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Approach to Assessing the Impact of Energy Conservation Policies on Transportation Demand

Rasin K. Mufti* and Michael J. Munson, Princeton University, Princeton, New Jersey

The federal government and many state governments are considering a number of policies that will alleviate the impacts of fuel shortages. To the extent that these policies deal with the use and supply of motor fuel they may have important impacts on transportation systems. This paper examines a number of energy-conservation policies and assesses, at a general level, their likely transportation impacts. The ability of existing transportation modeling techniques to rigorously assess the impacts of these policies is also examined. In particular, where available modeling devices appear unable to deal with the impact of energy policies on the overall demand for travel and on the choice of mode, preliminary suggestions on revisions to the models are offered.

The oil embargo of 1973-1974 generated the first serious curtailment of energy supplies in the United States. The Northeast, which is particularly dependent on petroleum fuels, suffered more intensely than did other parts of the country. The difficulties were manifest in terms of gasoline shortages, lines at filling stations, rapid escalation of fuel prices, and an inability of the supply of natural gas to meet demands as consumers shifted from petroleum to gas as a fuel source. The crisis subsided somewhat when the embargo was released, but for the first time the United States became aware of the critical aspects of diminishing supplies of all types of energy sources. Since that time a number of federal programs have been proposed or enacted (a) to reduce the consumption of the nonrenewable energy sources and (b) to reduce the dependency of the nation on foreign supplies of energy. Examples of this are Project Independence and the National Energy Conservation Act of 1974.

Several studies have been made of the estimated impact of these federal programs on the overall consumption of energy and on the various sectors of consumption. These studies have necessarily been aggregate in nature and have not gone into the detailed aspects of how the reductions in consumption would actually take place or the kinds of behavioral consequences associated with various programs. This paper examines these energy-related policies in the context of the state of New Jersey and anticipates the consequences in terms of travel behavior.

Changes in the availability and cost of energy, particularly gasoline, will have consequences on the ways in which people travel. If energy policies are going to have major consequences on individual travel behavior and the demand for various kinds of transportation services, an estimate, in advance, of the kinds of transportation services that will be needed is necessary. Steps to provide those services will have to be taken so that they will be in place and usable as the demand materializes. This paper lists possible energy policies and describes some of the possible behavioral responses to them as they relate to transportation. A number of individual and group responses will be examined and their potential impact on the provision of and demand for transit services will be discussed. Some of these responses represent a marked break from transportation and travel behavior of the past and, therefore, make formal modeling and analysis somewhat difficult. Traditional models used for forecasting transportation demand are described, and the ability of these models to accommodate energy policy responses is explored. Finally, modifications to existing modeling devices are explored and new ones are suggested that will allow a more rigorous analysis of the impacts of these policies on transit demand.

ENERGY POLICIES AND TRANSPORTATION RESPONSES

Some energy policies affect overall travel and others affect the distribution of trips among various travel modes. Potential energy policies can be grouped into seven general classes, depending on the way in which they directly change the transportation system. Within each class fall a number of individual policy actions that various levels of government might consider as ways of reducing or curtailing the consumption of energy by transportation. The policy components of each class are indicated in Table 1.

The effects of these policies on the transportation system can be grouped into a small number of responses by travelers. In the most basic sense, consumers of transportation services can respond to the various policy actions by simply deciding to travel less; that is, by making either fewer or shorter trips. Consumers may also decide to change their modes of travel, at least for some trips, or to acquire more energy-efficient automobiles so that the same amount of travel can be made with less fuel. Another possibility is relocation so as to have fewer travel requirements. Finally, some travelers may find that public policies cause them to change the daily pattern of their trip making and thus modify patterns of peak-hour travel.

Consumers can adopt one or more of these general responses to various public policy actions. Also, different policy classes will generate different patterns of consumer responses. Table 2 presents, in a simple format, the relationships among the seven policy classes and the various categories of consumer responses. This matrix forms the basis of the following analysis of the impacts of energy policies on transportation. The analysis can be approached from two directions. One can examine the rows associated with a particular policy class, or one can consider the column that represents a particular consumer response and look for the policy classes that can be expected to generate that response.

