

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<sup>3</sup>. The interior volume of the equivalent 1977 vehicle was 129 ft<sup>3</sup>. [The Environmental Protection Agency (EPA) defines a large car as a vehicle with more than 120 ft<sup>3</sup> 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.

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 1. Downsizing of a large car.

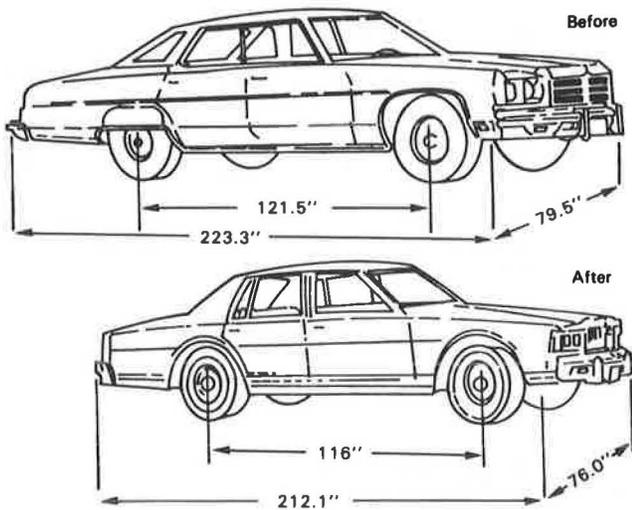


Figure 2. Major components of automobiles with rear-wheel and front-wheel drive.

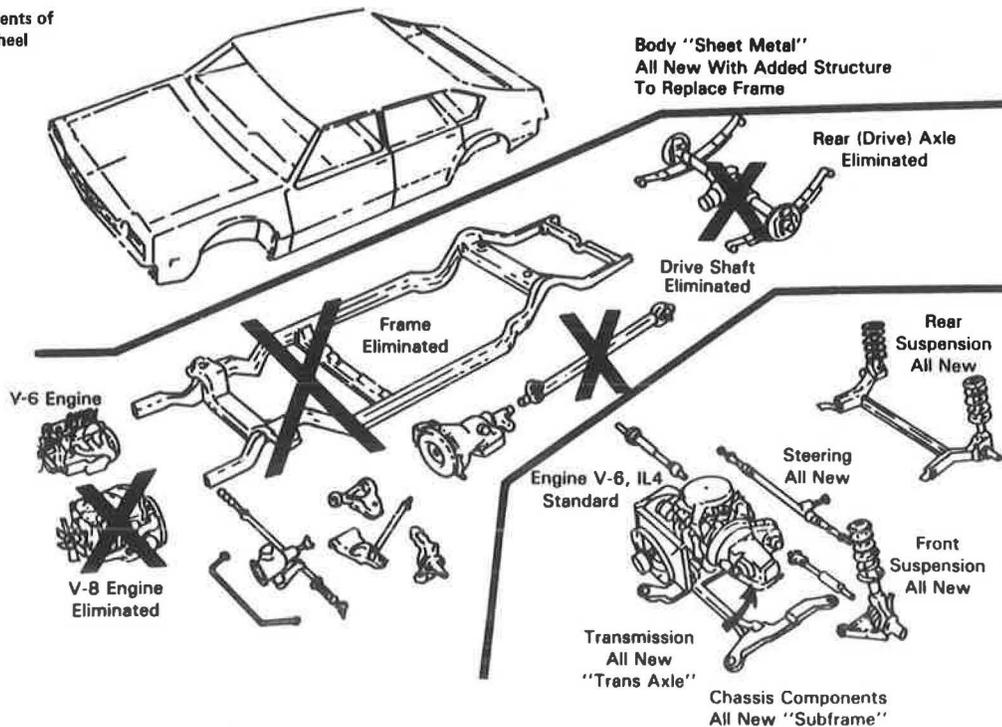


Figure 3. Material composition of typical automobiles.

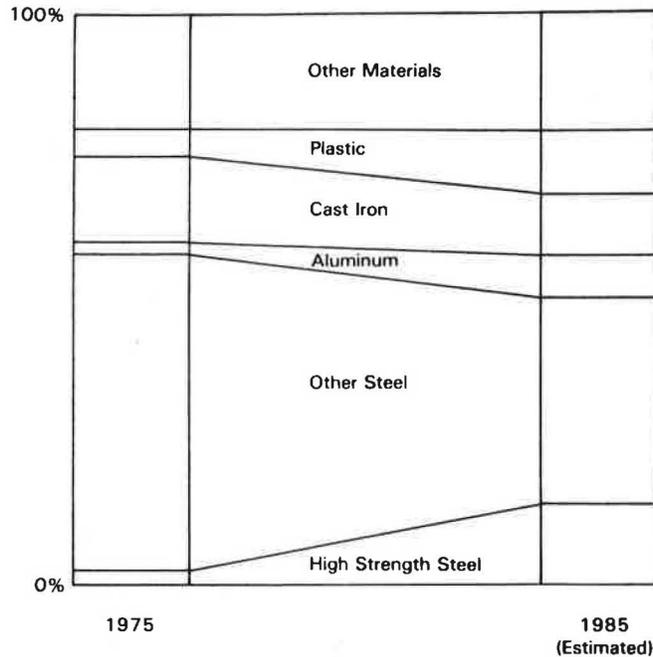


Figure 4. Average inertia weight of new automobiles.

