of traffic interaction.

DISCUSSION OF NOISE VALUES

From Figures 3 and 5, the following should be noted:

1. For low values of σ, such as the natural noise for a driver on a high-design type of facility, no additional fuel is consumed.
2. The maximum practical value for σ is about 1.0 m/s² (9). In circumstances in which this does occur, the extra fuel consumption due to traffic interaction can be as much as 50 percent of the free-flow fuel consumption.
3. Figure 20 in the report by Drew and others (9) shows that acceleration noise, measured for speeds higher than 2/3 u_f, is less than 0.12 m/s². This corresponds to densities less than 1/3 k_j. Since a value of σ = 0.12 m/s² does not contribute to additional fuel consumption, densities lower than 1/3 k_j are disregarded in calculations for additional fuel consumption due to traffic interaction.

CONCLUSIONS

The following conclusions can be drawn:

1. Fuel consumption during free-flow conditions can be calculated from the basic equations of movement.
2. For densities less than one-third of the jam density, fuel consumption due to traffic interaction is negligible.
3. Fuel consumption on freeways can be increased by as much as 50 percent in congested traffic.

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Measures of the Impacts of Changes in Motor-Fuel Supply in Massachusetts

BENJAMIN DANSKER, CHARLES KALAUSKAS, AND DEBORAH SCHREIBER

During the past decade, a number of significant changes have occurred with respect to the supply of gasoline. Most notable of these changes have been price, which has increased dramatically, and availability, which has become less secure as a result of political developments. The impacts of these changes on the demand for motor fuel in Massachusetts over the 1967-1979 period are examined. The relation between gasoline sales and price, registered automobiles, fuel efficiency, income, and a number of other variables is analyzed, and statistical formulations are developed to express these relations. The analysis indicates that the principal response to these supply changes has been increased fuel efficiency, which results from both improved driving efficiency and higher mechanical efficiency. Only during periods of fuel shortages and substantial price increases have there actually been decreases in the amount of fuel sold. Otherwise, the rate of increase in fuel consumption has slowed down. The work to date suggests that further analysis would be useful to determine the specific impact of supply changes on the type and distribution of trips and to determine the ways in which travelers have accommodated themselves to such changes.

This study examines the impact of changes in gasoline supply and demand during the 1967-1979 period and pays particular attention to the effects of price increases. By reviewing the impact of previous changes, the effects of future changes and policy actions can be better understood. There has been much debate concerning whether regulation of supply or decontrol of price is the better way to deal with energy shortages. The argument for price decontrol states that, if price is allowed to be determined by supply and demand, then all but the most drastic shortages can be resolved in the "marketplace" and neither rationing nor any other regulatory approach would be required. The argument for government intervention is that the behavioral response to price changes (elasticity) is small and that the impacts of shortages will not be efficiently distributed throughout society. This study addresses the issue by examining in detail the effects of past price increases and supply restrictions in Massachusetts to determine consumer response.

MEASUREMENT OF IMPACTS

A number of factors connected to both the supply of motor fuel and consumer demand have been investigated. These factors include gasoline price, population, the number of licensed drivers, the number of registered vehicles, vehicle miles of travel (VMT), income, and vehicle fuel efficiency. Some factors are used as corrective factors to make possible a proper understanding of a particular measurement, such as the population that uses motor fuel. Where appropriate, the factors were adjusted to account for inflation.

Motor-Fuel Sales

Motor-fuel sales, used here as a measure of consumer demand, are the focus of this study. This examination will deal with the actual amount of motor fuel purchased in Massachusetts during the 1967-1979 period. Table 1 gives annual fuel sales during this period taken from the Federal Highway Administration (FHWA) (1) and monthly sales reports of the Massachusetts Department of Revenue.

According to the data presented in Table 1, an upward trend in motor-fuel sales is evident until 1974. The amount of motor fuel purchased during 1974 was lower than that purchased the previous year because of the Arab oil embargo of 1973-1974. Sales increased in 1975, but it was not until 1976 that motor-fuel purchases reached preembargo levels. Sales increased between 1975 and 1978 but at a slower rate than between 1967 and 1973. Sales dropped in 1979 with the gasoline shortage during the summer.

Motor-fuel sales are certainly not a perfect indicator of consumer demand during a period of actual shortage; however, for most of the period under consideration, a shortage did not exist. It is therefore appropriate to compare motor-fuel sales with other indices, such as price and income, and to examine their relations.

Gasoline Prices

The average price of regular gasoline in the Boston metropolitan area is given in Table 2 (2) for the month of October for 1967 to 1979. October was selected because it is a fairly typical driving month in terms of weather conditions and has only minor vacation and holiday travel. An average annual price would tend to hide the significance of monthly price increases. The price of gasoline is used to represent the price of motor fuel throughout this paper, since approximately 95 percent of the motor fuel sold in Massachusetts is gasoline.

Until the Arab oil embargo of 1973-1974, gasoline prices experienced a long period of stability. In 1974, the price of gasoline increased by more than 25 percent; this was followed by a period of moderately increasing prices--on the average, less than 5 percent/year. In 1979, after a period of political instability in Iran, substantial price rises by the Organization of Petroleum Exporting Countries (OPEC), and the dissolution of the unified OPEC pricing structure, the cost of crude oil took the significant leap that brought gasoline prices to more than $1/gal.

The real price of gasoline, which is the pump price of gasoline adjusted by the consumer price index (CPI) for the Boston area, is also given in Table 2 for the month of October during 1967-1979 (2,3).

The real price of gasoline declined until late 1973 and then increased for the next few years. Prices declined again in 1976, rose slowly over the next few years, and then surged dramatically in 1979. The effects of the first OPEC price rise were almost negated by inflation in 1976, 1977, and 1978; however, the price increase during 1979 was much greater than even the high rate of inflation experienced during that year.

Although the pump price increased more than 200 percent between 1967 and 1979, when corrected for inflation, the price increased by only 38 percent.

Per Capita Income

Although per capita income has increased significantly, real income has gone up only slightly during the period. In some years--1974, 1975, and 1979--per capita income rose more slowly than inflation, and therefore real income dropped (4). It is expected that, as income rises, travel, and therefore gasoline consumption, will increase. Automobile ownership is also expected to increase.

Population and Licensed Drivers

Table 3 gives data from various sources on annual population and number of licensed drivers for Massachusetts. Population growth has been quite slow during the period and is therefore unlikely to have affected motor-fuel sales. The rate of growth bears little relation to either the number of licensed drivers or the number of registered vehicles, which have both increased substantially during the period. Since the population has remained essentially the same, it is not used as a factor to explain or to correct motor-fuel sales.

The number of licensed drivers has generally increased over the period, which probably reflects demographic trends whereby the number of persons 16 years and older had been increasing faster than the population as a whole (this trend has now slowed down). It is also reflective of higher income, which has translated into increasing numbers of automobile drivers. In Massachusetts, the trend appears to have peaked in 1974 and in recent years shows signs of leveling off.

Vehicle Registrations

Another factor that may influence motor-fuel purchases is the number of registered automobiles and registered vehicles (registered automobiles represent approximately 88 percent of registered vehicles), as presented in Table 4 (1). Vehicle registrations show an upward trend since 1967, increasing at a rate significantly faster than the number of licensed drivers. Slowdowns in both vehicle registrations and driver licensing occurred in 1975 and 1979.

This information is used to translate motor-fuel sales into sales per unit. Table 5 gives data from FHWA (1) and the Massachusetts Department of Public Works on sales of fuel per registered vehicle. Fuel sales per registered vehicle increased slightly between 1967 and 1973 and decreased sharply thereafter. Since travel (which will be discussed below) has not decreased as much, the decreased fuel consumption must be related to both increased fuel efficiency and reduced travel per vehicle.

Table 1. Annual sales of motor fuels in Massachusetts: 1967-1979.

	Annual Motor-Fuel Sales[a]		
		Change (%)	
Year	Gallons (000 000s)	From Previous Year	From Base Year
1967	1844.2	–	–
1968	1961.9	6.4	6.4
1969	2047.4	4.4	11.0
1970	2174.3	6.2	17.9
1971	2255.7	3.7	22.3
1972	2391.7	6.0	29.7
1973	2483.5	3.8	34.7
1974	2380.9	–4.1	29.1
1975	2412.5	1.3	30.8
1976	2500.3	3.6	35.6
1977	2528.1	1.1	37.1
1978	2587.5	2.3	40.3
1979	2557.6	–1.2	38.7

[a] Includes all highway gasoline and diesel fuel.

Vehicle Miles of Travel

VMT, which is given in Table 6 for Massachusetts from 1967 to 1979 (data of the Massachusetts Department of Public Works), is related to both fuel consumption and vehicle efficiency. Although total statewide VMT has generally increased, VMT per registered vehicle, also given in Table 6, increased only until 1973 and has generally decreased thereafter. This indicates that reduced travel has played a role in the reduced demand for gasoline.

Fuel Efficiency

Increased fuel efficiency also explains part of the reduction in gasoline consumption per vehicle. According to data from FHWA (1) and the Massachusetts Department of Public Works, given in Table 7, vehicle fuel efficiency in Massachusetts has been increasing slowly since the early 1970s.

As consumers replace their cars with newer, more fuel-efficient cars, average fuel efficiency automatically improves. In addition, consumers may choose to trade in older, less efficient cars sooner or purchase new cars that have especially good fuel consumption as a means of enabling themselves to purchase less motor fuel without decreasing their travel. This explains the fact that fuel consumption per vehicle has slowed down much more than travel.

DISCUSSION OF TRENDS

In this section, trends in the relation among motor-fuel sales and price, income, automobile registra-

Table 2. Average price and real price of regular gasoline in Boston in the month of October: 1967-1979.

	Pump Price			Real Price		
		Change (%)			Change (%)	
Year	Price (cents/gal)	From Previous Year	From Base Year	Price[a] (cents/gal)	From Previous Year	From Base Year
1967	32.9	–	–	32.6	–	–
1968	33.9	3.0	3.0	31.1	–4.6	–4.6
1969	34.9	2.9	6.1	31.0	–0.3	–4.9
1970	35.9	2.9	9.1	30.1	–3.0	–7.7
1971	37.9	5.6	15.2	30.5	+1.3	–6.4
1972	37.9	0.0	15.2	29.4	–3.6	–9.8
1973	40.9	7.9	24.5	29.5	+0.3	–9.5
1974	51.7	26.4	57.1	33.9	+14.9	+4.0
1975	58.9	13.9	79.0	35.7	+5.3	+9.5
1976	59.9	1.7	82.1	34.0	–4.8	+4.3
1977	61.9	3.2	88.1	33.3	–2.1	+2.1
1978	63.9	3.2	94.2	32.3	–3.0	–0.9
1979	98.9	54.8	200.6	44.9	+39.0	+37.8

[a] Obtained by dividing pump price by CPI and multiplying by 100.

Table 3. Population and licensed drivers in Massachusetts: 1967-1979.

	Population			Licensed Drivers		
		Change (%)			Change (%)	
Year	Number	From Previous Year	From Base Year	Number	From Previous Year	From Base Year
1967	5 594 000	-	-	2 791 000	-	-
1968	5 619 000	0.4	0.4	2 850 000	2.1	2.1
1969	5 650 000	0.6	1.0	2 901 000	1.7	3.9
1970	5 704 000	1.0	2.0	2 988 000	3.0	7.1
1971	5 768 000	1.1	3.1	3 060 000	2.4	9.7
1972	5 789 000	0.4	3.5	3 141 000	2.6	12.5
1973	5 805 000	0.3	3.8	3 209 000	2.2	15.0
1974	5 800 000	–0.1	3.7	3 567 000	11.1	27.8
1975	5 818 000	0.3	4.0	3 554 000	–0.4	27.3
1976	5 792 000	–0.4	3.5	3 644 000	2.5	30.6
1977	5 777 000	–0.3	3.3	3 652 000	0.2	30.8
1978	5 774 000	–0.1	3.2	3 726 000	2.0	33.5
1979	5 770 000	–0.1	3.1	3 700 000	–0.7	32.6

Note: Data on population are from the Survey of Current Business (4) and the Survey of Buying Power, and data on licensed drivers are from the Massachusetts Registry of Motor Vehicles and FHWA (1).

Table 4. Automobile and vehicle registrations in Massachusetts: 1967-1979.

			Change in Registered Vehicles (%)	
Year	No. of Registered Automobiles	No. of All Registered Vehicles[a]	From Previous Year	From Base Year
1967	2 002 000	2 256 000	-	-
1968	2 104 000	2 367 000	4.9	4.9
1969	2 182 000	2 459 000	3.9	9.0
1970	2 312 000	2 620 000	6.5	16.1
1971	2 432 000	2 752 000	5.0	22.0
1972	2 543 000	2 877 000	4.5	27.5
1973	2 653 000	3 020 000	5.0	33.9
1974	2 726 000	3 125 000	3.5	38.5
1975	2 776 000	3 188 000	2.0	41.3
1976	2 865 000	3 273 000	2.7	45.1
1977	3 110 000	3 520 000	7.5	56.0
1978	3 190 000	3 636 000	3.3	61.2
1979	3 220 000	3 720 000	2.3	64.9

[a] Refers to all registered vehicles publicly and privately owned, excluding motorcycles and buses.

Table 5. Annual motor-fuel sales per registered vehicle in Massachusetts: 1967-1979.

	Motor Fuel per Registered Vehicle		
		Change (%)	
Year	Gallons	From Previous Year	From Base Year
1967	817	-	-
1968	829	1.5	1.5
1969	833	0.5	2.0
1970	830	–0.4	1.6
1971	820	–1.2	0.4
1972	831	1.3	1.7
1973	822	–1.1	0.6
1974	762	–7.3	–6.7
1975	757	–0.7	–7.3
1976	764	0.9	–6.5
1977	718	–6.0	–12.1
1978	712	–0.8	–12.9
1979	688	–3.4	–15.8

Table 6. Vehicle miles traveled in Massachusetts: 1967-1979.

	Annual VMT for All Vehicles			Annual VMT per Registered Vehicle		
		Change (%)			Change (%)	
Year	Number (billions)	From Previous Year	From Base Year	Number	From Previous Year	From Base Year
1967	21.769	-	-	9 649	-	-
1968	23.223	6.7	6.7	9 811	1.7	1.7
1969	25.378	9.3	16.6	10 320	5.2	7.0
1970	26.072	2.7	19.2	9 951	–3.6	3.1
1971	28.030	7.5	28.8	10 185	2.4	5.6
1972	29.442	5.0	35.2	10 234	0.5	6.1
1973	30.319	3.0	39.3	10 039	–1.9	4.0
1974	30.001	–1.0	37.8	9 600	–4.4	–0.5
1975	30.652	2.2	40.8	9 615	0.2	–0.4
1976	31.881	4.0	46.5	9 741	1.3	1.0
1977	33.779	6.0	55.2	9 596	–1.4	–0.5
1978	35.053	3.8	61.0	9 640	0.5	–0.1
1979	35.178	0.4	61.6	9 456	–1.9	–2.0

tions, and fuel efficiency are discussed. Specific attention is given to the trends that have followed supply shortages. The relation between the factors and the demand for motor fuel as quantified through regression analysis is presented, and price elasticities are estimated.

General Trends

The relation of gasoline price to motor-fuel consumption is as follows: As the real price of gasoline increases, consumption decreases; as the price decreases, consumption increases. At times, there may be some lag between the change in price and the change in consumption, although it is difficult to specify the length of delay. Much of the drop in consumption during this time period may be the result of greater fuel efficiency rather than reduced travel.

The relation between income and demand for motor fuel has already been discussed. Between 1967 and 1979, real per capita income increased at a slow but

Table 7. Vehicle fuel efficiency in Massachusetts: 1967-1979.

	Average Vehicle Fuel Efficiency		
		Change (%)	
Year	Miles per Gallon	From Previous Year	From Base Year
1967	11.8	-	-
1968	11.8	0	0
1969	12.4	5.1	5.1
1970	12.0	-3.2	1.7
1971	12.4	3.3	5.1
1972	12.3	-0.8	4.2
1973	12.2	-0.8	3.4
1974	12.6	3.3	6.8
1975	12.7	0.8	7.6
1976	12.8	0.8	8.5
1977	13.4	4.7	13.6
1978	13.5	0.7	14.4
1979	13.8	2.2	16.9

fairly steady pace, except for one or two periods when it dropped. Motor-fuel consumption appears to follow the same general pattern as income, although not as closely as price and consumption. Fuel efficiency has also increased during the period and appears to explain part of the drop in motor-fuel consumption.

Motor-fuel sales have increased at a rate very similar to the rate of vehicle registrations and at a slightly faster rate than licensed drivers until 1973. After 1973, fuel sales have increased at a rate similar to the rate of increase in licensed drivers. Population, which has remained quite stable during the period, is unlikely to have had any effect on sales.

Trends Following Supply Changes

Motor-fuel sales, measured in absolute amounts, show two periods of significant decline: following the 1973-1974 embargo and again in mid-1979. An examination of fuel sales per registered vehicle indicates an even more precipitous decline beginning in 1973, much less recovery after 1975, and a drop in 1979 greater than the one for absolute motor-fuel sales.

By 1974, fuel sales per registered vehicle were below the 1967 level. Consumption per registered vehicle dropped by approximately 16 percent between 1967 and 1979. This drop is roughly equivalent to a 17 percent increase in fuel efficiency experienced during this time. VMT per registered vehicle has declined by only 2 percent since 1967, which is not nearly as great as the decline in fuel consumption per registered vehicle during this same time.

Fuel efficiency measures both improved mechanical efficiency and the improved driving efficiency caused by such actions as observance of the 55-mile/h speed limit and more frequent engine tuning. To determine how much of the change in fuel efficiency is the result of choice by consumers and how much is simply the result of changed regulations and changes by the manufacturer requires data that are currently unavailable. What is most important is that increased fuel efficiency plays a greater role than reduced travel in bringing about a decrease in fuel consumption. This fact is important for policymakers because it indicates that consumers will respond to higher prices not by reducing their travel but by more efficient driving. Therefore, the focus of policy should be primarily on improving vehicle efficiency.

Regression Analysis

To determine the relative importance of the various factors related to the demand for gasoline and the magnitude of these relations, a regression analysis was performed. A number of specifications were tested in order to develop an equation that was theoretically sound and statistically significant. Although many of the variables previously discussed are related to the demand for gasoline, because of the strong correlation among groups of variables, very few were used in the same regression equation to avoid the problem of multicollinearity. In the equations, the independent variables, the number of registered vehicles and the cost of driving, were regressed against the dependent variable, monthly motor-fuel sales. Out of the large number of equations tested, the following are preferred:

$$\mathrm{MFUEL}_i = 50\,385.3 + \underset{(97.4)}{0.060\,266\,22\ \mathrm{REGVEH}_j} - \underset{(15.1)}{69\,145.8\ \mathrm{PPRGAS}_i} \qquad (1)$$

$$\mathrm{MFUEL}_i = 125\,999.2 + \underset{(226.3)}{0.046\,206\,69\ \mathrm{REGVEH}_j} - \underset{(21.9)}{2084.5\ \mathrm{RLPRGAS}_i} \qquad (2)$$

$$\mathrm{MFUEL}_i = 166\,730.0 + \underset{(64.1)}{0.061\,143\,33\ \mathrm{REGVEH}_j} - \underset{(9.7)}{12\,414.69\ \mathrm{FLFUELEF}_j} \qquad (3)$$

$$\mathrm{MFUEL}_i = 157\,878.3 + \underset{(156.7)}{0.036\,246\,71\ \mathrm{REGVEH}_j} - \underset{(15.9)}{26\,494.28\ \mathrm{CENTMILE}_j} \qquad (4)$$

where

MFUEL = motor-fuel sales to retailers in month i at quarterly intervals (gal 000s),
REGVEH = registered vehicles in Massachusetts in year j,
PPRGAS = pump price of regular gasoline in month i ($/gal),
RLPRGAS = real price of regular gasoline in month i (¢/gal),
FLFUELEF = average vehicle fuel efficiency in year j (miles/gal), and
CENTMILE = average real cost of fuel per mile of vehicle travel (¢).