Policies That Increase the Cost of Automobile Travel Relative to Travel by Other Modes

This class of policies includes increases in both the fixed and operating costs of automobile travel, increases in the costs of storing the vehicle at destinations, and decreases in the costs of nonautomobile modes of travel. It is associated with the most comprehensive set of consumer responses of any of the seven policy

Table 1. Energy policy classes and their policy components.

Class	Component
1. Policies that increase the cost of automobile travel relative to travel by other modes	Increase in fuel cost, either by tax or market rises in price
	Increase in automobile storage (parking) costs via parking fees
	Increase in automobile purchase price by tax or market price increases
	Increase in the time cost of automobile travel by enforced lower speed limits
	Reduced costs of other modes by changes in production technology or direct fare subsidy
2. Policies that limit the supply of gasoline available to travelers	Government imposed fuel rationing systems
	Market shortages (probably caused by external events or price controls)
	Restrictive queuing process for gasoline purchase (i.e., odd and even days)
3. Policies that physically limit the use of automobiles	Enforced automobile-free zones at major trip destination zones
	Highway lanes reserved for buses only
	Drastically reduced parking capacity at major trip-destination zones
	More restrictive driver licensing regulations
4. Policies that change the characteristics of automobiles	Excise tax or rebate system based on fuel efficiency
	Enforced fuel-efficiency regulation on new vehicles
	Annual registration fees based on fuel efficiency
	Encouragement of new technology
5. Policies that change characteristics of nonautomobile transportation systems	Subsidies for expanded or improved existing transit systems
	Encouragement of vanpooling by subsidy, graduated tolls, or graduated parking fees
	Encouragement of new systems such as demand-activated minibus systems or people movers
6. Policies that affect the geographic distribution of trip ends	Encouragement of industrial parks
	Encouragement of large commercial centers
	Encouragement of higher-density residential development in close proximity to work and shopping centers
7. Policies that attempt to directly change travel patterns	Modified workweek
	Staggered work shifts

Table 2. Policy-response matrix.

Policy		Response					
Class	Component	Reduced Travel	Trip Purpose Change	Mode Shift	More Efficient Automobiles	Relocation	Peak-Hour Shift
1	Gasoline tax, tolls, parking fees, high automobile prices, speed limit, transit fare subsidy	Yes	Yes	If available	For gasoline tax only	Possibly	
2	Rationing, shortage policies	Yes	Yes	If available	Yes		
3	Automobile-free zone: exclusive lanes, limited parking	Not clear		If available		Possibly	
4	Excise tax, distance regulations, technical change, registration fees on efficiency				Yes		
5	Transit subsidies (service) encourage vanpooling	Possible increase		Slight			
6	Density: industrial or office parks, land patterns	Yes		If available		Yes	
7	Modify workweek, staggered shifts	Not clear	Yes	Possibly			Yes

classes. In the most general sense, policies that increase the cost of automobile travel will cause an overall reduction in travel, all other things being equal. This may result from a shift from single-purpose trips to multipurpose trips, elimination of marginal trips, and, in the extreme case, relocation so that necessary trips are shorter. If alternatives to automobile travel are available, some of the reduction in automobile travel may be countered by an increase in travel by other modes—a mode-shift response. This, of course, is dependent on the quality of services offered by the alternative modes.

Perhaps more important, policies that increase the fixed or operating costs of automobile travel (i.e., increased gasoline prices or increased vehicle prices) may result in consumer decisions that reduce those costs without requiring a reduction in travel. An example of this kind of response is the purchase of more fuel-efficient automobiles that may also have lower fixed costs (such as purchase price, registration fee, and insurance premiums). Looked at from this perspective, policies that encourage more fuel-efficient automobiles counter policies that encourage reduced travel or shifts to mass transit, even if high-quality transit service is available.

In order to predict the impacts of this class of energy policies, it is important to specify the responses more carefully. Reduced travel can result from a modified pattern of trip generation and trip length, both of which are dependent on the cost per vehicle kilometer. Thus, the increased cost of fuel must be modified by increases in fuel efficiency. Also, changes in the distribution of trip purposes will be dependent on the relative value of trips of different purposes and the cost per vehicle kilometer of travel. Relocation will occur if the change in the cost of travel is sufficient to overcome the benefits of the existing location and if alternative desirable locations are available. Similarly, mode-shift decisions are dependent on the availability of alternatives and on the relative levels of service of automobile vis-à-vis the alternatives.