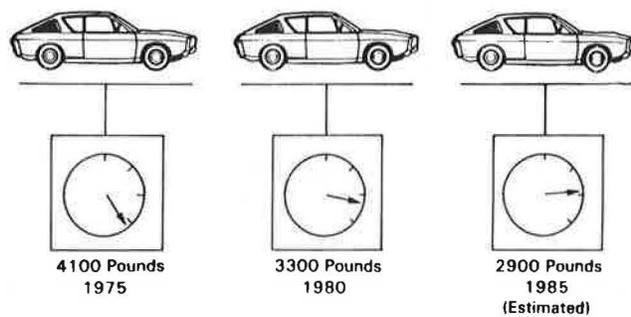


Table 1. Average inertia weight of automobiles by size class.

Year	Weight (lb)			
	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.

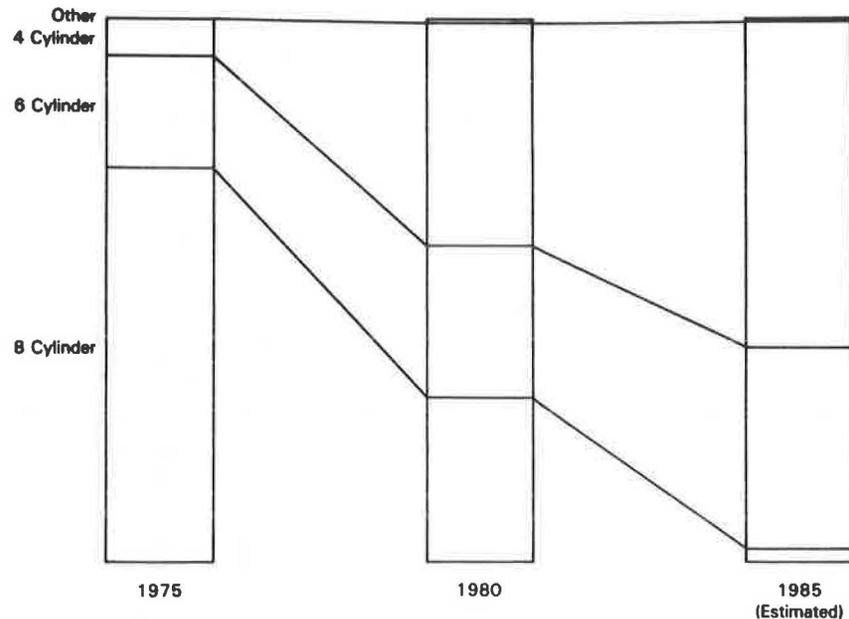
It is expected that by the mid-1980s some automobiles (and some light trucks) may be powered by electricity. GM has announced that it may offer an electric vehicle in 1985. The market share of the electric vehicle is difficult to predict, since it will be highly dependent on its cost relative to that 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 applied 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 =  $1 / [(0.55 / \text{urban fuel economy}) + (0.45 / \text{highway fuel economy})]$ .] 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.

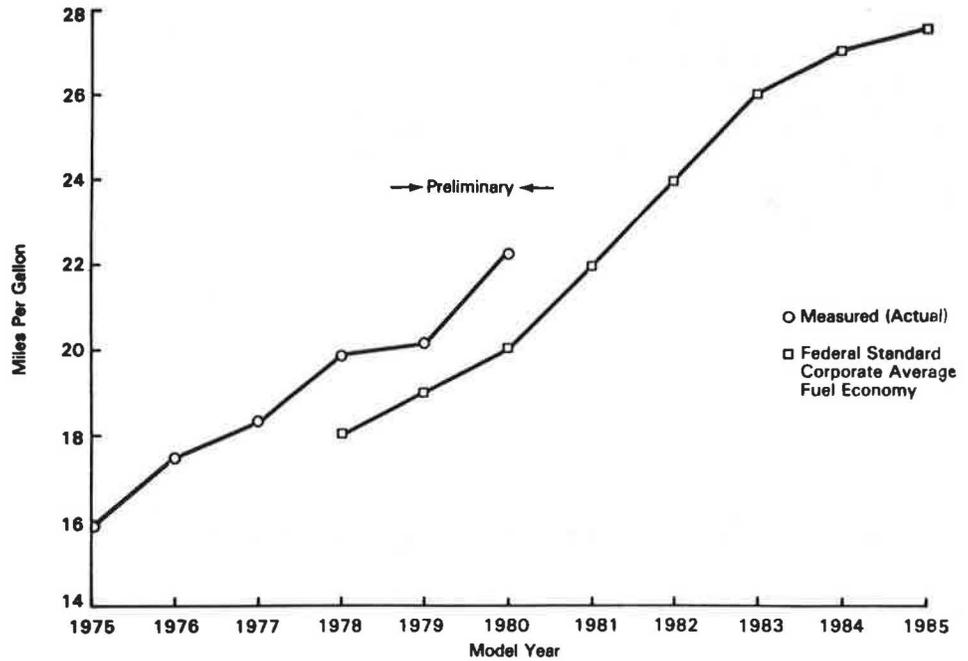


Table 2. Average fuel economy of automobiles by size class.

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

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 proba-

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

bly 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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*Notice: The Transportation Research Board does not endorse products or manufacturers. Manufacturers' names appear in this paper because they are considered essential to its object.*

## 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 disagree-

gated 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 comprehen-