The numbers in parentheses are t-scores. Coefficients of correlation and statistics for Equations 1-4 are given in the following table ($r_{x_1x_2}$ represents the correlation coefficient between the independent variables, and DW indicates Durbin-Watson statistics):

Equation	$\bar{R}^2$	F	$r_{x_1x_2}$	DW
1	0.80	104.2	0.88	2.3
2	0.82	117.8	0.48	2.4
3	0.78	93.3	0.92	1.9
4	0.80	105.8	-0.25	2.2

All of the variables in each of the equations are statistically significant at the 0.05 level, as is each of the four equations as a whole. The fact that the $\bar{R}^2$ values, which measure the degree to which the independent variables predict the dependent variable, are all relatively high indicates that the equations have good explanatory ability. The correlation coefficients between the independent variables ($r_{x_1x_2}$) are high in Equations 1 and 3. Although a high $r_{x_1x_2}$ value may indicate that multicollinearity is present, since the variables and equations are statistically significant, it will be assumed that this condition is not creating a serious problem. Serial correlation does not present a problem in these regression equations, as indicated by acceptable Durbin-Watson statistics.

Dependent Variable: Motor-Fuel Sales

MFUEL turned out to be the most successful dependent variable in the equations that were tested. Monthly motor-fuel sales at quarterly intervals (March, June, September, and December) were used. Only quarterly data were used because the method by which suppliers report fuel sales results in large monthly fluctuations, which are unrelated to the independent variables. Other dependent variable specifications that were tried included the total fuel sales in a quarter and the average monthly fuel sales per quarter. MFUEL performed better than any of these. Nonlinear formulations were also tested with no greater degree of success.

Independent Variables: Registered Vehicles and Driving Cost

The variable REGVEH, the number of registered vehicles in the state, appears in each of the equations. It was believed that motor-fuel consumption would be related mainly to some measure of population, whether population of vehicles or population of licensed drivers. Both of these variables were tested for use as the measure of population in the regression. The number of registered vehicles performed slightly better. Another variable highly correlated with both of these, real income, also performed well, although not quite as well as the other two.

In Equation 1, the coefficient for REGVEH means that each additional registered vehicle will result in 60 gal of gasoline sold in a particular month.

The variable PPRGAS, which appears in Equation 1, is the pump price of gasoline in a given month. The equation performs fairly well with regard to the test statistics. The price coefficient indicates that a 1¢ increase in the pump price would result in a decrease of 691 000 gal of gasoline. This is approximately 0.3 percent of monthly fuel sales in December 1979.

Equation 2 is the same except that the real price (RLPRGAS) is substituted for the pump price. The coefficients in Equation 2 are highly significant and have a slightly higher $\bar{R}^2$ than Equation 1. Basically, a 1¢ increase in real price will result in a fuel decrease of 2.1 million gal/month.

In Equation 3, the variable FLFUELEF is used with registered vehicles. Although both price and fuel efficiency would affect fuel consumption, a very high correlation between the two variables prevents their being used in the same equation. Even with the possibility that multicollinearity is present because of the correlation between registered vehicles and fuel efficiency, the variables are all statistically significant. For each mile-per-gallon increase in fleet fuel efficiency, the equation predicts that consumption will decline by approximately 12.4 million gal/month. Each additional registered vehicle still accounts for an increase of 60 gal of gasoline.

In Equation 4, real price and fuel efficiency are combined into one variable, CENTMILE, which is calculated by dividing the real price per gallon by miles per gallon. Therefore, if the real price were 45¢/gal and fuel efficiency were 15 miles/gal, the value for CENTMILE would be 3¢/mile (real cost). The advantage of this equation over Equations 1-3 is that, without introducing multicollinearity into the equation, it is possible to use both real price and fuel efficiency with registered vehicles. For each 1¢ increase in the cost of driving a mile, the equation predicts that approximately 26.5 million gal less would be consumed. A 1¢/mile increase in the cost of driving is a substantial increase. In the above example, where the real price is 45¢/gal and fuel efficiency is 15 miles/gal, it would take a real-price increase of 15¢ to achieve a 1¢/mile increase in the fuel-related cost of driving. This is a fairly substantial increase, achieved only recently.

It should be pointed out that each of these equations contains an error term that relates to the variation explained by variables not included in the equation. Overall, unexplained variation accounts for 20 percent of the variation in the demand for motor fuel according to these regression equations.

Price Elasticity of Gasoline

The relation between gasoline price and motor-fuel consumption was also quantified through the calculation of the price elasticity. An elasticity is a measure of the responsiveness of demand for a particular product (or service) to changes in a characteristic of its supply--in this case, price. It is defined as the percentage change in quantity divided by the percentage change in price. The formula for an arc elasticity, which is commonly used, is as follows:

$$e_{arc} = (q_2 - q_1)/(q_1 + q_2)/2 \div (p_2 - p_1)/(p_1 + p_2)/2 \qquad (5)$$

where

q_1 = quantity of gasoline sold at the beginning of the period being measured,
q_2 = quantity of gasoline sold at the end of the period being measured,
p_1 = price at the beginning of the period, and
p_2 = price at the end of the period.

The following table gives several short-term elasticities calculated over one-year periods during which shortages occurred:

	Elasticity	
Time Period	Real Price	Pump Price
June 1978 to June 1979	-0.24	-0.18
December 1978 to December 1979	-0.26	-0.19
March 1973 to March 1974	-0.44	-0.29

Elasticities reported in a number of studies produced between 1973 and 1975 (5) are given below (all of these studies use pre-1972 data; generally, short-term refers to a one-year period):

Study	Year	Elasticity
Data Resources, Inc.	1973	-0.23 to -0.30
McGillivray (Urban Institute)	1974	-0.23
Rand Corporation	1975	-0.26 to -0.43
Charles River Associates	1975	-0.18

As the first table above indicates, the elasticities for real price are somewhat higher than for pump price. This is because the difference in real price from the beginning to the end of a period is always smaller than pump price. The first table also shows that elasticities are generally higher for the 1973-1974 comparison than for 1978-1979. One reason for this could be that the earlier period contained the first major price increase and therefore subsequent price increases, no matter how great, might be expected to have less of an impact. In addition, since the absolute price increase in 1973-1974 was smaller than that in 1978-1979, it would not take such a great change in demand to result in the calculation of a higher elasticity. In other words, although an elasticity may be a good indicator of consumer response, it may fall short when one compares different periods of time with substantially different base prices and base quantities. The elasticities derived in this study, which are based on real price, are quite similar to the real-price elasticities from previous studies.

CONCLUSIONS

The purpose of this paper has been to present the results of an investigation of changes in motor-fuel consumption during a period in which significant changes in the supply of motor fuel have occurred. The examination was performed by using data for the state of Massachusetts during the 1967-1979 period. The focus of the research has been to relate the trends in fuel consumption to a number of factors related to its supply. These factors include price, fuel efficiency, and vehicle registrations. As might be expected, the number of vehicle registrations is the dominant factor, which indicates that the size of the vehicle fleet is the primary determinant of motor-fuel consumption. Price does play a role, and it is estimated that the short-term price elasticity of gasoline is between -0.18 and -0.44, depending on the price definition and the time period studied. Fuel efficiency relates to fuel consumption in that, as fuel efficiency increases, consumers can purchase less motor fuel without limiting the amount of vehicle miles of travel.

It would be useful to investigate further the specific ways in which consumers have changed their behavior in the face of rising gasoline prices and supply uncertainty (6). Monitoring of the overall fuel efficiency of the automobile fleet would be most useful in determining how consumers are adapting to rising fuel prices, and improvements in the procedure for collecting motor-fuel data would make possible a refinement of the analysis. Further research should also be performed by using more refined vehicle registration data. In short, while some conclusions as to the relative impacts of various factors on fuel consumption can be drawn, this study also points the way toward future research.

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Dual Price System for Management of Gasoline Lines

YOSEF SHEFFI AND VICTOR PRINS

The problem of crisis management during a shortfall in gasoline supplies is how to distribute the available gasoline in the most efficient and equitable fashion. Several approaches to this problem are reviewed, and particular emphasis is placed on a dual market scheme. The dual market system allows gasoline station operators to charge as much as they want for gasoline as long as for each high-price pump there is one pump operating at the regulated or controlled price. This creates a situation in which customers can either wait in line for the regulated-price gasoline or pay more and avoid queuing. The way in which this system actually creates a continuum of choices for each customer is described. Efficiency and equity criteria are emphasized, and some of the issues that may be associated with implementing the system are reviewed.

Most forecasts of energy availability in the near future include a provision for shortages in gasoline supplies for various periods of time. It is likely that the ongoing research into and development of alternative energy sources will not produce results in time to prevent such shortfalls. Thus, one of the questions confronting planners is how to best accommodate such a shortage. The focus of this paper is on one of the most visible consequences of a petroleum shortage--queues at gasoline stations.

This paper deals with some strategies for gasoline-line management.

The problem of emergency preparedness in the context of the gasoline market is different from the long-term issues of energy conservation. The fundamental difference is that the objective of crisis management is to best allocate the limited available supply to end users, not to reduce their consumption. This view of the problem objective leads to a set of criteria for judging various solutions based on comparisons between the scenario under each strategy and under the "do-nothing" alternative. These criteria are the subject of the first section of the paper. The next section concentrates on some specific crisis-management strategies and, in particular, the dual market mechanism that is the focus of the paper. Under such a scheme, the demand for gasoline is satisfied by having a portion of the population pay more in monetary units while others pay more in time units.

Examples of dual pricing in other markets are included in the third section, which also includes a simple model of the demand for gasoline and the queuing phenomenon. This model demonstrates numerically some of the topics discussed in this paper. The final section reviews some of the issues that may be associated with the implementation of the dual market system, including the required implementation effort, enforcement, and institutional and legal perspectives.

CRITERIA FOR MANAGEMENT OF GASOLINE LINES

The problem of managing gasoline lines is the problem of allocating limited supplies in the "best" way. In this section, we discuss criteria for ranking various solutions and judging the best one.

In order to evaluate any strategy, we must first describe a base case with which the strategies' effectiveness can be compared. The do-nothing alternative in this case is a gasoline shortage scenario in which queues form at every pump and regulated prices are similar to what they were in many states during the summer of 1979.

Thus, the situation is characterized by gasoline prices that are below the level that people are willing to pay. This creates the other mechanism for clearing the gasoline market--the queues. In queuing situations, people are paying in two forms: spending money to buy the gasoline and spending time waiting in the queue.

It should be realized that gasoline queues play more than one role in the crisis. On the one hand, they are an evil that government may be trying to eliminate by means of management schemes. On the other hand, they are a form of payment and thus one of the main causes for the aforementioned reduction in the demand for gasoline. This role of the queues may explain the limited effectiveness of some of the traditional queue-management schemes, a point discussed in the next section of this paper.

At the beginning of the shortage, there may be a transient phenomenon of "tank topping", which may exaggerate the crisis. Daskin and others (1) even argue that this panic buying is the main driving force behind the queuing. The view presented in this paper, however, is that it is the fundamental imbalance between prices and demand that drives the crisis. This view is similar to the approach taken by Dorfman and Harrington (2), Prins and others (3), and other researchers (4,5). Furthermore, based on data from California (collected during the summer of 1979), Goldstone (6) concluded that the queuing could not be explained by panic buying and is probably due to the above-mentioned supply-demand imbalance.

Let us now analyze this situation from two points of view: the economic and the social. The economic view gives rise to the efficiency criterion and, as noted by many authors (2,4), the do-nothing alternative scores poorly here. The queues are a very inefficient way of handling the gasoline payments. The main reason is that queues represent a loss of a resource (time) to the economy. The queuing time spent by the buyer cannot be enjoyed by the seller, and it cannot be taxed and used for public goods or income redistribution. The perfect solution to this inefficiency problem is, of course, to let the price rise to the point at which the market is cleared.

The social view of the problem leads to an equity criterion. Under the do-nothing alternative, people pay the difference between the controlled price and the market-clearing price by waiting in the queues. People with higher values of time "pay" more than people with lower values of time. This appears to be acceptable, since a higher value of time is typically associated with higher income and thus the queue may seem to serve as a direct income redistribution function. This is not the case, however, since even though high-income people may "pay", low-income people gain nothing from these "payments".

A second approach to the equity issue is from a regional perspective. Under the do-nothing alternative, some regions may suffer more than others because longer queues in one region do not provide any incentive to distributors to allocate gasoline to these harder-hit areas from areas where queues are shorter. This situation was apparent during the summer of 1979, when some states did not suffer any shortages while queues in other areas were getting longer and longer. The conclusion from these arguments is that the do-nothing situation is hardly equitable, even though all users pay the same monetary price for gasoline.

Letting the price rise may be economically efficient but is usually criticized as inequitable. This criticism is correct in the sense that low-income segments of the population will carry a large part of the burden and so will the segments associated with more driving. From the aforementioned arguments, it is clear that, under such a scheme, endogenous funds that may be earmarked for compensating those segments of the population can be generated. It seems, however, that societal values, as reflected in the political process, tend to discriminate against the economically efficient solution, mainly on the grounds of equity.

EXISTING STRATEGIES

The criteria discussed in the previous section did not include a conservation measure; i.e., no scheme for gasoline-line management is expected to save any gasoline. This means that no scheme is expected to include measures that effectively set the gasoline price above its market-clearing level (such as an extremely high tax or severely limited accessibility to the pumps). The role of gasoline-line management strategies is to distribute the limited available supply in the most efficient and equitable fashion. Before describing the dual market approach, let us review some of the existing approaches that have been used to solve the problem.

The first approach is the license-plate-based odd-even plan, which has been used in many states. This plan calls for gasoline purchases on either odd or even days of the month according to the last digit on the buyer's license plate. As noted by Prins and others (3), this plan may cause a small reduction in the average length of the queues, since the inconvenience incurred by the plan can be seen as some form of payment. In other words, the total price of gasoline under this plan includes the monetary price, the queuing time, and the inconvenience associated with not being able to join the queue on the spur of the moment.

This plan does not solve the problem on several counts. This may be due to the fact that a potential small reduction in the queues reduces the actual price paid for the gasoline. Since this price comprises money and queuing time, a reduction in the queue length may increase demand. Total consumption, however, is constrained by the supply so that the increase in demand shows in a higher propensity to wait and, thus, longer queues. The effect of such a plan may therefore be minimal. Furthermore, the transformation of one form of inefficient payment (waiting in line) to another (the mobility to buy gasoline when desired) cannot result in an efficient solution. From the equity point of view, this plan does not contribute much because the distribution of the burden remains as in the do-nothing alternative. Exemptions from the plan for some segments of the population can hardly be classified as equitable solutions, since they are based on making everybody else worse off rather than making the target population better off. (Without exemptions, this plan would discriminate against those users who have to fill up every day. Users who normally fill up every few days should not be affected at all by this plan, or they may decide to fill up when possible rather than when needed and thus aggravate the situation even more.) It seems that, although the odd-even plan may be effective against panic buying or the tank topping that follows the initial stages of the crisis, it does not bring about either a more efficient or a more equitable allocation as compared with the do-nothing alternative.

Other well-known schemes include minimum and maximum purchase restrictions. The analysis of all these schemes is analogous to the analysis of the odd-even plan. The maximum-minimum plans are clearly as inefficient as the do-nothing situation is and may be even less equitable. It seems, however, that these strategies are conceived as measures against transient tank topping, and thus it is not surprising that none of the above-mentioned schemes causes a measurable improvement in shortening queues or distributing the burden. (The usefulness of many of these schemes may be rooted in the restoration of public confidence in the government, which is obviously "trying to do something about the situation".)

None of these schemes fundamentally changes the situation in comparison with the do-nothing alternative and in fact can be viewed as minor variants of it. The only substantially different alternative discussed so far is letting the price rise to its market-clearing level, which gains much in efficiency and trades off some forms of inequity against others. Such a plan, however, is not politically feasible. This situation is the motivation for the dual market system proposed here, which combines some features of the do-nothing alternative with features of the economically efficient solution.

The dual market scheme allows each gasoline station to sell gasoline at two prices, each price associated with a distinct pump (or island of service). The operator may sell gasoline through one of the pumps at any price that he or she wishes provided that the other pump is operated at the regulated (controlled) price. In other words, for each free-price pump there should be at least one controlled-price pump operating.

Under this scheme, one can expect the price at the uncontrolled-price pump to rise. Gasoline stations will offer their customers two types of service to choose from: either wait in line and pay the regulated price, or avoid the long queue and pay more for the gasoline. Given the price at the controlled-price pump, the length of the lines at both pumps will be a function of the price set at the uncontrolled-price pump. In other words, the queue at the expensive (uncontrolled-price) pump may not be eliminated if the price differential is not high enough. It will, however, be shorter than the queue at the cheaper (controlled-price) pump. The key to the analysis of this scheme is the expected behavior of station operators. This subject is discussed in the next section, where we present a simple model that deals with operator behavior. In the remainder of this section, the dual market system is evaluated by using the efficiency and equity criteria.

At this point, let us assume that the price at the pump where gasoline is more expensive would rise to its market-clearing level. It is obvious that people who put a higher value on time (i.e., high-income people) will choose to pay for their gasoline in monetary units and avoid the queues while people who put a higher value on money (low-income people) will choose to wait. It can be expected that the prices at the uncontrolled-price pump will be higher than the prices that would have prevailed if the entire market had been allowed to clear in monetary units (the economically efficient approach). Similarly, the queues at the controlled-price pumps should be longer than in the do-nothing alternative. Both of these things happen because each market clears with a segment of the population that exhibits, by definition, a lower elasticity to the market-clearing measure. In other words, the uncontrolled portion of the market clears with a population segment that has a relatively lower value of money in comparison with the general population, whereas the controlled portion of the market clears with a population segment characterized by its relatively low value of time.

This scheme is clearly more efficient than the do-nothing alternative, since as much as half of the population will not have to wait in line at all or wait through a significantly shorter queue. The money paid by these people represents a transfer of resources rather than waste and thus leads to a more efficient solution than the do-nothing alternative. Furthermore, the population segment whose wait has been eliminated (or significantly reduced) is (by definition) associated with a high value of time, high opportunity costs, and probably high productivity. Thus, most of the waste is eliminated by reducing the wait time for this population segment. The time spent in the queue by people purchasing gasoline at the controlled market price is still an economic loss. It is, however, a much smaller loss than one may expect, since by definition the opportunity cost is very low for most of the people waiting in line. (In fact, according to neoclassical demand theory, most of these people would have preferred to wait even longer in exchange for even lower gasoline prices.) Thus, the dual market system is almost as efficient as the market-clearing price scheme.