Policies That Limit the Supply of Automobile Fuel Available to Travelers

The amount of automobile fuel available to travelers may be limited by a number of factors, such as publicly imposed fuel-rationing systems, market shortages resulting from disequilibria in the supply and demand structure of gasoline (a situation that usually results from some outside stimulus such as the embargo or publicly imposed price controls), or limitations on the purchase of fuel by forced queuing processes or maxima or minima limits on the amount of fuel to be purchased at one time. In many ways, this class of policy actions is an extreme case of the first class, which increased the cost of automobile travel, and the responses are also similar. If the limits on supply are severe, travel will undoubtedly be reduced, although the likelihood of mode shift is probably greater since satisfaction of all demand for automobile travel becomes impossible. People will tend to use more efficient automobiles in order to get more travel out of the available fuel. Unnecessary or marginal trips will be eliminated, and the number of multipurpose trips will probably increase. Necessary travel in excess of that allowed by available automobile fuel will be forced to other modes. Relocation is a distinct possibility if the situation is persistent.

Prediction of the impacts of this class of policies is similar to that for the previous class. There are, however, two major differences. First, the estimated shift from automobile to other modes of travel will be dependent not only on relative monetary costs of the various modes but also on the time and psychic costs of queuing and waiting to buy the limited amount of gasoline available. Also, after the amount of fuel available is adjusted to account for more fuel-efficient automobiles, it will be necessary to determine the excess amount of travel demand over that allowed by automobile. This excess will probably be shifted to alternative modes.

Policies That Physically Limit the Use of Automobiles

A number of energy-related policies attempt to limit the use of automobiles by prohibiting them in specified areas. Automobile-free zones have been implemented in several cities, and severe limitations on the actual number of parking spaces have also been proposed. In both cases, the intent is to shift travel from automobiles to other modes. If the use of automobiles is prohibited at important destination points, travelers will have to use other modes of travel to reach destinations. This assumes that alternative modes of travel exist and that the quality of services that they provide is reasonably high. It also assumes that there are no significant alternative destinations that are not encumbered by the automobile restrictions. For the most part, these assumptions can only hold for certain kinds of work trips since it is unlikely that all nonwork destinations can be covered by the restrictions.

Prediction of consumer response to policies of this type is difficult. If alternative transportation modes exist, it can be assumed that a large portion of work trips can be diverted from automobiles if the cost of the alternatives is not greatly higher than that of automobiles. These policies will probably not generate a reduction in travel. In fact, the opposite may occur. Automobiles may be left home, free for other uses during the day. For nonwork trips, consumers may opt to drive to competing nonrestricted destinations that are farther from their origin than are the restricted destinations. Another possible response, particularly likely if transit service is nonexistent or of low quality, is the relocation of employment and commercial establishments out of the restricted area in order to facilitate automobile commutation. In sum, the impacts of this type of policy will have to be estimated on the basis of the relative attraction of the restricted destination and the availability of alternative modes of travel.

Policies That Change the Characteristics of Automobiles

A number of policies have been proposed or implemented that attempt to reduce fuel consumption by changing the fuel-efficiency characteristics of automobiles. Examples include the graduated excise tax or rebate system proposed in the national energy plan, the specified fuel-efficiency requirements for new automobiles established by the National Energy Conservation Act of 1974, annual registration fees based on fuel efficiency, and policies to encourage research into more efficient automobile technologies. For the most part, these policies will have only one major impact on transportation consumers—they will begin to drive more efficient vehicles. There is no reason to expect these policies to generate a reduction in travel (in fact, they might generate an increase in travel as the cost per kilometer of travel decreases, unless savings are completely offset by increases in fuel cost), shift in mode of travel, or a shift in the distribution of trip purposes. Indeed, this class of energy-related policies, by itself, will have relatively little impact on the overall transportation situation.

Policies That Change the Characteristics of Nonautomobile Transportation Systems

Policies in this class generally take two forms: those aimed at expanding and upgrading existing transit systems and those aimed at encouraging the development of new systems, such as carpooling, vanpooling, or demand-activated minibus systems. In all cases the expected impact on transportation consumers is the diversion from automobile travel to travel on these alternative modes. In some cases, where access to transportation services is significantly increased, overall travel may actually increase as consumers use the expanded or new systems to make trips that they would otherwise not have made. These policies will only have a noticeable impact on transportation energy consumption if they generate a significant diversion from automobile travel. However, it is unlikely that this will occur without the concomitant implementation of other policies that actively discourage automobile use.