The dual market approach may be at least as equitable as both the do-nothing alternative and the market-clearing price alternative. In comparison with the do-nothing alternative, the dual market scheme favors high-income people but requires them to pay more than they would have to pay under the market-clearing alternative. The people waiting in line for the controlled-price gasoline may have to wait somewhat longer than under the do-nothing alternative. This, of course, is a minus on the equity side, which may be somewhat softened by the fact that most people who choose to wait do not have a high value of time. In comparison with the market-clearing price alternative, the dual market system is more equitable since it allows low-income people to still obtain gasoline at the regulated price and not be priced out of the market. A population segment that may be disadvantaged by the plan (as compared with the free market system) includes those people who could have afforded the price and avoided queuing under the market-clearing price alternative but would not be able to afford the higher gasoline price under the dual market system. This group may not be a traditionally disadvantaged one and thus may not warrant special consideration; as we show next, however, the system offers a dimension of choice that may ease the aggravations of many population segments.

It should be realized that, even after equilibrium in both markets has been reached, consumer choice is not actually limited to two alternatives. In fact, over a long period, consumers can choose their optimal mix of money and queuing time by varying the frequency of choosing either alternative. Thus, any combination of length of queues (between zero and the length of the queue at the controlled-price pump) and price (between the controlled and uncontrolled prices) can be chosen. Moreover, by virtue of the frequency-of-choice mechanisms, the dual market system can account for varying values of time for the same individuals. In other words, individuals may either choose a combination of frequencies a priori, as described before, or choose based on their momentary value of time. For example, individuals may choose to avoid the queue and pay a higher price when going to work or to an important appointment and choose to wait in the queue at other times.

On the equity issue, then, the dual market system seems to be comparable to both the do-nothing alternative and the market-clearing price system. It may be more equitable than the do-nothing alternative in that it does not discriminate against people who have a high value of time and it may generate funds that can be used to compensate any severely affected group. It is, of course, more equitable than the market-clearing price alternative in that it does not discriminate against low-income population segments. Note that the segment of the population that is committed to a lot of driving will be hard hit under any scheme. Under the dual market scheme, some of the strain may be eased for some members of this group by providing them the opportunity to choose an optimal combination of time and money payments and by the possible availability of compensatory funds. At the same time, the dual market system is significantly more efficient economically than the do-nothing alternative and almost as efficient as the market-clearing price alternative.

DUAL MARKET SYSTEM

A dual market system is not a unique or a new idea. In fact, most of the existing markets are operating at multiple prices. One of the most vivid examples of this operation is the air-travel market, which offers first and coach classes as well as an array of lower fares associated with some restrictions (e.g., advance reservations, stay limitations, and standby status). In fact, the whole idea of different packaging (e.g., Oldsmobile Omega versus Pontiac Phoenix versus Buick Skylark versus Chevrolet Citation) may be viewed as some form of dual or multiprice market, where the same basic product is offered at several prices. Furthermore, a dual market in gasoline exists even now as gasoline stations offer the same type of gasoline at self-service or limited-service islands and at full-service islands but charge higher prices for the latter.

In all of these cases, the supplier of services tries to segment the market and charge each segment what it will bear. The motive of the private sector in practicing this approach is to convert some nonmonetary units of payment, such as prestige (or the lack of it), convenience, or time, into monetary units that can be translated into greater profits. In this case, the public welfare criteria would be very similar, since some forms of these payments, such as waiting time, induce waste (as argued in the preceding section). The conditions of the suggested dual market are much simpler than some of the aforementioned examples, and thus the situation can be modeled by using a very simplified approach.

The simple model developed below tries to demonstrate numerically some of the points mentioned in the discussion of the dual market system. It demonstrates the trade-offs faced by the gasoline station operator, including his or her optimal (profit-maximizing) price level and the length of both queues as a function of the price (at the uncontrolled-price pump) set by the operator.

Our model looks at the demand for gasoline at a single, isolated, two-pump station. The total number of customers is fixed, since we assume that all of the available supply is exhausted under any scheme. The choice between the two types of operation can be modeled by using a logit formula in which

$$Pr_c = e^{v_c}/(e^{v_c} + e^{v_u}) = 1/(1 + e^{v_u - v_c}) \qquad (1a)$$

and

$$Pr_u = 1 - Pr_c \qquad (1b)$$

where Pr_c and Pr_u are the probability of choosing the controlled- and uncontrolled-price gasoline pumps, respectively, and v_c and v_u denote the measured utility of buying gasoline at those respective pumps. [The theory and applications of the logit model and the choice models in general can be found in a variety of references (7,8).] In order to specify the measured utility functions, let R_c and R_u denote the controlled and uncontrolled prices, respectively; let W_c and W_u denote the associated waiting time; and let I denote the decision maker's income. Using these notations, let

$$v_c = -(R_c/I) - \alpha \cdot W_c \qquad (2a)$$

and

$$v_u = -(R_u/I) - \alpha \cdot W_u \qquad (2b)$$

where α is an estimated parameter [$(\alpha \cdot I)$ can be interpreted as the value of time for the decision maker with income I]. We further assume that income is distributed across the population according to the probability mass function $f_I(I)$ (a discrete density was assumed for purposes of clarity and simplicity), given by

$$f_I(I) = \begin{cases} f_L & \text{for } I = I_L \\ f_M & \text{for } I = I_M \\ f_H & \text{for } I = I_H \end{cases} \qquad (3)$$

where subscripts L, M, and H designate low, medium, and high income, respectively. Thus, if the total number of users (per unit of time) purchasing gasoline at the station under consideration is N, the number purchasing the gasoline at the controlled price (N_c) is given by the weighted sum of the choice probability (Equations 1a and 1b) with the corresponding income levels. In other words, if we let

$$(v_u - v_c)_j = (1/I_j)(R_c - R_u) + \alpha(W_c - W_u) \quad (4a)$$

for j = L, M, H, the number of gasoline buyers at the controlled-price pump is given by

$$N_c = N \cdot \sum_j \{f_j/1 + \exp[(v_u - v_c)_j]\} \quad (4b)$$

and

$$N_u = N - N_c \quad (4c)$$

The prediction of the number of users at each pump is not completely straightforward because of the dependence between N_c, N_u, and the waiting time. In other words, the more people who want to purchase a certain type of gasoline, the longer will be the queue in front of this pump (at a given price). This side of the system is modeled by using a simple M/G/1 queuing model, which can be viewed as nothing but a formula relating the average waiting time at a certain pump to the number of users at this pump; i.e.,

$$w_c = N_c \cdot (\mu^{-1} + \sigma^2)/2(1 - N_c/\mu) \quad (5a)$$

and

$$w_u = N_u \cdot (\mu^{-1} + \sigma^2)/2(1 - N_u/\mu) \quad (5b)$$

where μ is the average service rate at which gasoline is filled and σ^2 is the variance of the service rate.

It should be noted that a queuing formulation may not be an appropriate representation for the controlled-price pump, since the queue there is most likely to persist continuously. In other words, in this queue customers enter service at a rate that equals the service rate. According to queuing theory, such a queue should be of an infinite length, a phenomenon that does not occur in reality due to the balking effect as the queue grows. This leads to queuing systems with state-dependent arrival rates, which are mathematically complicated to handle and represent fine tuning that is meaningless in the absence of data. We thus chose to ignore this difficulty and use a relatively simple queuing formula. [This approach may also be justified if one looks at the pump including a certain length of the queue (such as the steady-state length) as the "server" in this system.] A similar approach has also been used by others (9).

In order to solve simultaneously for the waiting times and the number of users (per time unit) choosing each pump type, Equations 1 and 5 have to be solved simultaneously. This problem parallels the well-known equilibrium problems of traffic assignment (10,11) or of transportation in general (12, 13). A similar problem in the context of mode choice has been discussed by Sheffi (14), who also recently suggested a mathematical-programming-based formulation of the general problem of equilibrium with logit models (15) and an efficient solution algorithm. The focus of this paper is on the model results rather than on solution techniques, and these results are discussed next.

The following numerical values were used for this model: $I_L = 1$, $I_M = 2$, $I_H = 3$; $f_L = 0.25$, $f_M = 0.50$, $f_H = 0.25$; $R_c = 1.50$, $\sigma = 0$, $\alpha = 2$; and $N = 45$, $\mu = 45$. Since we are interested in the general shapes of the resulting functions rather than specific values or units (which would require data and model estimation), the specific numerical values are not important. It should be noted, however, that having three income levels serves as a sensitivity analysis on most of the model parameters.

Figure 1 shows the percentage increase in the operator's revenue as a function of the percentage change in the uncontrolled price over the controlled price (the operator revenue is proportional to the sum of the quantity sold at each pump times the price at which it is sold). As expected, the curves at all income levels show a steep increase as the prices rise, since users are shifting to the high-price pump. Beyond a certain point, however, people cannot pay the price and go back to the low-price pump. The higher the income, the less price sensitive the population is and the higher the optimal price and profits are.

This means that the price charged at the unregulated pump may vary quite substantially among neighborhoods. The price at the unregulated pumps should be higher in the high-income neighborhoods, since this market may be clearly with higher-income populations. Such price variations may be seen as another positive attribute of the dual market system from the equity perspective in comparison with the do-nothing alternative. (Similar price variations may also occur to some extent under the market-clearing price alternative.)

The waiting time at the controlled-price pump will increase as the gasoline price at the uncontrolled-price pump is increased, as shown in Figure 2. This is obvious since, the higher the latter price is, the more people will join the queue for cheaper gas. Figure 3 shows the (expected) decrease in the average waiting time at the uncontrolled-price pump as a function of this price.

This simple model shows that there is an optimal price that the profit-maximizing operator will charge and this price will be finite even under a shortfall situation. Furthermore, it is likely that most operators will charge less than this price due to the competition effect. Under the dual market system, operators will have to compete in setting the price level of the unregulated gasoline. Thus, the equilibrium price under competitive situations may be somewhat lower than that indicated by the model. Moveover, under the dual market system, operators have less discriminatory power and opportunity for unfair practices (e.g., forcing oil changes or spare automotive parts on customers or accepting other forms of bribes). Many station owners may also choose to charge less than what the market will bear in order not to alienate good customers if the shortage is perceived as a transient phenomenon.

OPERATIONAL ASPECTS AND VARIATIONS

The dual market system has been evaluated so far on the basis of two criteria only: efficiency and equity. This section discusses some of the operational issues associated with the plan and some variants on it. The operational issues can be broken down into four categories: (a) the ease of implementation and cancellation of the plan, (b) the question of enforcement, (c) institutional issues, and (d) legal constraints.

In order to put the dual market system into effect, one would require a public information campaign, one that should not be more extensive or complicated than, say, an odd-even plan. The dual market scheme, however, has a built-in "sunset" mechanism of fading away on its own, unlike license-plate-based strategies or other schemes. As gasoline supplies return to preshortage levels, station hours will get longer and the price at the uncontrolled-price pump will start to decline. This is caused by competitive pressures from stations that suddenly (as the shortfall eases) do not sell all their allotment at the given prices.

The enforcement of this scheme should not require

Figure 1. Increase in operator revenue versus increase in uncontrolled price over controlled price.

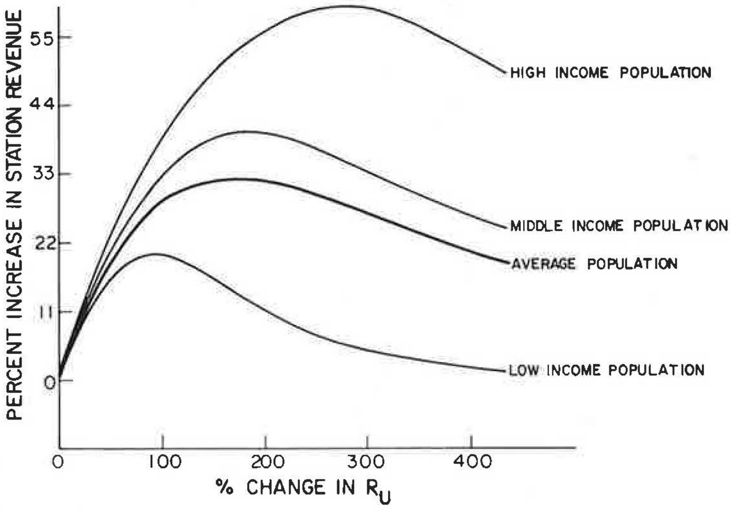


Figure 2. Increase in waiting time for users of controlled-price pump versus increase in uncontrolled price over controlled price.

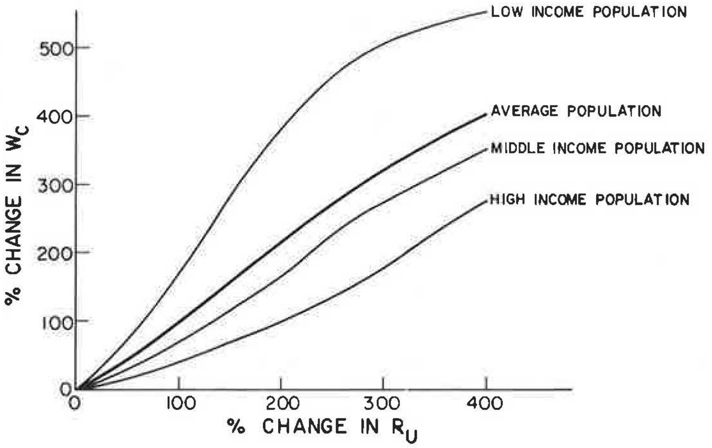
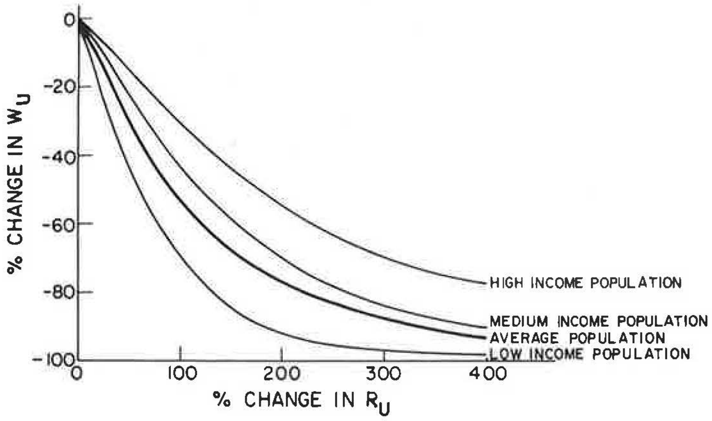


Figure 3. Decrease in waiting time for users of uncontrolled-price pump versus increase in uncontrolled price over controlled price.



more resources than the enforcement of the regulated price in the do-nothing alternative. Furthermore, the plan is self-enforcing to a large degree because it is so simple: There should be one pump operating at the controlled price for every uncontrolled-price pump. Violations of this scheme should be easy to spot (e.g., when a station operates only the high-price pumps). It may be harder to spot and enforce another type of violation: When the rate of gasoline flow is not equal at both pumps, operators may try to increase the service rate at the uncontrolled-price pump by using more attendants, processing payments faster, etc. This should be noticeable both to customers and to law-enforcement agents. It implies, however, that the dual market scheme should specify that the rate of gasoline flow at both types of pumps should be equal rather than that the number of pumps should be equal.

An institutional analysis of the dual market system may include identification of all of the actors involved in implementing this plan and those who may be affected by it. On the face of it, it seems that no major population segment may be adversely affected by the plan because it offers, basically, a continuum of choices, as explained in the previous section of the paper. The plan should be presented as a compromise between the do-nothing alternative and the market-clearing price alternative in that it has most of the better aspects of both and offers more choice. The only population segment that may be discriminated against under this plan is operators of small, one-pump stations, who will have to sell at the regulated price. Thus, the system may include a provision for such stations by letting them apply for the higher prices and evaluating such applications ad hoc. Other provisions may also be possible, such as collaboration between two adjacent one-pump stations so as to alternate the pricing between them. At any event, this is a small, well-defined group that should not present any particular problems.

Opposition to the dual market system may also be rooted in people's objections to any one group (gasoline station owners) making a substantial profit from a crisis situation. Inasmuch as this may impede implementation, the law may include provisions for a "windfall profit" type of tax or a similar mechanism to extract these profits from the station owners. The regulated price level may even be set below the operator's costs. This, in fact, forces the operator to cross subsidize the lower price directly. Such a scheme represents an effective income transfer to low-income groups, since no transaction costs are involved.

The legal situation concerning the implementation of a dual market plan is not certain at this time. Currently, the act that gives the federal government the right to control prices is the Emergency Petroleum Allocation Act of 1974. This act is due to expire on September 30, 1981, and it is unclear whether it will be renewed. Should it be renewed, the implementation of a dual market system is an open legal question, since under the act such a mechanism is neither prohibited nor specified as a possible alternative. Should the act not be renewed, it is up to Congress or to each individual state to enact a law that would make possible the implementation of a dual market in gasoline.

The basic dual market system presented in this paper can be implemented with many variations. For example, instead of letting each operator charge whatever the market will bear at the uncontrolled-price pump, the government may designate special stations that would be allowed to raise their prices. Under this alternative implementation plan, the taxing of these profits would be much simpler. Furthermore, the gasoline sold at these special stations could be taxed on a per-gallon basis. This plan, however, does not offer as much choice as the original one because of the spatial distribution of gasoline stations (i.e., some people may perceive that the controlled- or uncontrolled-price gasoline is not available in a certain locality). Yet, basically, this variation is similar to the original one in terms of efficiency and equity.

Other variations on the original plan include the imposition of traditional measures, such as an odd-even arrangement or maximum-minimum purchase restrictions, in conjunction with the dual market system. This is not recommended because there does not seem to be any potential benefit from such "add-ons".

The relative rate of flow of the controlled- versus uncontrolled-price gasoline can be changed from the equal amounts specified under the original plan. In other words, the rule can be two controlled-price pumps for each high-price pump or any other combination instead of the "one-for-one" rule. Such rules will affect both the uncontrolled price and the length of the queue at the controlled-price pump. As more controlled-price pumps are needed per each uncontrolled-price pump, the price at the uncontrolled-price pump will go up and the length of the queue at the controlled-price pump will shrink and get closer to the queue length that would prevail under the do-nothing alternative. As more uncontrolled-price pumps are allowed to operate (per each controlled-price pump), the uncontrolled price will come down toward the prices that would have prevailed under the market-clearing price alternative. Again, this alternative does not fundamentally change the situation because of the continuum of choice that is actually available to consumers, as discussed in the preceding section. The simplicity and ease of implementation associated with the original scheme should thus make it the most attractive alternative from this perspective.

SUMMARY AND CONCLUSIONS

This paper describes a dual pricing mechanism of distributing the burden of a shortfall in gasoline supply. This scheme is compared with the do-nothing alternative on the one hand, which is characterized by controlled prices and queues at the pumps, and a free market system, in which the price is allowed to rise and clear the market. The comparison is based on the two criteria of efficiency and equity, and the dual market scores well in both of these.

The main problem with the do-nothing alternative is the gross inefficiency associated with the queuing. This inefficiency can be eliminated by letting the market price rise to a level that would clear the market. Such a solution discriminates, however, against low-income population groups and therefore is perceived as inequitable. The dual market system can be viewed as a compromise that is better than either of the extremes. It is almost as efficient as the market-clearing solution, since the people who choose to pay and not wait place a high value on time. The discrimination against low-income groups is minimal and may be eliminated altogether if so desired.

In order to understand the plan and why it may work, it is important to realize two concepts. First, the total number of buyers in the market is fixed, and the question is mainly who buys. Thus, for example, no aspect of any plan can be criticized as encouraging consumption and no plan can be advocated as conserving gasoline. Under the dual market system, the high-income groups are better off (since they can pay with monetary units that they have) and the low-income people are not particularly hurt (since they can pay in terms of waiting time, which does not cost them as much).