Policies That Affect the Geographic Distribution of Trip Ends

Policies in this class are basically land-use control activities aimed at creating more compact patterns of development that require less travel for both work and nonwork purposes. If these policies are effectively implemented, they would cause some relocation of both jobs and residences and reduce total travel. If alternate modes of transportation were developed in conjunction with the land use policies, the result could also be a substantial shift from automobile to alternative modes of travel.

Policies That Attempt to Directly Change Travel Patterns

These policies generally attempt to change the number and timing of work trips by modifying work schedules. Examples are staggered work shifts and four-day workweeks. The former policy will distribute peak travel loads over a longer period of time and thus reduce congestion, improve traffic flow, and reduce fuel consumption. This, however, may have perverse results as it also tends to reduce the cost of automobile travel and may cause more people to travel by automobile or to extend the length of their commute. The result may well be a net increase in total travel.

The implementation of four-day workweeks, even with a constant level of actual work time, is intended to reduce the number of weekly work trips from 10 to

8 per person, thus reducing the energy consumed by work commutation. Again, the results may be perverse. Work trips might be reduced, but the increased amount of leisure time may generate more nonwork trips. Another possibility is that workers will find it possible to have two jobs, and thus the number of work trips will increase. Altogether, the net impact on total travel is quite uncertain. It is unlikely, however, that policies in this class will have any impact on mode shift or automobile efficiency.

The previous pages have provided a qualitative discussion of the ways in which consumers of transportation services might respond to various energy-related policies. It is clear that there is a wide variety of such responses and that not all of them will result in a shift away from the use of automobiles. They may not actually generate a reduction in total travel. Still, in order to effectively anticipate the consequences of implementing the various energy policies, it is important to be able to predict those consequences as systematically as possible. Ideally, this would be done by using rigorous models of transportation systems. The next section discusses basic transportation demand-forecasting models and examines their capability for dealing with the kinds of responses to energy policies described above.

DEMAND FORECASTING

Classical demand-forecasting models can be classified as aggregate or disaggregate and sequential or simultaneous. All of them use socioeconomic variables to model the decision-making process of trip makers. The socioeconomic variables act as surrogates for the true behavioral phenomena of trip-making decisions. As in all modeling of social phenomena, a trade-off must be made between the number of variables included in the modeling process and the economic feasibility of collecting the required data for corroborating the model. This limits the number of variables used and makes it difficult to apply the models to situations other than those for which they were originally designed.

Aggregate models differ from disaggregate models in that they use as variables measures of the mean value of specific characteristics for the geographic units that make up the study area. Disaggregate models, on the other hand, use as variables specific characteristics of individual trip makers. Simultaneous models use a single-step process to forecast trip origin, destination, and mode of travel. Sequential models use the classical four-step process of trip generation, distribution, mode choice, and trip assignment. The latter is the most commonly used in urban transportation planning; however, recent studies have combined two or more of these steps.

The first step in the analysis is to review potential linkages between consumer responses and demand-forecasting techniques. Table 3 is similar to Table 2, but the entries in the various cells indicate whether or not existing demand-forecasting techniques are capable of modeling the particular policy response. For this analysis, each response will be discussed. It is hoped that this procedure will eliminate the chance of considering a policy in a manner that examines only one of several possible trip maker's responses. Furthermore, the relationship of the matrix to demand forecasting seems more consistent when viewed along the response line than along the policy line.

Reduction in Travel

Reduction in travel can result from reduction in trip rates or reductions in trip length. The former response falls in the trip-generation phase of the traditional demand-forecasting process. Trip rates used in disaggregate trip-generation models are based on historical data and may not be appropriate for predicting the effects of energy policies that are not simply extensions of past behavior. Trip-generation techniques that use regression equations that include independent variables to represent transportation costs relative to income might be suitable for predicting responses to policies that affect the cost of automobile travel. Simultaneous models might be capable of dealing with this response more readily if the response was the result of policies that limit automobile use or change the characteristics of the transit system. Responses to changing land-use patterns would follow naturally from the exogenous land-use forecasts. Some aspects of the responses to all policies that cause reduced travel can be seen in the interzonal attractiveness factors included in most trip-distribution models.

The work schedule can be modified by shifting the workweek or staggering the working hours. Since most forecasting efforts are based on a typical workday, reducing the number of working days does not change the daily forecast of work trips even though weekly or annual travel demand might change. Nonwork trips, however, may change substantially.

In all of the above, the elasticity of demand for travel with respect to cost of travel is assumed to hold constant over the entire range under consideration. If this assumption is inadequate, it is unlikely that any of the currently existing models can be used to forecast the responses to policies that increase the relative price of automobile travel.

Changes in trip lengths are generally included in the trip-distribution phase of the forecasting process and are based on the relative location of trip origins and destinations. Assuming that origins do not change (at least for home-based trips), changes in trip length will reflect changes in the desirability of various destinations. Trip makers attempting to make a single trip for several purposes will look for a destination that has more shops or activities than they would if they were making a single-purpose trip. Also, trip makers who have budgetary or fuel constraints will select nearby destinations, even if these destinations are slightly less desirable than alternative destinations at a greater distance. Given appropriate data on types and desirability of various potential destinations, current trip-distribution models could accommodate trip length changes.

Change of Trip Purposes

This response falls primarily in the trip-generation phase of transportation demand forecasting. The response (as Table 2 suggests) is the potential consequence of three classes of energy policies. As a response to the first (increasing the relative cost of automobile travel), it can be modeled in the framework of a set of trip-generation equations that are stratified by purpose and include travel cost as independent variables. Few, if any, current trip-generation models can readily be used.

Modifying work schedules (especially shortening the workweek) introduces the possibility of long weekends. Existing modeling processes have rarely, if ever, addressed the question of weekend travel, primarily because work trips have dominated peak-period travel, and peak-hour capacity and demand have always been the primary forecasting concerns. The change in the trip-purpose distribution as a result of changing

Table 3. Forecasting models and responses to energy policies.

Forecasting Model Component	Reduce Travel	Change Trip Purpose	Mode Shift	More Efficient Automobiles	Relocation	Peak-Hour Shift
Trip generation	In travel cost, in socioeconomic variables	In travel cost if generation is stratified by purpose		In travel cost		
Trip distribution	In interzonal impedance		For land use policies	In interzonal impedance	May change trip rates	
Mode choice			For the cost, service levels, and transit availability	In relating costs		
Trip assignment						Change in peak-hour factor
Exogenous forecasts					Land use, employment, or population forecasts	Independent prediction

the workweek is a new area for research.

Mode Shift

The classical demand-forecasting process is best suited to address this response. Regardless of whether the process is aggregate or disaggregate, simultaneous, or sequential, most forecasting models include a modal-choice component. The ability of the models to deal accurately with this response, however, is dependent on the type of policy being studied. Increases in the relative price of automobile travel and changes in the characteristics of the nonautomobile transportation system can readily be modeled (1-3), again assuming that the elasticity of demand with respect to price and service continues to hold. The modal-shift response to physical limitations on automobile use in certain areas can be modeled if there is an alternative mode of travel available and if the area of concern can be considered as separate analysis zones.

Assessment of modal shift as a result of changing land-use patterns, assuming the availability of alternative modes, is the central point of trip-distribution and modal-choice models.

Modal shift as a result of modification to daily work schedules can indirectly be assessed on the supply side by extending the peak period and reducing peak-hour factors. However, only periodic monitoring can produce the data necessary to carry out model adjustment. Shortening the workweek might have tangible impacts on mode choice that cannot currently be modeled. It is also likely to be accompanied by lengthening of the workday, which, in turn, might increase peaking characteristics because of shorter options on starting and quitting times. This consequence is equally applicable to highway and transit, but has little impact on modal choice.

The longer workday leaves less time for trips for other purposes in the evening but provides more time on weekends. Some changes in mode choice might take place as automobile commuters may decide to leave their automobiles home to be used for other purposes. Alternatively, some transit commuters might opt to drive due to reluctance to use transit during late hours.