Middle-income groups are not adversely affected by the plan because of the second concept associated with it--the continuum of wait-time/price combination that may be chosen by each individual in the long run. This means that most of the population is going to be better off under this plan, which is almost as efficient as the market-clearing alternative.

The paper also mentions several implementation issues and concludes that the major impedance to the implementation of the plan is legal. Currently, only the federal government has the authority to alter the price of gasoline, and it is not clear if the dual market system is legal under current laws. The current law is due to expire shortly; if it is not renewed, it may be left to each state to set the gasoline price, and the states could enact a law that would make it possible to implement a dual market system. Alternatively, this may be provided for in a new congressional act.

This paper does not cover all the issues that are associated with a dual market system and all the complications that may follow. For example, we do not deal with the question of multiple gasoline types and their pricing, nor do we predict the role that the oil companies may play under such a system. These issues and others are left for further investigation.

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Projections of Changes in Vehicle Technology and Characteristics to Improve Fuel Economy

RICHARD L. STROMBOTNE AND STEPHEN LUCHTER

Probable changes in the technology and characteristics of vehicles in the 1985 new-vehicle fleet, as well as some possible changes for the period after 1985, are discussed. In the 1975-1985 period, the designs and characteristics of new passenger automobiles are changing radically. The same can be said about the designs and characteristics of light trucks but to a lesser extent. By 1985, the average weight of all new vehicles and of four-, five, and six-passenger cars will have dropped by about 800-1200 lb. In addition, the recently initiated conversion to front-wheel drive will be virtually complete, sophisticated electronic controls to reduce emissions and improve fuel economy will be used almost universally, and all passenger cars will have automatic restraint systems.

Revolutionary changes in the design of automobiles and light trucks are expected between now and 1985. Vehicles will weigh less, there will be more small vehicles in the fleet, and the technology of engines, transmissions, tires, aerodynamics, and emission controls will be at a much more advanced level. These trends are expected to continue after 1985.

AUTOMOBILES

Typical new automobiles in 1985 will differ from today's automobiles in many respects. With few exceptions, they will be "downsized", have front-wheel drive, and make greater use of lightweight materials. Other anticipated improvements include smaller, more efficient engines, reduced aerodynamic drag, tires with lower rolling resistance, and improved transmissions. As a result of these changes, average fuel economy will increase to more than 27.5 miles/gal. Beyond 1985, further increases in fuel economy are expected.

Vehicle Changes

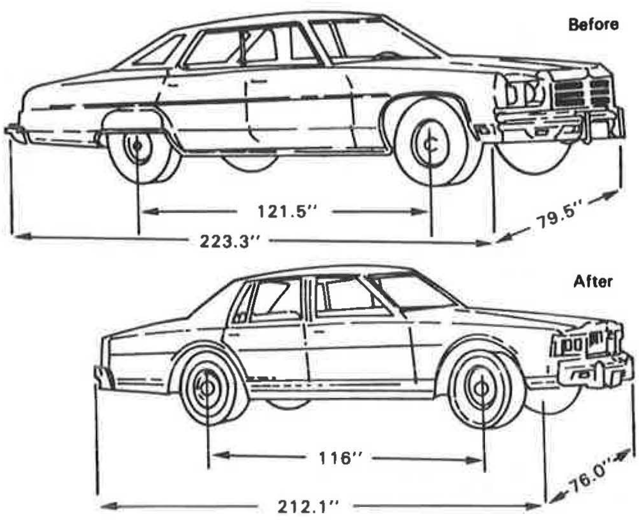
Three major trends are foreseen in vehicle design by 1985, all resulting in significant weight reductions: Automobiles are expected to (a) be downsized, (b) have front-wheel drive, and (c) use lightweight materials to a large degree. Beyond 1985, further applications of lightweight materials are expected, and a two-passenger "urban car" will be introduced by most manufacturers.

Downsizing means that an automobile's external dimensions are reduced without changing the interior volume. Figure 1 shows the main dimensions of the 1977 General Motors (GM) large cars compared with those of the corresponding 1976 model. Overall length was reduced from 223.3 to 212.1 in, and the width was reduced by 3.5 in, from 79.5 to 76 in.

The interior volume of the 1976 GM large cars was 130 ft^3. The interior volume of the equivalent 1977 vehicle was 129 ft^3. [The Environmental Protection Agency (EPA) defines a large car as a vehicle with more than 120 ft^3 of interior volume.] A weight reduction of about 800 lb was realized by downsizing the 1976 large cars. By 1981, all domestic manufacturers will have downsized the large, mid-sized, and compact cars. Significant downsizing is not applicable to subcompact automobiles.

Front-wheel drive means that, instead of driving the rear wheels, which has until now been the conventional approach, the power of the engine drives the front wheels. In general, automobiles with front-wheel drive use the inherently lighter-weight unit-body construction technique. (In unit-body construction, there is not a separate frame. The body structure is strengthened to incorporate the frame function.) Figure 2 compares the major components of automobiles with front-wheel drive and rear-wheel drive. A net weight of about 200 lb can be removed from a typical automobile by eliminating the drive shaft and the rear axle, even though some weight must be added to the body to make it stronger. By the mid-1980s, it is expected that almost all new automobiles will have front-wheel drive.

Figure 1. Downsizing of a large car.



Material substitution means that aluminum, plastic, and high-strength, low-alloy (HSLA) steel are substituted for carbon steel, the main component of current automobiles and light trucks. All of these lighter-weight materials are expected to be used to a greater extent in the mid-1980s than they are today. The specific mix of substitute materials actually used in the 1985 designs will depend on the development of production techniques and the relative economic advantages of the different materials.

An estimate of the material changes between 1975 and 1985 is shown in Figure 3. Use of HSLA steel is estimated to increase from 2.6 percent in 1975 to 14.3 percent in 1985, use of aluminum is estimated to increase from an average of 2.1 percent of the total vehicle weight in 1975 to 7.5 percent in 1985, and use of plastic is estimated to increase from 4.1 percent in 1975 to 10.7 percent in 1985. The main reductions are estimated to occur in the use of carbon steel--from 55.3 percent in 1975 to 35.7 percent in 1985--and cast iron--from 15.2 percent in 1975 to 10.9 percent in 1985. The other materials are estimated to stay at about 20 percent of the total weight.

These vehicle changes are expected to reduce the average inertia weight (curb weight plus 300 lb) of automobiles from about 4100 lb in the 1975 model year to about 3300 lb in the 1980 model year and to about 2900 lb in the 1985 model year (these weight estimates include both domestic and imported vehicles). Figure 4 illustrates these changes.

The average weights of vehicles of different sizes sold in 1975, 1980, and 1985 are given in Table 1. In Table 1 (and, later, Table 2), the following should be noted:

Figure 2. Major components of automobiles with rear-wheel and front-wheel drive.

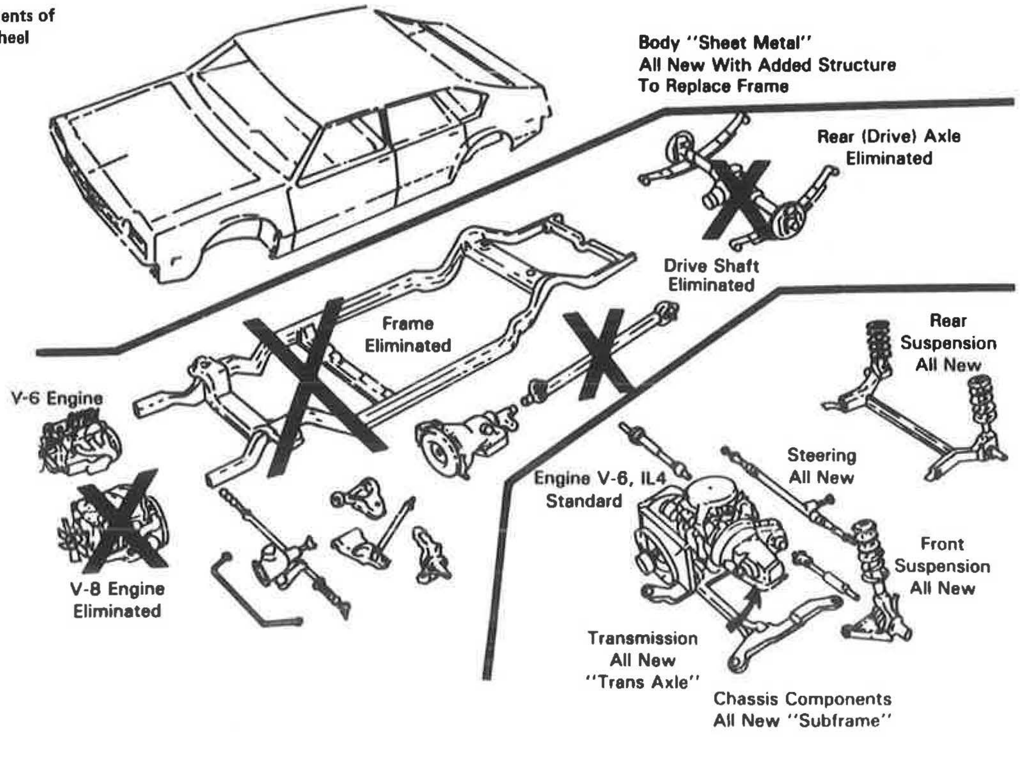


Figure 3. Material composition of typical automobiles.

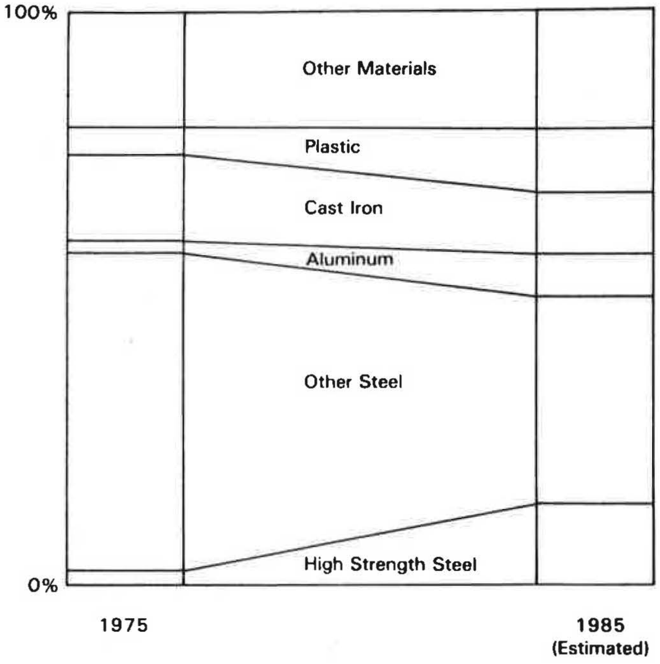


Figure 4. Average inertia weight of new automobiles.

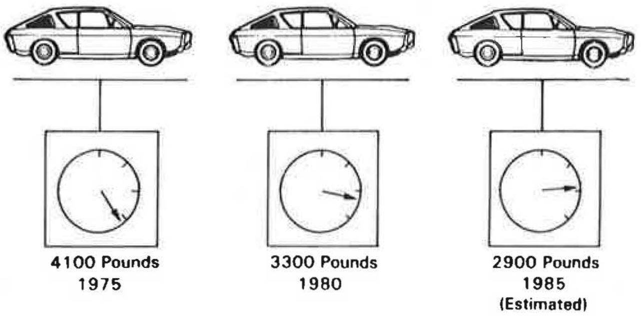


Table 1. Average inertia weight of automobiles by size class.

	Weight (lb)			
Year	Large	Mid-Sized	Compact	Subcompact
1975	5185	4560	3960	2990
1980	4200	3700	3100	2800
1985	3700	3300	2800	2500

1. Station wagons are included with related sedans.
2. Subcompact includes minicompact and two-seater.
3. Urban cars are not included in 1985 estimates.
4. No electric cars are included.
5. Weights for 1975 are actual, and 1980 and 1985 weights are as estimated by the National Highway Traffic Safety Administration (NHTSA).
6. Entries represent the total new-car fleet, domestic and imported.

The size classes correspond to EPA interior-volume classes. The weight of the large, mid-sized, and compact automobiles will be reduced by about 30 percent between 1975 and 1985. The subcompact car weight will be reduced by about 18 percent during this period. In each case, more than half of the weight reduction will have occurred by 1980.

Engine Improvements

The trends foreseen in the engine area include a dramatic shift to four-cylinder engines, increased use of diesel engines, and the application of more advanced technology to meet stringent emission standards while maintaining overall engine efficiency.

One of the more dramatic changes in the engine field is the shift toward four-cylinder engines. Figure 5 compares the market shares of different engine types. In 1975, the percentages of four-, six-, and eight-cylinder engines in the new-car fleet were 7, 20, and 73, respectively. In 1980, these percentages have changed to 42, 28, and 30, respectively. By 1985, the eight-cylinder engine will essentially be gone, and the percentages will be 61, 37, and 2, respectively. A few five-cylinder engines are now available, and it is expected that these will continue to be used in some applications. Three-cylinder engines are expected to be in domestic production before 1985.

The spark-ignition engine is expected to continue to be the dominant engine in the mid-1980s, accounting for 75-90 percent of the new-vehicle fleet. On the average, the fuel efficiency of spark-ignition engines will have changed little between 1978 and the mid-1980s because of the counterbalancing effects of the more stringent schedule of emission standards on the one hand and the technological advances in combustion chamber geometry and electronic controls on the other.

Diesel engines are already being used in some car models. In the first five months of 1980, about 4 percent of the total cars sold had diesel engines. Between 10 and 25 percent of the new-passenger-car fleet may use diesels by 1985, and there should be fuel-economy improvements of at least 25 percent at the same acceleration performance level and as much as 40 percent with reduced acceleration performance. The extent of diesel-engine application will depend on the results of biomedical investigations on the possible health effects of diesel particulate emissions and the success of manufacturers in developing engines that meet the new diesel particulate standards.

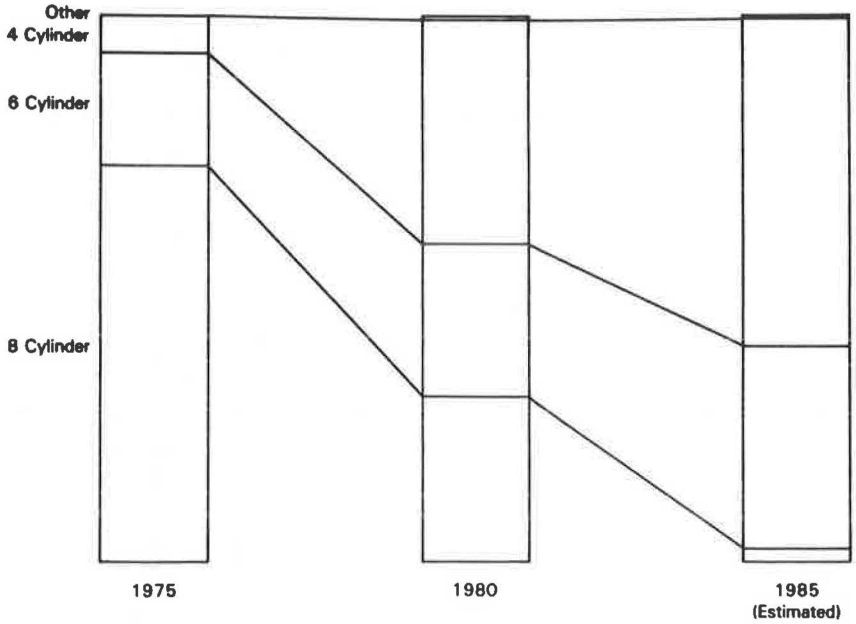
It is expected that by the mid-1980s some automobiles (and some light trucks) may be powered by electricity. GM has announced that it may offer an electric vehicle in 1985. The market share of the electric vehicle is difficult to predict, since it will be highly dependent on its cost relative to that of other vehicles.

Transmission Improvements

One significant cause of energy loss in automatic transmissions is the loss inherent in torque-converter slippage. A lockup clutch on the torque converter eliminates this slippage and increases overall vehicle fuel economy by 3-6 percent. Chrysler and GM now offer some three-speed automatic transmissions with lockup torque converters. By the mid-1980s, it is expected that most automatic transmissions will incorporate either lockup clutches or other means of mechanically bypassing the torque converter to avoid energy losses.

Further gains in fuel economy can be made by adding an overdrive feature, either in the form of a wide-range three-speed (a change from the conventional ratios) or a fourth gear. Overdrive allows the engine to operate at a lower rotational speed.

Figure 5. Market shares of various engine types.



With an overdrive transmission, a 2-5 percent improvement in fuel economy is possible; this improvement is in addition to that obtained from the torque-converter lockup by itself. Five-speed manual transmissions also will be appplied to a greater degree.

Reduced Tire Rolling Losses

By the early 1980s, it is expected that tire rolling resistance will be reduced by 35 percent over that of today's radial tire, which will result in a 5 percent improvement in the fuel economy of passenger automobiles. The 35 percent reduction in rolling resistance may be achieved by combinations of technical design and operational improvements in the following four areas: (a) type of rubber base stock and additives used in rubber compounds, (b) cord and belt material, (c) increased inflation pressure, and (d) use of an oversized tire operated in an underloaded condition.

Reduced Aerodynamic Drag

NHTSA estimates that fuel economy will be improved by 5 percent in the early 1980s, when new body designs with low aerodynamic drag are introduced, or by 3 percent through the use of aerodynamic add-on devices. Currently, at highway speeds, approximately half the amount of energy being consumed by the engine is used to overcome aerodynamic drag. It may ultimately be possible to reduce the aerodynamic drag of passenger automobiles by 20-50 percent by careful body design.

Alternative Fuels

By the mid-1980s, NHTSA expects gasohol (a mixture of gasoline and alcohol) to account for a small percentage of the total fuel consumed, assuming a continuing federal and (in some cases) state subsidy. Other alternative fuels are not expected to be available in any significant quantity by the mid-1980s, although it is likely that work on production of such fuels will be further along than it is today.

Fuel Economy

As a result of the changes in vehicle configuration, engine technology, and other technologies, the fuel economy of the automobile fleet is expected to increase. Figure 6 shows actual fuel-economy values for 1975-1980 (the 1979 and 1980 values are preliminary) as well as the standards for 1978-1985. All values represent the "combined" fuel economy, a 55/45 harmonic average of urban and highway values. {The harmonic average is actually an average of the fuel-consumption values. The formula for determining this is as follows: Combined fuel economy = 1/[(0.55/urban fuel economy) + (0.45/highway fuel economy)].} It is obvious that the overall average fuel economy has exceeded the standard for 1978-1980. This situation is expected to continue. For example, several domestic manufacturers have announced that they will exceed an average fuel economy of 30 miles/gal in 1985.

A comparison of average fuel-economy estimates for passenger cars of different sizes for 1980 and 1985 is given in Table 2. Data were not available for 1975 in this form. The 1985 values represent the results of a preliminary internal NHTSA analysis; the 1980 values are based on EPA projections. Between 1980 and 1985 an average increase in fuel economy of about 10 miles/gal is expected for all size classes.

LIGHT TRUCKS

Between now and 1985, there will be significant changes in the light-truck fleet. The new vehicles of the 1985 era are expected to differ from current new trucks in two main ways: (a) Current designs will be upgraded, and (b) new designs will be introduced. In both cases, the motivation for these changes is the need to increase the fuel economy of the light-truck fleet.

The application of technology to the light-truck fleet will in many ways be similar to the changes expected in the automobile fleet, differing, of course, according to the differences in application of automobiles and light trucks. Changes such as smaller engines, improved transmissions, and reduced rolling resistance will all be applied to light trucks in order to increase their fuel economy. The increase in fleetwide light-truck fuel economy through 1985 is expected to occur primarily as the result of domestic manufacturers introducing new lighter-weight trucks with high fuel economy.

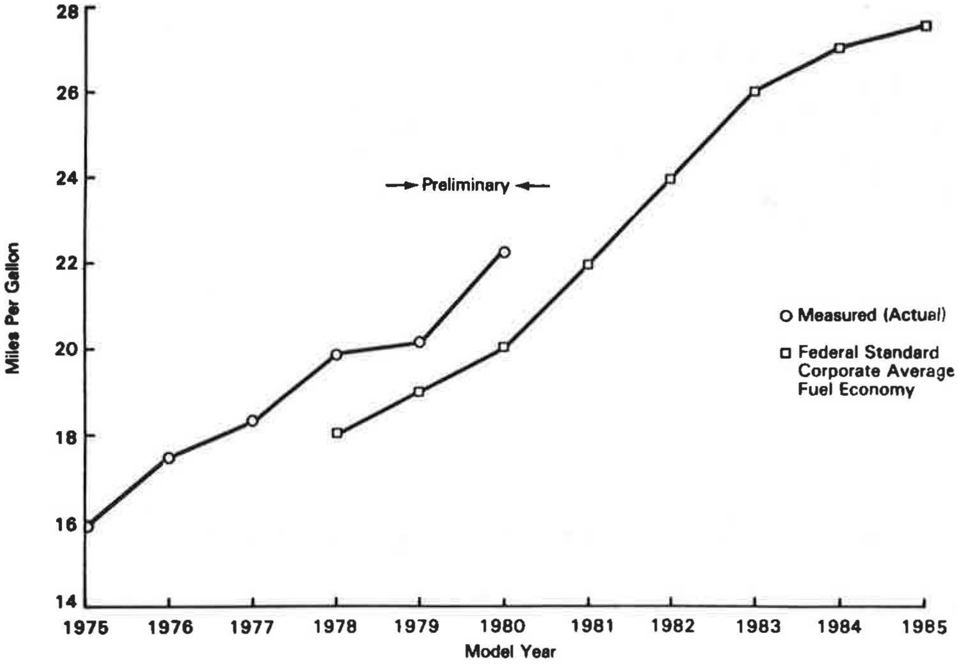


Figure 6. Average fuel economy of new automobiles.

Table 2. Average fuel economy of automobiles by size class.

	Avg Fuel Economy (miles/gal)			
Year	Large	Mid-Sized	Compact	Subcompact
1980	18.7	21.2	23.5	26.3
1985	28.6	30.1	34.1	35.3

Table 3. Current and future inertia weight and fuel economy of typical light trucks.

Truck Category	Inertia Weight (lb)		Fuel Economy (miles/gal)	
	Current	Mid-1980s	Current	Mid-1980s
Pickup or utility				
Compact	2950	2870	25	25
Standard	4660	4170	17	18
Van	4640	4620	17	17
Compact van		3250		22

The new light-truck models expected include small pickups, new "standard-sized" pickups, and compact vans. Utility vehicles based on both the small and the new standard-sized pickups are also projected. Table 3 gives the major features of light trucks now and as anticipated in the mid-1980s. The market share of the compact pickup-utility and the compact van is expected to be larger than the market shares of the standard pickup-utility and the van. The main fuel-economy increase is expected to result from this market shift. Although average weights will be reduced for some of the truck types, more stringent emission standards will limit the attainable fuel economy. In all cases, there will be numerous trucks that have higher fuel economies than the typical value shown.

Small Pickup-Utility Vehicle

A new small pickup will be available that will be larger than the current imported pickups but smaller than the new standard-sized pickup described below. The pickup bed, as well as that of the related utility vehicle, may be reduced to less than 4 ft between wheel housings; it is also likely that the bed will be less than 8 ft long with the tailgate of the pickup closed. The sales-weighted average test weights of the new small pickups are expected to be similar to those of current imported pickups with four-cylinder engines, which have test weights on the order of 2750-2875 lb and 3125-3250 lb for the two- and four-wheel-drive versions, respectively. Some of the small pickups will be derived from automobile designs.

The engines used in the small pickups will probably include four-cylinder spark-ignition engines in the 170-200 cubic-inch-displacement (CID) range. Four- and five-speed manual transmissions and a three-speed automatic transmission with a lockup torque converter will be used in these vehicles.

Standard Pickup-Utility Vehicle

New standard-sized pickup-utility vehicles that are lighter than the current domestic 0.5-ton vehicles are expected. The sales-weighted average test weights are projected at 3750 lb and 4250 lb for the two- and four-wheel-drive versions, respectively. This compares with 3875-4000 lb and 4750 lb for the 1980 model-year Ford F-150 two- and four-wheel-drive pickups, respectively. These new trucks will be slightly smaller than current 0.5-ton pickups but will preserve the three-man cab and the 4x8-ft clear area in the bed with the tailgate closed. Major components may no longer be shared with larger trucks as is the current practice.

Spark-ignition engines for the standard pickup will probably be larger than those used in the small pickup. A 200-CID six-cylinder engine and a 200- to 320-CID V-8 engine are expected, as are a four-speed manual overdrive transmission and a four-speed automatic overdrive transmission with a lockup torque converter. A possible alternative automatic transmission is a three-speed wide-ratio unit with a lockup torque converter.

Compact Van

The new-model compact van is expected to be larger than the current Volkswagen van sold in this country but smaller than the current domestic products. The sales-weighted average test weight is estimated at 3200 lb, between 600 and 1000 lb lighter than current domestic six-cylinder vans. The available engines and transmissions will probably include the same types as the small pickup-utility vehicles.

CONCLUSIONS

Between now and 1985, automobiles and light trucks will become lighter, have components that incorporate more advanced technology, and will be more fuel efficient.

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Framework for Analyzing the 1979 Summer Fuel Crisis: The New York State Experience

RONALD H. BIXBY, THOMAS M. CORSI, AND MICHAEL A. KOCIS

Past experience has demonstrated the need for coordinated statewide and local plans for responding to energy emergencies. At these levels, however, the characteristics, implications, and impacts of such emergencies are complex. Shortage levels, travel responses by the public, transportation resources, and other factors exhibit wide geographic variations during an emergency. Reliable data concerning these variables are scarce and uncoordinated for energy emergency planning purposes. No framework exists for analyzing the past experience of individual states and local areas in order to plan for appropriate responses to possible future energy emergencies of various durations and intensities. Ongoing efforts by New York State to develop such an approach are described. Available data sources are examined, and a framework is presented for integrating data with base-case control totals to develop a model of travel behavior during the 1979 summer fuel crisis as the basis for future emergency scenarios. It is shown how this framework can be used to measure the effectiveness of individual actions within the context of the total possible responses by the public and government to replace the mobility that is lost during energy emergencies.

During the summer of 1979, New York State experienced a period of rapidly increasing fuel prices coupled with severe supply shortfalls. Although residents in all areas of the state shared in a fuel price increase of approximately 21 percent between May and August, those in the downstate New York City metropolitan area faced a supply shortfall that was significantly greater than the one encountered by those in other areas of the state. The combination of fuel price increases and different shortfall levels had adverse consequences that ranged from minor inconveniences to serious mobility and economic losses. Beyond public-order measures (such as "odd-even" and minimum-purchase rules), government did little to minimize the disruptive impacts of the situation. The events of 1979, coupled with the experience of the Arab oil embargo of 1973, demonstrate convincingly the need for all levels of government (federal, state, and local) to develop in advance a coordinated response in the event that a comparable or worse situation should arise in the future.

This paper presents a framework through which New York State can prepare an organized response to future energy emergencies. The approach consisted initially of a detailed analysis of the effects of the 1979 crisis on travel behavior in different areas of the state based on available data. These disaggregated data were then related to an overall framework of statewide and local-area travel behavior under nonemergency (base-case) conditions. The framework served as a device for (a) measuring the impacts of the 1979 crisis and other crisis scenarios of greater or lesser magnitude and (b) measuring the effectiveness of various actions to replace lost mobility and alleviate the disruptive consequences of energy emergencies. The effectiveness of individual actions and improvements in fleet fuel efficiency can then be used to estimate the total possible response by government and the public to maintain mobility during different levels of gasoline shortage.

Mobility is defined as the ability of a person to travel for different purposes by whatever mode and circumstance (i.e., cost or time) he or she would choose. Mobility is calculated in terms of person miles of travel that could be maintained by public and government actions as people shift to more use of carpools and transit. Shortage is defined as the percentage reduction in gasoline available compared with what would be required immediately to maintain personal mobility by normal modes of travel.

SUMMER CRISIS OF 1979

The initial task was to assemble all relevant evidence about how households in New York State adjusted to the fuel shortage in the summer of 1979. Responses to the crisis included (a) purchasing more fuel-efficient automobiles, (b) driving more slowly, (c) reducing the number of trips taken and/or their length, (d) trip chaining (travel to several destinations before returning home), (e) substituting transit or automobile passenger trips (ridesharing) for driver-only automobile trips, and (f) shifting the location of a residence to reduce work-trip distances.

Available data concerning the selected response patterns consisted of monthly data on the use of gasoline for highway travel, traffic-count information, ridership figures for public transportation, trends in summer vacation travel, and survey responses regarding the adjustment strategies adopted.

Although the available data were not comprehensive, they were appropriate for identifying both the range and the magnitude of consumer adjustments during an energy emergency. When related to a framework of base-case travel conditions in New York State (described later in this paper), these and other data sources can provide an effective framework for analyzing potential responses to a statewide energy emergency.

Gasoline Sales

For the purpose of tax collection, New York State keeps a record on monthly wholesale gasoline sales. By examining the sales figures during the 1979 summer crisis, it is possible to develop an overall measure of the level of a shortage. Gasoline sales in New York State for June, July, and August 1979 were down 12, 11, and 9 percent, respectively, from the corresponding monthly totals in 1978, and the percentage decline for the entire three-month period in comparison with 1978 was 10.5 percent. Changes in fuel use during the shortage are attributable primarily to two factors: (a) changes in the average fuel efficiency of the fleet and (b) travel reductions (either canceled trips, trips of shorter distances, or the substitution of transit trips for automobile trips). Direct evidence of travel reductions in each part of New York State was available from traffic counts, figures for transit ridership, trends in vacation travel, and survey response data.

Traffic Counts

The availability and comprehensiveness of traffic-count data covering the 1979 summer fuel crisis vary significantly among the geographic areas within New York State. Traffic counts in all areas of the state are available for the 29 permanent counting stations maintained by the New York State Department of Transportation (NYSDOT). Traffic-count information differentiated by weekend versus weekday as well as by time of day is available only for the New York City metropolitan area. Despite the small number of permanent count stations, traffic-count data are instrumental in defining both the overall magnitude of the impacts as well as their distinct geographic variations.

The data reviewed showed that the most dramatic declines in traffic occurred in the New York City metropolitan area, ranging from 11 percent in the city to approximately 18 percent in the suburbs. The percentage declines in the New York City area were exceeded at some count stations located on Interstate highways or other major highway links that primarily attract intercity travelers. Depending on the area, declines from 16 to 24 percent were recorded. Traffic-count stations in urban areas outside of New York City as well as in small urban or rural communities generally recorded only 1-3 percent reductions in traffic during the crisis.

The above traffic-count information is based on 24-h traffic volumes added together and averaged for a month but not differentiated by time of day or day of the week. As noted, some information for New York City does make such distinctions. Where available (primarily for the facilities of the Port Authority of New York and New Jersey), the data show that the sharpest decline in traffic during the crisis occurred at night and on the weekends and that relatively more modest declines occurred during the weekday morning and evening peaks.

Transit Ridership

Although some of the observed decline in local traffic can be attributed to trips not made, some was caused by the substitution of public transportation for the private automobile. Most systems experienced increases in ridership, which ranged from a high of approximately 20 percent for the New York suburban buses and Albany-Schenectady transit to 6 percent for Buffalo transit.

Although transit data are available for all operators throughout the state, they do not differentiate the increase in transit ridership either by time of day or day of the week. As a result, it is necessary to assume that the overall figures are representative of changes in specific types of transit trips--e.g., work trips and shopping trips. On the basis of such an assumption, the portion of observed travel reduction attributable to increases in transit ridership can be estimated. Thus, even though the available transit data lack desirable detail, they are capable of being related to base-case travel conditions within New York State.

Trends in Vacation Travel

Changes in vacation travel accounted for a greater share of the observed travel reductions during the 1979 crisis than they did during the 1973 situation, since the 1979 crisis occurred during the peak vacation season. Data are available on both park attendance and resort occupancy to show the magnitude of the impact on vacation travel during 1979.

Aggregate figures show that overall statewide park attendance was down by 4.2 percent in 1979 from 1978 and attendance at selected attractions throughout the state was down 22 percent during the comparable period. These data are limited in usefulness, since they cannot be readily translated into estimates of travel reduction.

Some of the resort-occupancy data, differentiated by vacation area, show that while statewide occupancy decreased by 2 percent in 1979 compared with 1978, occupancy increased at facilities near major metropolitan areas but fell off in the most remote areas. For example, occupancy at resorts on Long Island increased by 4.4 percent in 1979 over 1978 whereas in the Adirondacks it decreased by 9 percent. In contrast to statewide figures on park attendance, the disaggregate resort-occupancy information, which shows the tendency to substitute shorter- for longer-distance trips, can be used in conjunction with traffic-count data to account for the portion of travel reduction attributable to changes in vacation travel. Once this is accomplished, the data can be related to base-case travel conditions within the state.

Survey Response Data

The final evidence regarding travel adjustments during the crisis is provided by a survey of households in New York State taken in October 1979 (1). The objective of the survey was to determine what types of actions households selected during 1979 to cope with the situation. The data are particularly useful because they can be summarized not only on a statewide basis but also for specific geographic regions. Such disaggregation demonstrates clearly the varying nature of the crisis as well as the adjustments selected.

The results showed a clear ordering of response preference during the crisis in which shopping actions and minor changes in driving habits and car maintenance dominated. In fact, approximately 47 percent of the households polled said that they initiated trip chaining for shopping, and 42 percent said that they reduced their driving speeds in response to the crisis. Vacation-related changes were second in priority as adjustment strategies: Approximately 17 percent of the households took their vacation closer to home, 16 percent took public transportation for their trips, and 16 percent canceled vacation plans. Other strategies adopted by a slightly smaller share of the households were purchases of new fuel-efficient cars and work-travel adjustments. Strategies such as relocation of either home or job, elimination of recreation vehicles, or walking to work were substantially less popular.

The survey information has some significant limitations. For example, it cannot be translated directly into specific travel reductions, since it does not give an indication of how many shopping trips households eliminated or how much travel was involved. The information cannot stand on its own but must be used in connection with the other data sources on travel reduction. The survey information is valuable in that it demonstrates household preferences in selecting the type of trip activity to reduce during a crisis. Thus, it can be used to interpret observed reductions in travel and allocate these reductions to specific trip purposes as well as geographic areas.

Another weakness of the information is that it does not separate changes that would have occurred anyway from the ones directly attributable to the crisis. Thus, although 15 percent of the households said that they bought new fuel-efficient cars, it is probable that most of the households would have purchased the vehicles anyway as part of the general trend in car purchasing established before the crisis.

Summary

The combination of available data sources documenting the impact of the 1979 crisis does not answer all the questions about the magnitude of the travel reduction or the extent to which particular types of trips or geographic areas were affected. Data gaps exist because of incomplete documentation of travel behavior during the crisis. Nevertheless, the data that are available provide the basis for demonstrating the manner in which base-case travel conditions in New York State were altered by the crisis. The focus of the next section of this paper is to show how the base-case travel condition framework was developed to demonstrate how all the data regarding travel changes during the crisis (summarized in this section) were related to that framework in order to develop a model of the 1979 crisis and future energy emergency scenarios.

OVERALL FRAMEWORK FOR ASSESSING ENERGY EMERGENCIES

Available data on observed travel-behavior changes from the sources outlined in the previous section were integrated to the extent possible to ensure consistency and were related to an overall framework of base-case travel conditions in New York State. The framework consists of information concerning the amount of fuel consumed and vehicle miles traveled in the various geographic areas within the state for various trip purposes, both on weekdays and on the weekend, for local and intercity travel.

By applying the percentage declines in travel observed during 1979 to the range of base-case conditions, a statewide model of the 1979 summer crisis was derived. Furthermore, the effects on base-case travel conditions of other situations more or less severe than the one in 1979 were modeled in a similar fashion. The 1979 crisis model and its variations (scenarios) provide a quantitative basis for measuring the impacts of different energy emergencies on New York State. In particular, they provide an overall approach for measuring the effectiveness of public and government actions to replace the mobility that is lost during energy emergencies (as described later in this paper).

Base-Case Control Totals

The base-case travel framework consists of vehicle miles of travel (VMT) control totals that reflect the relative distribution of travel within New York State. An annual statewide automobile VMT estimate of 64.3 billion prepared by NYSDOT was allocated among local areas [the New York City metropolitan area, eight upstate standard metropolitan statistical areas (SMSAs), and small urban or rural areas] based on previous estimates of differences in VMT within these geographic areas (2). For each area, the VMT total was further distributed between local and intercity travel, among various trip purposes, and between weekday and weekend travel.

The estimate of total intercity VMT travel in New York State was based on data contained in the National Travel Survey (3) on the number and average length of long-distance trips (i.e., trips in excess of 200 miles round trip) in New York State. The estimate for total intercity VMT was 6.71 billion.

The distribution of local automobile VMT by trip purpose and weekday-weekend travel was accomplished by reference to the Nationwide Personal Transportation Study results by city size (4). The local areas of the state were grouped on the basis of size--i.e., large SMSAs with more than 3 million people, smaller SMSAs in various size categories, unincorporated areas, etc.--and the distribution of VMT from the survey results appropriate to their size category was applied. This distribution provides reasonable, statewide trip-purpose estimates that can be adjusted or updated by local-area planners based on more recent or discrete data sources.