More Efficient Automobiles

Policies that encourage the use of more efficient automobiles have the effect of reducing the cost of automobile travel vis-à-vis other modes. This can be incorporated in the trip-generation, trip-distribution, and mode-choice segments of the demand-forecasting process.

Relocation

This response shows up in one of two ways: residential relocation or employment relocation. The prevalence of one or the other is a function of the type of residential area. Either of the two types of relocation can be given consideration in the process of forecasting household and employment location. Activity allocation models include variables such as budget constraints and transportation costs, as well as land availability and existing land patterns. Clearly, this type of analysis should include the relocation response to energy policies, but it is generally considered as exogenous to the transportation demand-forecasting process.

Peak-Hour Shift

This response (as Table 2 suggests) is the result of modifying the work schedule. It is an intermediate response and may or may not induce other responses. Shortening the workweek but lengthening the workday only shifts peak periods. However, longer workdays may reduce second-job opportunities and thus change travel patterns somewhat. On the other hand, three-day weekends may encourage second jobs. None of these secondary responses can be predicted by the traditional travel-forecasting models. In fact, peaking is usually an input into the process rather than an output. Thus, peak-hour shifts must be considered exogenously to demand forecasting.

MODAL SHIFT AS A POLICY RESPONSE

Past and Current Work

Investigation of modal shifts that result from energy-related transportation policies is relatively new, and only a limited number of studies have emerged. Some of these studies use data collected during the 1974 energy shortage to assess the impact of the shortage on highway and transit travel, to draw conclusions regarding modal shift and elasticity of demand with respect to gasoline prices, and to suggest areas for further research (4-8).

Peskin, Schofer, and Stopher (7) report on a survey conducted in a northern suburb of Chicago in the spring of 1974. They found no increase in the use of transit during the shortage and showed that work trips were the most resistant to change. The availability of gasoline, not its price, was found to be the determining factor in the decision to make a trip. Keck (5), in a survey of three small urban areas in New York during and immediately after the energy crisis, showed that automobile users responded to the shortage by reducing speed, combining nonwork trips, and, to a lesser extent, by carpooling. Hartgen (4), in comparing the data from the two previous surveys, showed that the joint elasticity of price and availability for work trips in both studies was -0.1. The elasticity for nonwork trips in the Chicago study was -0.25.

Nizlek and Duckstein (6) studied transit ridership in Tucson, Arizona, during the energy shortage and concluded that "there was negative correlation between gasoline sales and transit ridership and that the demand for gasoline was highly inelastic."

Sanger (8) studied the effect of employment density on the type of response to the short-term energy shortage. He pointed out the logical ways in which responses will differ with employment density and the existing level of transit usage; however, he concluded rather heuristically that, if the supply of gasoline fell 10 percent short of the demand, 60 percent of the shortfall would be made up by increased transit usage (mode shift), 20 percent by carpooling, and the remainder by a reduction in total trips.

Other studies dealt more directly with the modeling of modal choice under the gasoline shortage. Crow and Savit (9) used three different models to predict travel demand between pairs of northeastern cities in light of price increases for gasoline and reductions in speed. All three models used cost, travel time, and service frequency, and all three yielded the expected results in terms of modal shift between automobile, rail, bus, and air travel. These models, however, are not likely to be appropriate for intraurban conditions. Furthermore, although the paper presented results for increases of 50-100 percent in the price of gasoline, the study considered a 200 percent increase. Although they recognized that they had assumed only out-of-pocket costs, and that, in the case of the automobile, gasoline costs amount to about 88 percent of that cost, they expressed no concern for the validity of the model under extremely different pricing conditions.

Navine (10) presented a utility-based modal-split model as well as a gasoline-rationing model based on a trip-purpose preferential model. He concluded from the first model that the percentage of modal shift is approximately one-fourth of the percentage of gasoline price increases. However, his results suggest a threshold below which an increase in the price of gasoline would not produce any tangible change in transit usage. Another intuitive result is the influence of trip length on modal shift. The gasoline-rationing model indentifies those trip makers who have the opportunity to make a modal choice and assumes that they will make modal shifts only in lower-priority trips (social or recreational), not in work trips.