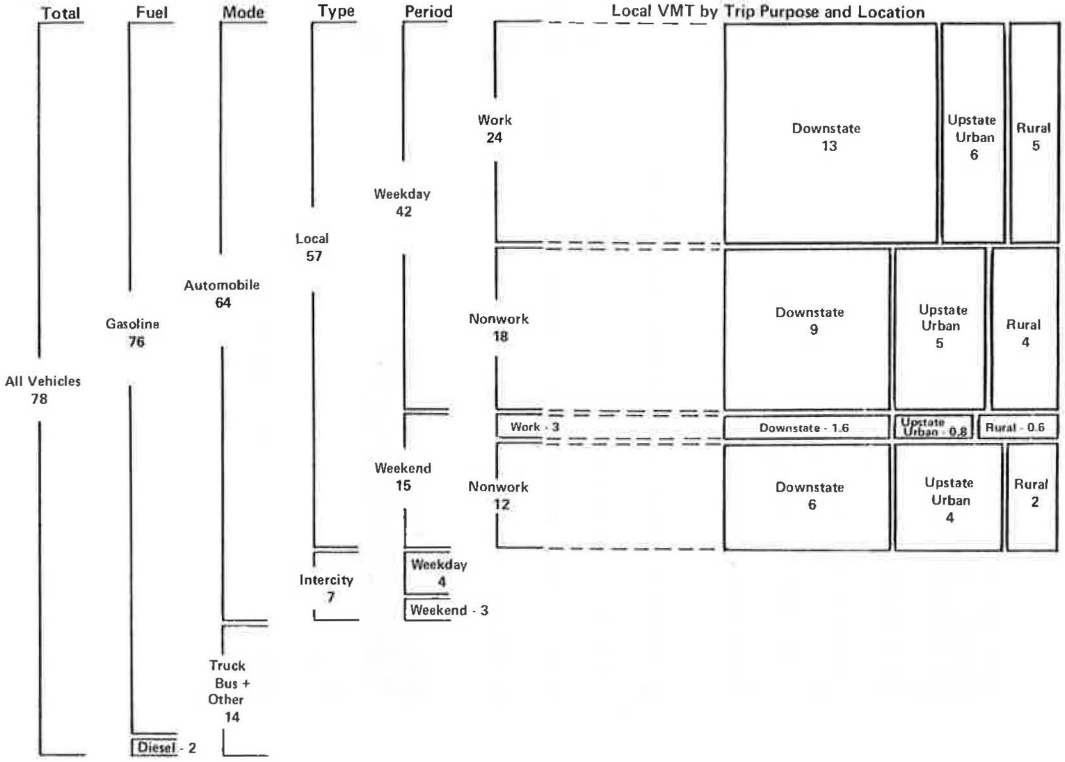
Figure 1 shows the distribution of travel in New York State that resulted from the process described above. These data provide a base-case travel framework, including automobile VMT control totals for each area of the state. The framework highlights the following key travel relations, which are important in assessing the changes that occur during energy emergencies:

1. Gasoline-powered automobiles and trucks will be the key types of vehicles affected by future energy emergencies, since they account for 97 percent of vehicle travel in New York State in 1979.
2. Local automobile travel constitutes approximately 90 percent of total automobile VMT; the remainder is categorized as intercity travel.
3. Approximately 75 percent of local automobile travel occurs on weekdays. Work-related trips account for more than half of local weekday automobile travel.
4. In contrast to local travel, a higher proportion of intercity travel occurs on the weekend. Both intercity travel and total weekend travel are oriented to activities other than work.
5. In all categories of local travel (i.e., weekday work, weekday nonwork, weekend work, and weekend nonwork), a majority (51 percent) of the VMT occurs within the downstate areas; the remainder is split between upstate urban areas (29 percent) and rural areas (20 percent).

Energy Emergency Model

The combination of all available data regarding public response to the 1979 shortage was used to develop an energy emergency model of New York State

Figure 1. Distribution of vehicle travel in New York State in 1979 (billions of VMT).



(i.e., temporary three-month gasoline shortage of 11 percent accompanied by price increases of about 20 percent). The situation assumes no active government intervention beyond "public-order" types of action such as odd-even purchases, minimum purchases, and special allocations from the state set-aside supply. The further assumption made is that the entire 11 percent shortfall is accounted for by VMT reductions resulting from trips not made, trips of shorter distances, or trips made on public transportation. The VMT reduction factor caused by the purchase of more fuel-efficient vehicles can be treated separately from travel reductions (as shown in the following section of this paper).

By using the available data, the percentage declines in VMT over the base-case conditions were calculated and used to distribute the statewide shortage among the various planning categories by trip purpose and by weekday versus weekend travel. These percentage declines in travel are shown in Figure 2. Although the estimates were based on the three-month experience during 1979, the data are presented on an annual VMT basis.

A more detailed review of reductions in weekday work-trip VMT, including the impact of transit and nontransit actions for different areas of the state, was conducted. It showed, for example, that weekday work-trip VMT in New York City declined by 9 percent, 5 percent of which was attributable to the observed increase in transit ridership. Although no specific data were available, the savings in nontransit work-trip VMT were attributed to ridesharing (carpooling), assuming people continued to make the trip and that other alternatives such as walking or temporary relocation were not widely adopted. Thus, the total decline in weekday work-trip VMT was 1.9 billion, of which 75 percent, or 1.4 billion, was attributed to carpooling.

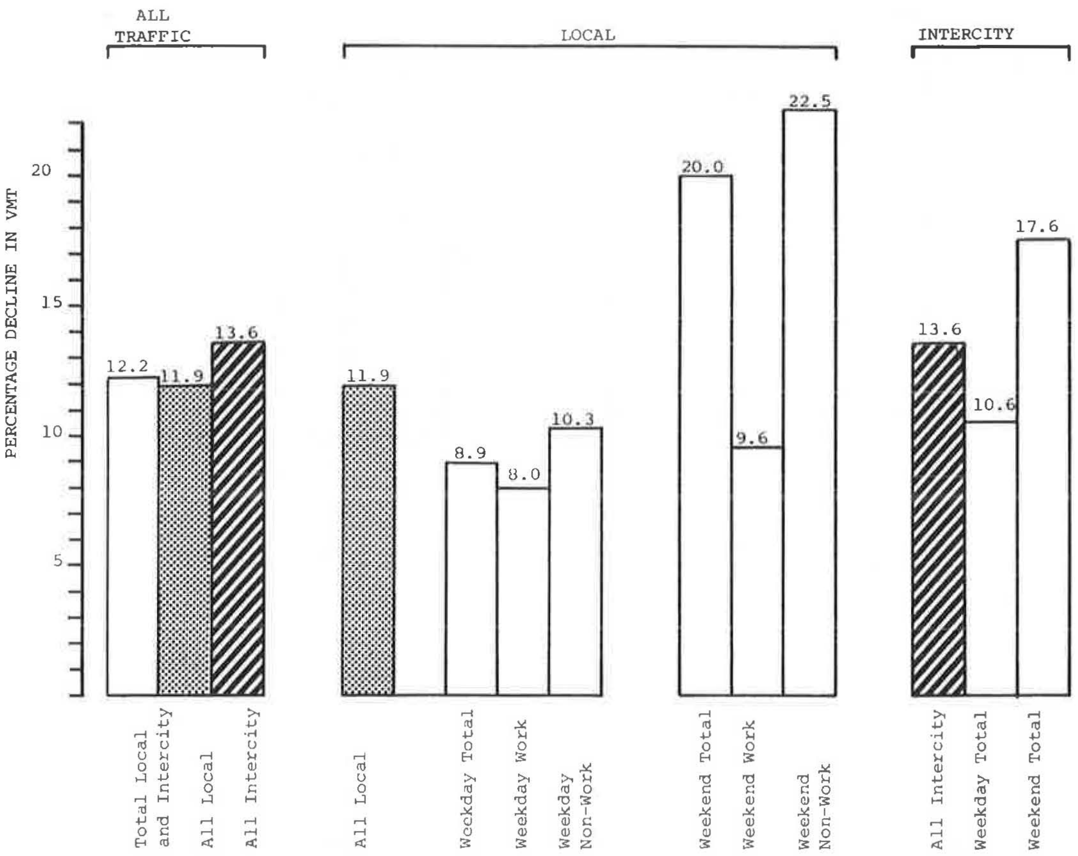
In New York City, 56 percent of work-trip savings was attributable to transit and 44 percent to carpooling. In contrast, the comparable figures for Long Island were 17 and 83 percent, respectively. The same dominance of carpooling held true for both the upstate SMSAs and the small urban and rural areas. Carpooling in these areas accounted for 89 and 99 percent, respectively, of the savings.

Scenarios

The model of travel reductions resulting from public responses to a real 11 percent shortage in New York State served as the basis for two additional energy emergency scenarios of 8 and 20 percent shortages. The underlying assumptions for these additional scenarios are as follows: (a) If the current gasoline allocation system remains unchanged, the distribution of fuel shortages in the future is likely to be similar to the pattern that occurred in 1979 (5), and (b) the public is likely to rely on past experience as long as shortage levels do not exceed those encountered in 1979 but will probably begin to modify behavior as shortages increase in size and duration beyond those levels.

The first type of scenario addresses the situation in which it appears to the President that a fuel shortage is imminent but is not yet apparent in the fuel supply system. In such a situation, the President may establish mandatory emergency conservation targets for each of the states pursuant to the Emergency Energy Conservation Act of 1979. It is felt by the federal government that, if enough fuel can be conserved by meeting these targets, a lesser shortage will occur in the future than if conservation efforts were not applied before the shortage occurred at the gasoline pumps. The reduction target would be established, a state would have 45 days to submit a plan, and the U.S. Department of Energy would monitor a state's efforts to comply with the target over the next 12 months. Failure to prepare a state plan or meet the target

Figure 2. Percentage decline in automobile VMT in New York State during 1979 summer fuel shortage.



means that federal travel-restriction measures could be imposed on a state.

The second type of scenario envisions a more serious, longer-term shortfall that could occur as the result of a very severe curtailment of oil imports (e.g., a blockade of the Persian Gulf or destruction of the oil fields) or that could evolve as a result of a worsening of the conditions during a temporary 11 percent shortage. Under this scenario, the shortages and price increases would be severe and would be sustained on a national basis, making decisive and effective federal actions necessary. Public perception would be characterized by a high level of belief in the urgency of the problem accompanied by widespread demand for direct government intervention to ensure that gasoline is distributed fairly. The level of shortage was set at 20 percent for this scenario. A shortfall of 20 percent in all fuels is the "trigger point" identified for a federal rationing program.

For purposes of discussion in the remainder of this paper, the three scenarios can be briefly described as follows:

Scenario	Condition
A	Mandatory target of 8 percent reduction in gasoline use
B	Temporary 11 percent gasoline shortage
C	Long-term crisis with 20 percent gasoline shortage

Forecasts of Travel Reductions

Forecasts were developed of the VMT reductions by area, trip purpose, and time of the week that would occur because of responses to each scenario. The statewide results are shown in Figure 3. For purposes of comparison, the VMT reductions for all three scenarios are on an annual basis. Similar forecasts were developed for each local area of the state by scenario.

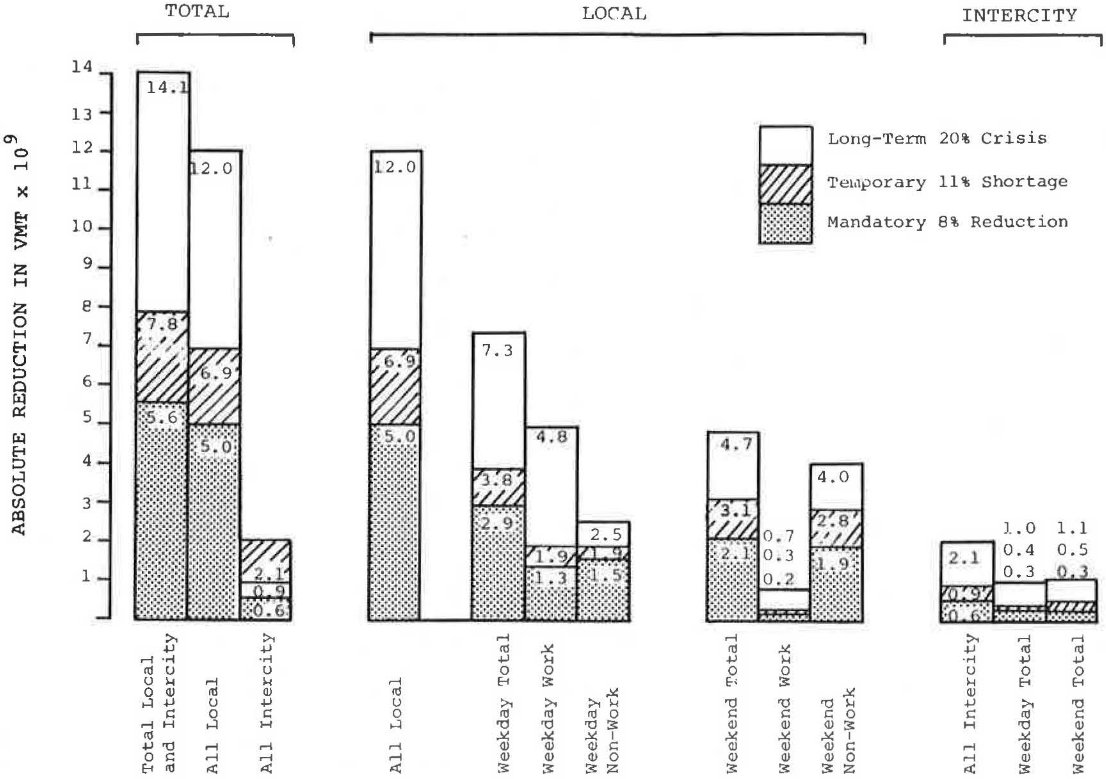
The bar graphs in Figure 3 demonstrate that the magnitude of VMT reductions under scenario C are significantly greater than are the reductions under either of the other two scenarios. Local travel rather than intercity travel accounts for the greater part of the VMT reduction under all scenarios.

There are also distinct differences among the three scenarios in terms of the relative reductions in VMT predicted by type of trip and day of the week. In scenario C, weekday travel (particularly weekday work travel) accounts for proportionately more of the total VMT reduction than it does under both other scenarios. Weekday work travel would account for 34 percent of the total statewide VMT reduction under scenario C but only 24 percent of the total under scenarios A and B. This will occur because people will concentrate on cutting their discretionary (nonwork) travel during temporary or minor shortages but will seek more fundamental changes in their means of work travel under longer-term shortfalls. By doing so, they can preserve more of their discretionary travel.

Summary

Available data from past energy emergencies and base-case VMT control totals can be used to develop a model of the type, magnitude, and distribution of statewide and local-area travel changes in response to a temporary 11 percent gasoline shortage. The

Figure 3. Immediate reduction in automobile VMT in New York State under three scenarios.



model can be varied to reflect different emergency scenarios in terms of severity, duration, fuel price, public policy, and other characteristics as well as likely public responses to these scenarios. Importantly, the model and scenarios provide a comprehensive basis for determining the mobility loss and other impacts suffered by the citizens, economy, and local areas of New York State during energy emergencies.

RELATIVE EFFECTIVENESS OF DIFFERENT RESPONSES IN MAINTAINING MOBILITY

New York State residents and businesses will face enormously different levels of adversity and hardship during future energy shortages, depending on whether the most appropriate actions, less appropriate actions, or no actions at all are taken. The data sources and framework described earlier in this paper provide a mechanism for analyzing the effectiveness of specific actions as well as the relative contributions that different types of overall responses can make in alleviating the negative consequences of energy emergencies.

This section demonstrates how the overall framework can be used to estimate the effectiveness of public responses, government actions, and fleet fuel-efficiency improvements in replacing the mobility that is lost during an energy emergency. Specifically, it focuses on the effectiveness of government action (or inaction) in replacing lost mobility in New York State and the role of government actions as part of an overall response to the three energy emergency scenarios previously described.

Public Response

When a fuel shortage occurs, all of the traveling that people would like to do cannot be done by the means they would normally use. By switching to public transit, carpooling, and organizing trips better, people can maintain mobility while cutting down on vehicle travel. These actions constitute the public response to an energy emergency and will occur even if no government actions are taken.

The estimate of diversion from automobile to transit and carpooling for the work trip during the 1979 summer crisis was used, along with survey data on actions the public might take at greater fuel-shortage and price levels, to estimate public response under different scenarios in comparison with the base case.

Government Actions

During a fuel shortage, additional actions can be taken by government agencies in cooperation with the private sector to help maintain mobility by helping people to use existing services and by providing new or expanded services. Based on a preliminary screening of more than 90 possible actions and the advice of a 40-member Energy Contingency Planning Advisory Group, 27 actions were considered in New York State (6). The actions are grouped below according to the different travel-purpose categories, or "markets", defined in the emergency planning framework described earlier in this paper, where they could be expected to have a significant effect:

1. Work travel--Employer-based carpooling, vanpooling, and subscription bus; mandatory vehicle occupancy; high-occupancy-vehicle lanes; staggered hours; standees on buses; spare transit vehicles; stockpiling of buses; route rationalization; park-and-ride lots; taxis; school buses; parking charges; and bicycle to work;
2. Nonwork travel--Carpool coordinator program, transit to state parks, transit to other recreational sites, and trip planning;

3. Intercity travel--"One-tank" campaign, transit to vacation areas, speed enforcement (55 miles/h), speed-limit reduction (50 miles/h), and intercity bus commuter stops; and
4. Other--Public information, data and management monitoring, and goods movement.

Other actions by governments to maintain order, reduce negative economic impacts, and distribute negative impacts equitably--such as odd-even or minimum-purchase plans, station hours, coupon rationing, a vehicle-sticker plan, tax rebate rationing, and the state set-aside program--were analyzed but are not discussed in this paper.

Not all actions are appropriate for each scenario. Moreover, of the actions that might be possible under any particular scenario, some are more appropriate than others in terms of their effectiveness, costs, required implementation time, and other factors. Finally, some actions may be appropriate but require considerable advance planning and negotiation during one scenario in order to be effective during another scenario. These factors necessitated a further distribution of the 27 actions by scenario.

An analysis of each action was conducted to determine the potential VMT savings for each scenario. Finally, these savings were stated as a percentage of the decline in VMT projected to occur in each travel category and area of the state for each scenario. Together, the total savings of these actions can be shown as the percentage reduction in gasoline use for each scenario that can be achieved without a reduction in mobility.

Improvements in Fleet Fuel Efficiency

During both emergency and nonemergency periods, people buy more fuel-efficient cars and retire older cars, and this results in improvements in average automobile fuel efficiency and mobility. However, the ability to purchase more fuel-efficient vehicles in response to an emergency is limited to the income consumers have available and the ability of manufacturers to alter the fleets thay have for sale. Both factors inhibit this response during short-term (three-month) emergencies.

However, the general trend of automobile purchasing patterns reflects an increasing emphasis on more fuel-efficient vehicles. These trends allow us to project the average fuel efficiency of a state's fleet of vehicles over time. In New York State, such trends show an average improvement in fuel efficiency of 4.6 percent/year between 1979 and 1985 and 3.6 percent/year between 1985 and 1990 (7). During the three-month period in the summer of 1979, improvements in automobile fleet fuel efficiency could have resulted in a fuel savings of 1.15 percent over the fuel consumed in the comparable three-month period in 1978.

Based on these findings, short-term (90-day) and long-term (one-year) fleet fuel-efficiency improvements were included in the calculation of the mobility that is replaced under different emergency scenarios.

Effectiveness of Responses

Figures 4-6 show the effect of public response, government actions, and fleet fuel-efficiency improvements over time on achieving the total reduction in gasoline assumed under each scenario without a reduction in mobility. The amount of mobility that must be lost under each scenario is also presented. The impacts of each response after 90 days and after one year are shown. It was assumed that the public's responses and the appropriate actions by governments and private employers could reach their full potential for replacing lost mobility within 90 days. The effects predicted are those that will occur if all appropriate responses are made.

These figures demonstrate that, in the short term (90 days), a coordinated consumer and government response can replace up to 57 percent of the mobility lost due to the shortage. Over the long term (one year), the mobility added by fleet fuel-efficiency improvements can increase this amount to about 80 percent. The role that government actions can play in maintaining mobility during an emergency is significant but less than what the public will do on its own and substantially less than the effect of fleet fuel efficiency over time. The government actions that are predicted to achieve the best results in replacing lost mobility are those that open up more of the travel opportunities that New York residents demonstrated they desired during the 1979 energy shortage.

Figure 4 assumes a federally mandated target of 8 percent reduction in gasoline use and shows a prediction of the portion of that target that can be met by each type of appropriate response without reducing mobility. Even though there is no shortage of fuel at the pumps, it is predicted that public and private employers and state and local agencies can take significant actions to maintain mobility while meeting the 8 percent target reduction. The appropriate response will enable New York to meet most of the target (6.4 percent) without adverse impacts on mobility. It is predicted that the public will make up all of the remainder of the 8 percent target (5 percent after 90 days and 1.6 percent after one year) by reducing mobility voluntarily. However, this depends largely on the public's perception of the emergency.

Figure 5 indicates that, during a 90-day period, the portion of an 11 percent shortfall that might be met by all appropriate responses would be 5.9 percent before a reduction in mobility was necessary. However, there is always a shortfall in fuel availability of at least 5.1 percent, and probably greater, that will be met by reductions in mobility during the first 90 days. If the contingency lasts longer than 90 days, continued fleet fuel-efficiency improvements result in substantial additional amounts of mobility being replaced. After a year, all appropriate responses can achieve most of the necessary reduction in gasoline use (9.3 out of 11 percent) without reducing mobility.

If the patterns of shortages observed in 1979 prevail, however, the loss of mobility that does occur after either 90 days or one year will not be distributed equally but will be concentrated in downstate urban and suburban areas. Thus, other actions should be taken at the state and local levels to equalize the remaining burden of the mobility loss as well as to maintain public order.

Figure 6 shows the relative impacts of appropriate statewide responses of each type in a crisis situation (20 percent or greater gasoline shortage). Under this scenario, the public is expected to make much more significant responses in order to maintain mobility so as to achieve a 6.4 percent reduction in gasoline use without reducing mobility. Actions taken by government and private firms to replace lost mobility can account for an additional 3.8 percent of the necessary reduction in gasoline use without reducing mobility. Improvements in automobile fleet fuel efficiency are predicted to be the same as in the contingency, since the public will not have any additional money available to accelerate the purchase of new automobiles.

After 90 days, all appropriate responses to replace mobility will have reduced gasoline use by

11.4 percent before any necessary reduction in mobility. After one year, 14.8 percent out of the 20 percent reduction will have been accomplished without reducing mobility. Thus, only a 5.2 percent reduction in mobility is necessary after one year compared with the 20 percent reduction that would occur if a shortage happened immediately.

At a crisis level of 20 percent shortfall, even if all appropriate responses are taken, and after a year has passed, the amount of reduced mobility that cannot be recovered by appropriate actions will be significantly greater than at the lesser shortage levels (5.2 versus 1.7 or 1.6 percent).

CONCLUSIONS

This paper demonstrates that, despite inadequate data, a useful quantitative framework can be developed at the state level for assessing the impacts of, and developing coordinated responses to, future energy emergencies. The framework consists of documentation of current travel patterns combined with available information on past shortages in order to develop future emergency scenarios for statewide and local-area analysis.

Analysis of statewide energy emergency scenarios can identify what adverse economic and social impacts are likely to occur in different regions and which residents are likely to lose the most mobil-

Figure 4. Impacts of all appropriate responses to mandatory target of 8 percent reduction in gasoline use: results after 90 days and one year.

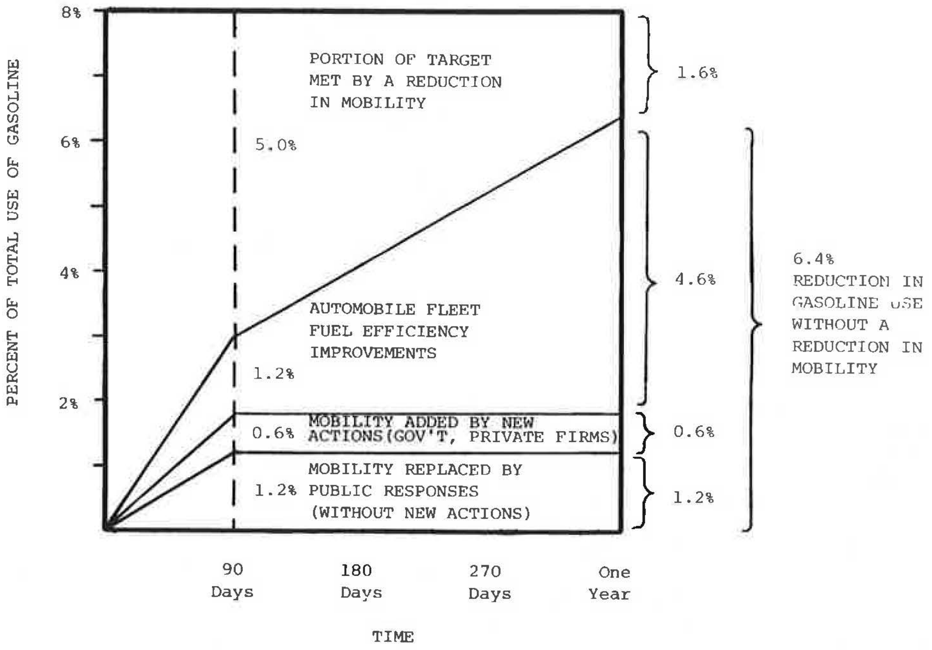


Figure 5. Impacts of all appropriate responses to 11 percent gasoline shortage: results after 90 days and one year.

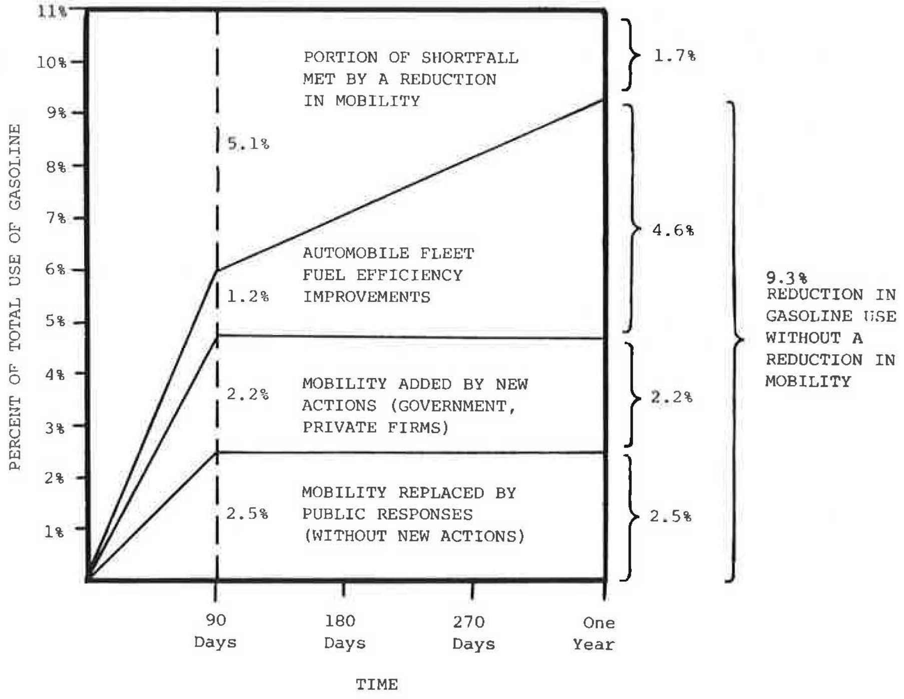
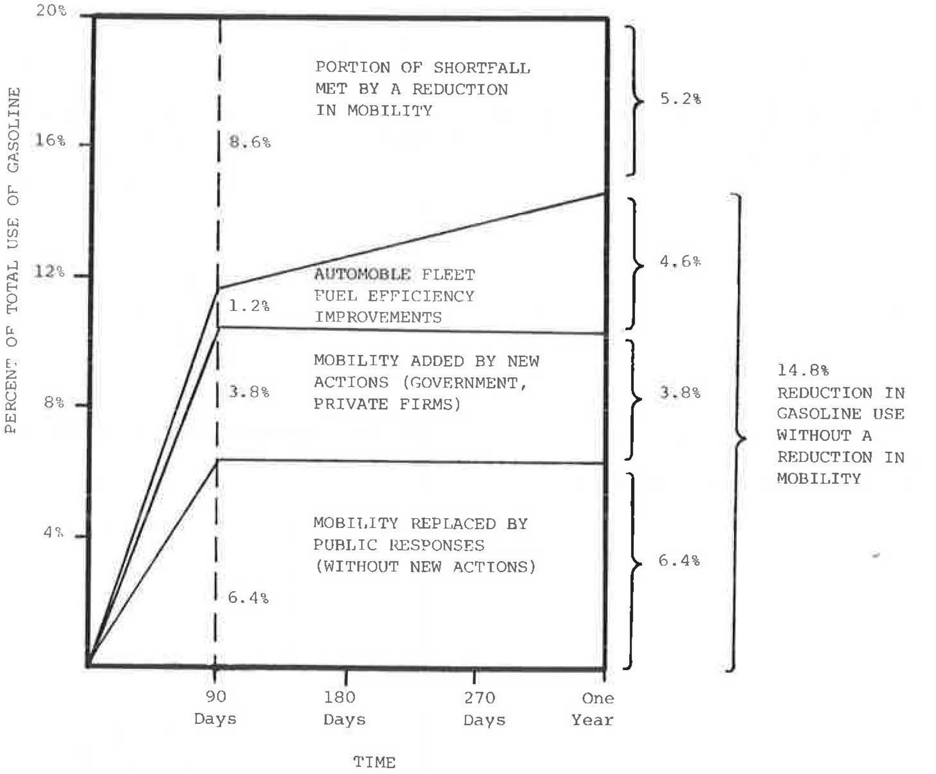


Figure 6. Impacts of all appropriate responses to 20 percent gasoline shortage: results after 90 days and one year.



ity. The framework facilitates evaluation of actions to minimize the adverse impacts of future shortages and can be used to identify how much individuals, business, and government can do together to preserve the mobility that would otherwise be lost.

If government does nothing, the public will make changes in their travel patterns to maintain a significant amount of mobility. If government, in cooperation with business and individuals, takes actions that open up more of the travel opportunities that New York residents demonstrated they desired during the 1979 energy shortage, then about half the mobility lost due to an energy emergency can be replaced within 90 days. The continuing additional impact of fleet fuel-efficiency improvements can help to replace a maximum of 80 percent of the lost mobility over the long term.

ACKNOWLEDGMENT

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

RASIN K. MUFTI AND MICHAEL J. MUNSON

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

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

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

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

RESEARCH OBJECTIVES

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

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

RESEARCH APPROACH

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

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

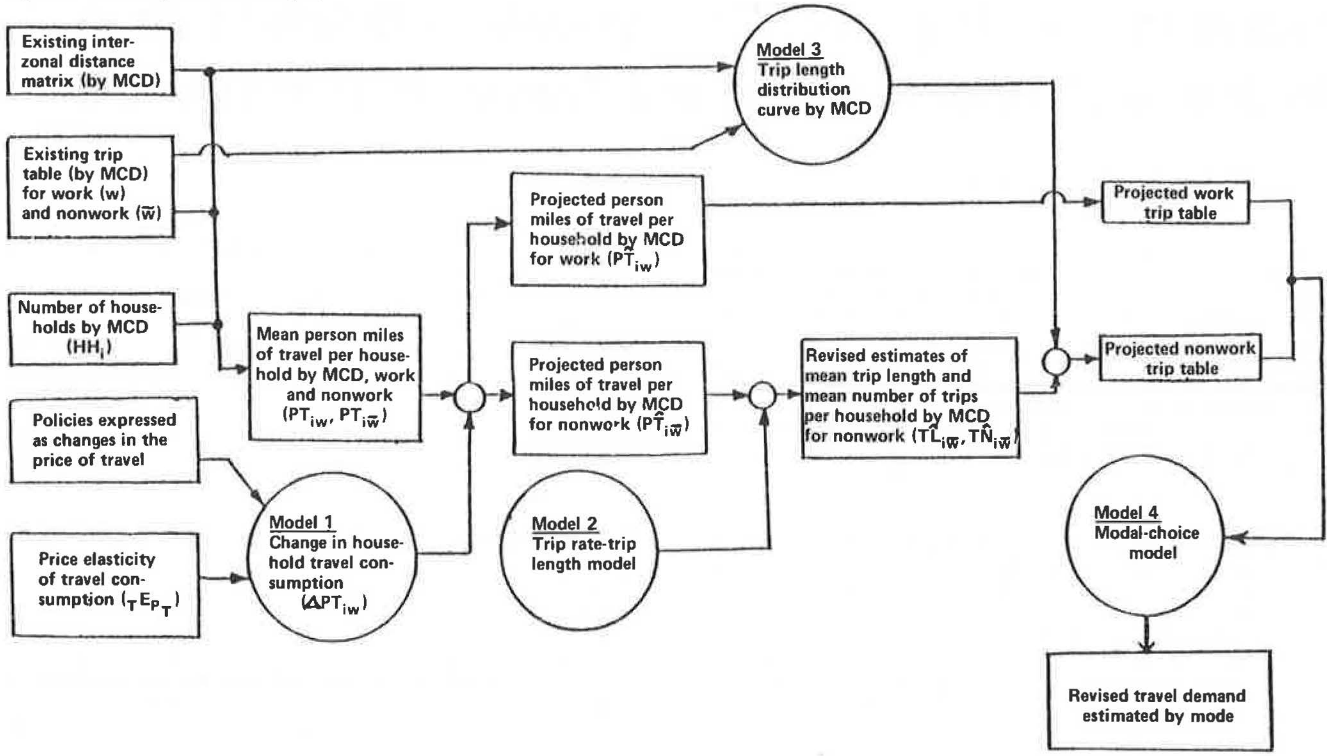
1. Potential energy policies were reviewed, and the likely consumer responses to them were outlined.
2. The likely responses were analyzed in terms of where in the transportation demand forecasting structure they would have an impact (1,2). The conclusion was that energy policies would affect travel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

SIMULATION MODELS

Overview

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

Figure 1. Flow diagram of the analysis.



price elasticity of travel consumption must be available.

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

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

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

Description and Development of Individual Models

Model 1: Total Travel

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

$$PT_i = PT_i \cdot {}_{T}E_{P_T} \cdot \%P_{T_i} \tag{1}$$

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

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

for work travel,

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

for nonwork travel, and

$$\Delta PT_{i,\bar{w}} + \Delta PT_{i,w} = \Delta PT_i \tag{4}$$

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

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

Model 2: Trip Rate and Trip Length

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

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

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

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

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

$$TR_{\bar{w}} = 1.566 + 0.170\,\overline{TL}_{\bar{w}} \tag{5}$$

$$PT_{\bar{w}} = TR_{\bar{w}} \cdot \overline{TL}_{\bar{w}} \tag{6}$$

Thus,

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

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

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

Model 3: Trip Distribution

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

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

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

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

$$\mu = b \cdot c$$

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

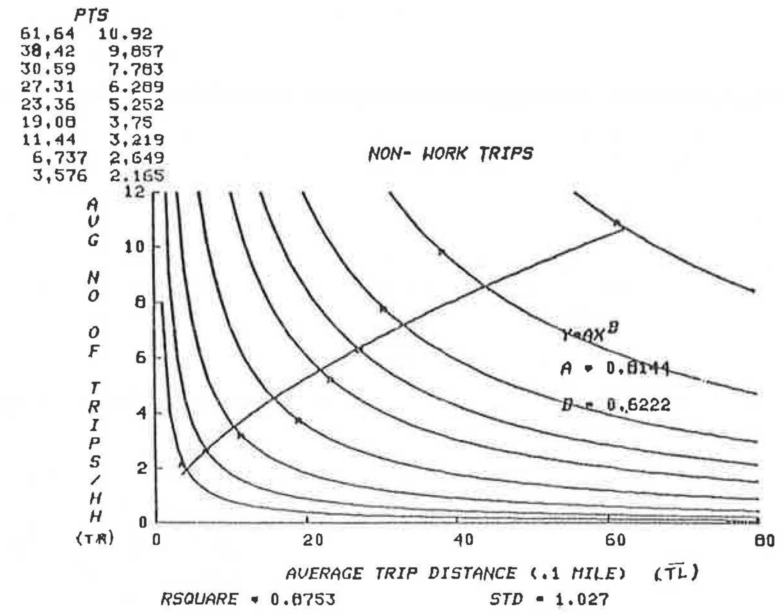


Figure 2. Nonlinear travel consumption path.

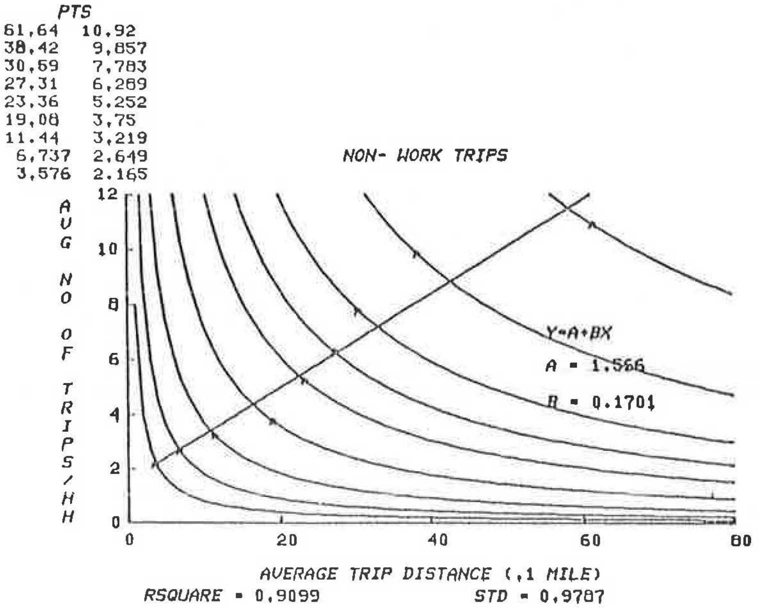


Figure 3. Linear travel consumption path.

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

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

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

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

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

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

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

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

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

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

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

Model 4: Modal-Choice Model

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

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

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

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

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

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

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

SIMULATING TRAVEL RESPONSES TO SELECTED ENERGY CONSERVATION POLICIES

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

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

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

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

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

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

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

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

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

Government-Imposed Gasoline Tax

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

Market Shortages with Queuing

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

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

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

[a] In constant 1977 dollars.

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

Government-Imposed Gasoline Rationing

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

Parking Taxes at Major Destinations

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

Annual Automobile Registration Fees Based on Fuel Efficiency

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

Subsidies to Encourage Carpooling

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

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

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

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

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

Summary

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

SIMULATED IMPACTS OF POLICIES ON TRAVEL BEHAVIOR

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

1. Government-imposed gasoline tax of $0.50/gal--Policy 1, which is very modest, generated a virtually negligible change in travel behavior in the nine MCDs. Total travel declined very slightly, primarily at the expense of the automobile-drive-alone mode. The transit share of total trips tended to increase very slightly. Total automobile person miles held constant while total vehicle miles of travel (VMT) declined slightly. It is apparent that a policy of this magnitude will not generate a substantial change in travel demand. If a gasoline tax is to be effective in generating changes in travel demand, it must account for a much greater proportion of gasoline costs.
2. Market shortages with imposition of queuing discipline--Policy 2 generated a noticeable shift in travel demand among the various modes. The transit share of total trips increased, on the average, by 0.47 percent while the share of automobile drive

Table 2. Policy impacts expressed as model inputs.

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

[a] In selected destination zones.

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

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

Note: B = baseline.

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

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

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

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

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

vere burden on the existing transit system.

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

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

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

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

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

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

SUMMARY ASSESSMENT OF SIMULATION METHODOLOGY

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

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An Assessment of Games as Methods of Providing Information on Gasoline Conservation

DIANNE CABRERA AND DAVID T. HARTGEN

The potential of informal game-type methods of informing conservers about transportation energy conservation is investigated. In an extension of earlier work on activity-based games, four separate procedures are developed that use simple cards and/or playing boards. Energy, money, and mobility impacts of actions are obtained from consumer response data on opinion polls and built into each procedure to varying degrees. The four methods are then tested on a small group of transportation analysts and planners and compared. Results show that the procedures differ widely in playability and realism but are generally well-received and interesting. Although the major use of such tools appears to be as teaching devices, their use as policy analysis and research procedures is also possible. It is concluded that the approach has enough potential to warrant further development.

In light of current economic and energy-related events, U.S. consumers and policymakers must find ways in which to deal with constraints on energy, money, and mobility. Whereas government urges carpooling, use of transit, and driving slower, these methods are not always consistent with the ways people cope (1). Consumers are internally consistent, since they attempt to maintain mobility.

How much personal conservation is possible? According to the Harvard Business School (2), the U.S. could save 30-40 percent of its energy consumption with very little change in life-style if a serious conservation program were implemented. One important factor would be increased transportation vehicle efficiency, both in design and use. Consumers have already moved rapidly in this direction: Average new-car efficiency in New York State in 1980 was 12 percent better than in 1979; this made possible a 4.7 percent cut in gasoline use with only a 0.5 percent cut in travel (3). It seems the public knows how to conserve gasoline.

Conservation options other than those mentioned above are available, but the information provided by government has not had much impact on their use. We suggest that one reason for this failure is that this information is not believable, probably quite boring in presentation, and ineffective. It is the goal of this study to investigate information programs that avoid these problems and that are nonpainful, informative, and highly relevant to current patterns of energy use.

The procedures described in this study have been developed on the principle that nonpainful information transmission is far more likely to be internalized by consumers and retained for future use. The methods generally resemble games based on cards, boards, or other common items but focus on energy-use strategies.

A wide range of realism is, of course, possible by using this approach. By simulating "real life" as much as is feasible, without making the complexity so great as to render the game unplayable, the policy analyst can transmit highly relevant information to the consumer. In this sense, the project is designed to be an educational device to inform consumers of ways in which they can conserve fuel. But, in addition, the procedures can be useful policy research and analysis tools to help policymakers determine and anticipate consumer reactions to various policy decisions or external events. This paper describes procedures developed by the Planning Research Unit of the New York State Department of Transportation (NYSDOT) to fulfill these two objectives.

Games have been engaged in by all cultures for recreation and sport, but as far back as 1780 they were also used to teach military tactics (4), and this use continues today. In addition to military uses, games have been found to have application in business and industry, where they can be a more effective training device than other, more traditional methods because they offer the participant the opportunity to learn by doing and can provide a good deal of practical experience in a restricted time span (3). Applications in education are also widespread.

In transportation, a major center of game-type work is the University of Oxford, England. There, a simple household activity-travel simulator (HATS) (5) has been developed to examine everyday household decision making and behavior. HATS is not a true game but a data-collection device to investigate household activity and travel patterns as well as the manner in which they adapt to the imposition of various constraints. A similar procedure was developed by the Planning Research Unit of NYSDOT to examine how households respond to energy constraints imposed by various government policies (1), and similar devices have recently been reported by Burnett (6) and Brög (7).

APPROACH AND RESULTS

Development

The above ideas suggest further investigation of informal game-like devices for encouraging energy conservation. The primary objective of the study was to develop educational tools. It was felt that the purpose of a policy analysis tool could best be accomplished by other methods. To ensure similarity of basic input data in each design, ongoing work by NYSDOT was used to prepare estimates of the savings and costs associated with energy conservation actions. Table 1 summarizes this work, which is described in more detail by Hartgen and Neveu (8). Estimates of mobility impact are judgmental. This material was used to varying degrees in each of the designs. After initial discussion of the basic components desired in the devices, researchers worked separately (to prevent the "watering down" of ideas that is quite prevalent in committee work). The result was the development of four different designs, which are briefly summarized below.

Designs

The four designs, described briefly below, are (a) Energy Rummy, (b) Calendar, (c) Ring, and (d) Spiral.

Energy Rummy is a card game in which each player shows cards of different fuel-saving actions and "points" (gallons of gasoline saved by each action). There are three levels to the game, each of which is reached by the acquisition of a set number of points. Level 1 requires players to acquire 35 points from the cards before moving to level 2, where 45 more points are needed, and then to level 3, where 55 more points are needed. The first

Table 1. Savings and impacts associated with various energy conservation actions.

		Savings If Action Is Taken		
Category	Action	Energy (gal/week)	Money ($/week)	Change in Mobility[a]
Work	Use bus or subway	6	10	−10
	Carpool	11	15	−8
	Walk or bicycle	1	5	−15
Shopping	Shop closer to home	2	3	−1
	Combine shopping trips	1	2	−1
	Shop less often	2	2	−1
	Use bus or subway	3	2	−5
	Shop on way home from work	2	3	−2
	Carpool	2	5	−2
Car	Buy fuel-efficient car	20	30	−2
	Tune-up	6	10	+3
	Drive slower (55 miles/h)	1	5	−1
	Sell car (do not replace)	20	40	−10
Vacation	Use plane, bus, or train	8	15	−2
	Vacation closer to home	2	10	−3
	Sell boat or other recreational vehicle	1	5	0
	Cancel vacation	5	30	−4
Moves	Move closer to work	8	10	−6
	Change jobs	8	10	−4

[a] Based on minimum value of −20.

player to complete level 3 wins. Also in the deck are "good news" and "bad news" cards that reflect the fluctuation of gasoline price and supply, which change the point values needed for the levels not already played. Figure 1 shows the setup for Energy Rummy. The game is a combination of luck (cards drawn) and skill (card grouping and trading).

Calendar (see Figure 2) is a simple game played with dice and a score sheet. Players roll the dice in turn, and appropriate actions are determined by the roll of the dice. The corresponding saving is based on estimates calculated from the data in Table 1. The object of the game is to save gallons of gasoline over a year's time by (a) making small changes in work, shopping, and social-recreational travel; (b) changing vacation travel; and (c) taking other one-time actions that yield large energy savings, some of which have a high investment cost. Since the game is entirely a matter of luck, learning takes place through repeated exposure to the game results.

Ring (see Figure 3) is a board game made up of three rings of squares and a "win" circle. The color-coded squares indicate the different spheres of life in which the actions may be taken (such as work, shopping, and recreation) and the gasoline saved annually by engaging in the action square. The outer ring is made up of minor actions, such as trip chaining, that save relatively small amounts of gasoline. The middle ring consists of actions that afford greater savings than those of the outer ring, and the inner ring has actions that are major actions in terms of fuel savings, monetary expenditures, and/or inconvenience. The object of the game is to travel around each ring enough times to accumulate the fuel savings and money needed for entry to the next ring and until, finally, entry to the win circle is achieved. The first player to enter the win circle wins the game. The game is primarily one of luck.

Spiral (see Figure 4) is a board game in which a spiral is divided into squares. The players travel around the board, and the first one to enter the center of the spiral wins. Along the way, the players land on different "event squares", which direct them to pick cards representing positive and negative events to which one player or all players must react. In order to meet the changes required on the event squares, the players must play action cards that they were given at the beginning of the game. These cards are played to respond to energy and mobility constraints resulting from event cards. Players must also change the distribution of money in their monthly budget or make changes in their indices for mobility and energy use. The game is useful to the policy analyst because it seeks to determine what type of actions players will or will not play when confronted with the various constraints imposed. It is a combination of luck and skill.

The characteristics of these games are summarized in Table 2.

Survey and Results

The sample size was small (7-10 players/game) and consisted of NYSDOT staff and members of the local chapter of the American Planning Association (APA). This sample was not random but was deemed adequate because the main objective at this early stage in the development of the games was to check on their playability and work the "bugs" out. Since the size of the sample was so small, concrete conclusions regarding the games cannot be made. However, even with this small sample size, general trends might be evident. Clearly, much more developmental work is needed.

A rather small, informal survey was taken after the playing of the games. The technique used was a combination of a brief questionnaire filled out by the player and the verbal responses of the players regarding the games. Table 3 summarizes the results.

Analysis

Generally speaking, all of the games were found to be fairly interesting by the players. However, in terms of challenge, Spiral was found to be more challenging than the other games. While the players of Energy Rummy, Ring, and Calendar found the level of challenge to be too easy or okay, players found the challenge of Spiral to range from adequate to too hard. Spiral requires each player to react to various policies and/or events by making changes in energy and mobility and monthly budget. Since many variables are associated with the decisions, each decision play is time-consuming and demands concentration. By contrast, Ring, Calendar, and Energy Rummy are faster games in terms of length of time devoted to each turn. They are also governed by a good deal of chance rather than deliberate decision making.

The most likely reasons why players found Spiral

Figure 1. Setup for Energy Rummy.

to be a little too challenging at times are that the game requires a good deal of concentration, dealing with many variables, and maneuvering a budget. Yet, in all likelihood, these reasons probably account for the players' feeling that Spiral had more realism and taught them more about energy conservation.

Ring, Calendar, and Energy Rummy depend on the "learning through repetition" technique. By this is meant that the players acquire information not so much by concentrating intensely on each individual energy-saving action as by repeated confrontation with these actions. In Ring, the intention is for the players to travel around each ring several times, thereby associating actions with their respective fuel savings. Players know that fuel can be saved by all the actions on the board and, after repeated playings, they come to learn which actions can save them more than others. The players do not intensely concentrate on the exact amount of gasoline each action saves, but through playings are exposed to and, it is hoped, learn the various methods of fuel conservation, which can then be used in their real lives.

Energy Rummy basically relies on the same principles as Ring to teach its players about fuel conser-

Figure 2. Score sheet for Calendar.

	MONTHLY			Costs (Credits)			CONTINUOUS							Gallons Saved	
	Work	Shop	Soc/Rec	Earned	Used	Bal. Fow'd	Drive Slower	Sell RV/Boat	Tune Up	Move Job	Move Home	Buy F.E. Car	Sell Car	For Month	Year to Date
JANUARY FEBRUARY MARCH															
Spring Fever Weekend															
APRIL MAY JUNE															
4th of July Weekend															
JULY AUGUST SEPTEMBER															
Labor Day Weekend															
OCTOBER NOVEMBER DECEMBER															
Seasons Greetings															
Grand Total Gallons Saved															
% Reduced															

	MONTHLY			
Roll	Action	Work	Shop	Soc/Rec
3	Lose Job	Lose	Turn	
4	Walk/Bike	5	1	1
5	Bus/Subway	15	3	3
6	Carpool	10	1	1
7	Drive Alone	0	0	0
8	Closer to Home	--	2	1
9	Do it less	--	1	1
10	Combine shop/ other	3	3	3
11	Accident	Lose Turn & Gal.		

Must move job before you can walk/bike to work

Must move home before you can use busline.

	HOLIDAY	
Roll	Action	Gal. Saved
2-4	Cancel Plans	8
5-7	Use Train/Plane/Bus	8
8-10	Closer to Home	4
11-12	No Change	0

		CONTINUOUS	
√	Cost	Action	Gal. Saved
	1	Drive Slower	1
	2	Sell RV/Boat	2
	3	Tune Up	4
	4	Move Job Closer to Home	7
	5	Move Home (on Busline)	7
	6	Buy Fuel Efficiency Car	20
	7	Sell Car (Do Not Replace)	30

Figure 3. Game board for Ring.

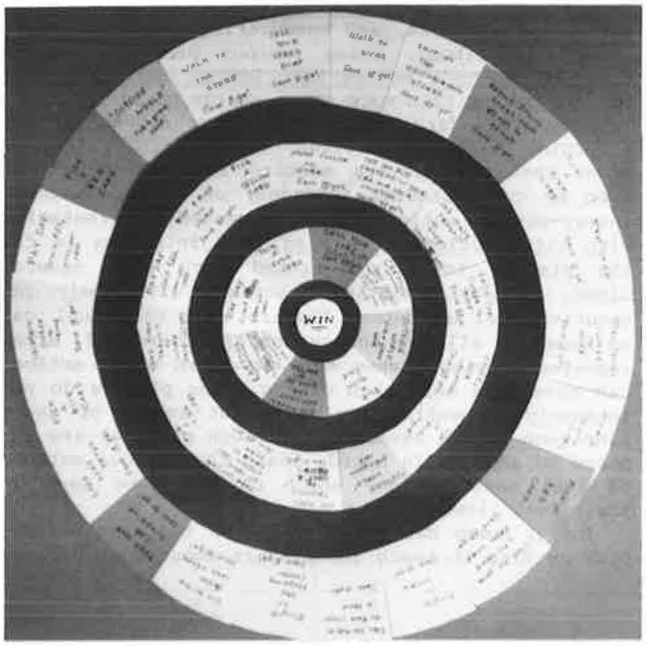
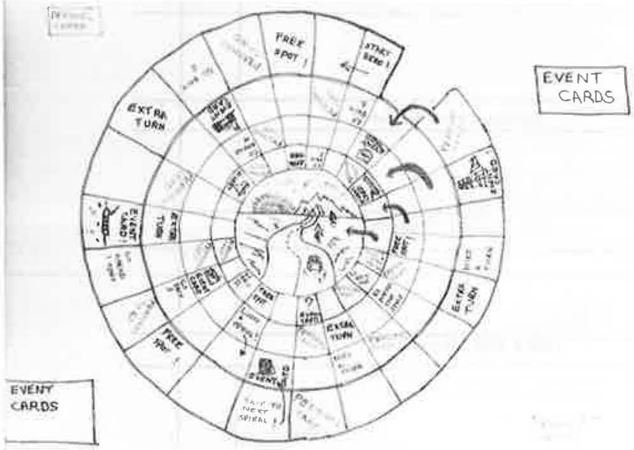


Figure 4. Game board for Spiral.



vation: exposure and repetition. By holding the various fuel-saving action cards in their hands for the length of the game, the players become familiar with actions and their gasoline savings. By repeatedly looking at these cards and using them for the various melds and point requirements in the game, the players realize that those actions that are valuable in the game are also valuable energy-saving actions in the real world.

Calendar, like Ring and Energy Rummy, also operates on the principal of teaching through repetition. The throw of one die determines what type of energy-savings action the player takes. By the repeated throwing of the die to determine which action is to be taken and the energy savings associated with this action, it is hoped that the player learns the significance of this action in his or her own life.

The question appears to be not whether the players learned anything but how much. Although no quantitative answer can be given to this question, responses to the questionnaire lead us to believe that the players did not learn as much as we had hoped. This is true of Energy Rummy, Calendar, and Ring and, to a lesser extent, Spiral. Although Spiral players did feel they learned more about fuel conservation than players of the other games, it is somewhat doubtful that what is learned in any of the games is carried over into real-life situations: When asked whether their responses were "real", most players said yes to all games. The results are inconclusive for possibly other reasons. First, since Energy Rummy, Calendar, and Ring use the principle of repetition to encourage learning, it could be that the games were not played enough times by each player for them to absorb the information and thereby make changes in their life-styles. A number of the sample players were affiliated with NYSDOT and may have been exposed to the concepts the games were trying to convey. Since they were already aware of, and possibly using, many of these fuel-saving actions, they may have learned little else that was new to them and thus reacted in much the same way after playing the games as they did before.

Up to this point, our main concern has been the educational value of these games to the players. Now, focus is given to the value of the games to the policy analyst.

From the data collected on the games, Energy Rummy, Ring, and Calendar appear to have limited value as policy research and analysis tools. These results were expected. As mentioned previously, these games, as they were envisioned by their creators, were to serve primarily as an educational device for the players and last, if at all, as a research tool.

Energy Rummy, Calendar, and Ring are not very close approximations to reality; therefore, the player's main objective is planning his or her optimal strategy to win the game, and this strategy may or may not be similar to one that may be used in real life. For example, a player may sell his or her car in the game with little hesitation because by taking this action he or she can win the game. However, in real life, a player may not be as quick to sell his or her car as in the game situation. This means that game actions are not necessarily indicative of actions that will be taken in real life, and little can be learned by the policy researcher in watching Ring, Calendar, and Energy Rummy.

Spiral, however, is another matter. Our data substantiate the fact that this game has greater potential as a policy analysis tool, as was intended by its developer. By watching decisions about actions and budgets, the researcher can see how consumers will react to various policies and events. The researcher may also "stack the deck", to evaluate selected policies. For example, as players react to a gasoline shortfall, within financial constraints, mobility can be studied. The researcher may find that players are quick to take money out of their recreation budget but are hesitant to engage in major fuel-saving actions that will restrict their mobility or require large capital outlays, such as moving closer to work. Under a policy that results in an increase in money or gasoline supply, the researcher may find that the players are quick to dispense with minor actions such as slower driving and tune-ups.

Overall, Spiral was the only game out of the four that could have major value as a data-collection tool. All of the games, however, have potential as educational devices.

CONCLUSIONS

Is the game approach to disseminating and collecting information a worthwhile endeavor? At this writing, given the limited amount of research that has been

Table 2. Characteristics of four energy conservation games.

Game	Pieces Required	Goal	Character	No. of Players	Primary Objective
Energy Rummy	Cards	Save gasoline	Mostly luck	3-4	Education
Calendar	Score sheet	Save gasoline	Luck, skill, and balance	2-3	Education
Ring	Board, playing pieces, dice	Save gasoline and money	Luck and skill	2-3	Education
Spiral	Board, playing pieces, dice	Maintain mobility	Luck and skill	2-4	Education and policy

Table 3. Summary of evaluation of energy conservation games by players.

Characteristic	Energy Rummy	Calendar	Ring	Spiral
Interesting	Yes	Yes	Yes	Yes
Competition between players	Yes	Yes	Yes	Yes
Responses real	Yes	Yes	Yes	Yes
Playing pieces	Hard to read	OK	OK	OK
Time needed to play	OK	OK	OK	Too long
Clarity of rules	OK	OK	Confusing	Confusing
Challenge	OK	Too easy	Too easy	Too hard
Realism	Good	Too simple	Too complex	Too complex
Teaches about energy	No	Partly	Partly	Yes
Cooperation between players	None	None	Some	Some
Overall view	So-so	Good	Good	Too complex
Market price ($)	1.50	3.00	3.00	5.00

done on these particular designs, the project has enough potential and was met with enough enthusiasm by staff and the game players to warrant further development. Although other methods may be as effective as methods of information transfer, this approach offers a unique experience to both the players and the researcher in that it affords a light, informal atmosphere for the give-and-take of ideas. The approach enables all of those concerned to get actively involved in a potentially useful learning situation and quite possibly will reach segments of the population that will not be reached by other methods. The results were not as positive as we could have hoped for, but they certainly were not so negative that the project should be scrapped. Further development and refinement are necessary before a final decision on the value of the project is reached.

Energy Rummy, Calendar, Ring, and Spiral have a number of potential uses:

1. They can be incorporated into classroom activities beginning in elementary school to teach children, the fuel consumers of the future, the benefits of conservation.
2. They can be used in conjunction with traditional teaching methods in courses such as driver education.
3. It has been suggested that they could be reconstructed simply and cheaply as supplements in local newspapers and thus provide an inexpensive and entertaining means of educating the public to conservation measures.
4. Spiral has potential value as a policy research and analysis tool, to educate the policymaker to the ways in which consumers cope with constraints on energy, money, and mobility.

Overall, despite the fact that all of the games can stand improvements, they all warrant further refinement and development. Whether or not the difficulties encountered in these games can be worked out is not yet clear. Whether the purposes of this project could be better accomplished by other methods is also unclear at this point. What is clear is that the games need to be played more and possibly revised before any definite conclusions as to their value are established.

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