The most conscientious effort at modeling the impact of gasoline shortages is a current study (of the Tri-State region) by the State University of New York at Stony Brook (11, 12). The automobile trip-fraction percentage is regressed against income and a weighted cost of intercounty trips. The cost function includes time, fare, and operating cost. Automobile operating cost includes, in addition to gasoline prices, variables that represent automobile occupancy and gasoline efficiency. These variables, in turn, are assumed to be functions of gasoline prices. Expressions for automobile occupancy and gasoline efficiency were developed in which the function becomes asymptotic to upper and lower bounds. To account for unavailability of gasoline, a search time that is inversely proportional to the probability that a station will have gasoline and a queuing time that reflects the reduced number of operating service stations are included in the total trip time.

This model, however, is somewhat limited. It predicts only changes to modal choice and fails to simulate the effects of fuel shortages on trip generation and trip length. In addition, it is calibrated on large trip interchanges (counties). Finally, a minor mechanical error results from leaving nongasoline automobile cost as a constant and not as a function of automobile occupancy.

This discussion sheds some light on the state of the art in transportation demand forecasting involving energy shortages, transportation policies, and modal change. Most studies have dealt with modal shift as a result of gasoline price increases and assumed constant elasticities. Gasoline rationing or unavailability have each been addressed in only one study. The impact on modal choice of policies such as increased prices of automobile travel, limits on automobile use, and changes in characteristics of nonautomobile travel is absent from the literature.

Approach for Future Work

Table 2 shows modal shift to be a possible response to a number of transportation policies related to a gasoline shortage. The first policy that might generate this response is increasing the relative price of automobile travel, for instance by increasing tolls, parking fees, or prices; by reducing highway speed; or by subsidizing transit fares. With the exception of automobile prices, all costs are considered out-of-pocket costs and are represented in most existing modal-choice models. So far, however, these cost components have been modeled independently of each other. This results in little error if conditions are stable and the costs continue to hold the same positions relative to each other. If a drastic change in the relative costs occurred, though, the independent modeling of all of these costs might cause excessive error. A case in point is the price of gasoline and fuel cost per vehicle kilometer or the high taxes on a non-fuel-efficient vehicle. Therefore, some of these variables must be substituted for by nested functions of other variables in the expression, possibly in the manner used in the Stony Brook model (12). The expression, however, must be incorporated and calibrated within a utility-based modal-choice model.

Limits on the availability of gasoline can be divided into two broad types: government control (rationing) and market control (scarcity). Rationing implies a limited amount of gasoline (G) available per registered automobile. This, in turn, suggests a limit to the distance that a vehicle can travel. The number of trips (NT) the vehicle can make, then, is a function of trip length (TL) and automobile efficiency (AE).

$$NT = (G \times AE)/TL \qquad (1)$$

Upper and lower bounds on TL and AE can be established from observation.

In order to apply this expression, assume first that the gasoline shortage has become sufficiently severe to require rationing. Therefore, assume that all trips that can possibly be made by automobile will be made by automobile, since demand will be much higher than supply. The remaining unsatisfied demand will be forced to shift to available alternative modes. It is more difficult, however, to determine which trip purposes will continue to be served by automobile and which will be shifted to other modes. The Chicago and New York State surveys differ considerably in their findings with respect to the trip purpose most affected by an energy shortage; the first found work trips most affected but the second found them least affected. The Chicago suburb would seem to be more representative of urban conditions. If we accept the Chicago findings, it is possible to determine in gross fashion not only how many but also which trips would be diverted to transit.

The second case, market control, can be modeled in a manner similar to that resulting from an increase in the relative price of automobile travel, but additional terms in the expression of the relative utility of the automobile mode are required. These terms correspond to the searching and queuing time necessitated by the scarcity of gasoline. The expression for the automobile time (T_A) might become

$$T_A = T_t + f(T_s) + g(T_q) \qquad (2)$$

where

T_t = travel time for automobile (A) mode,
T_s = search time for A mode, and
T_q = queuing time for A mode.

Limits or constraints on automobile use can, in general, be modeled on the supply side in the assignment phase of the forecasting process. This would suffice if the area were very small (one street or a number of separate streets). If the limitation applies to a sizable contiguous area, however, the most appropriate procedure is to consider the areas as a separate zone or zones and to heavily penalize automobile time and cost in that zone, leaving only other modes as feasible alternatives.

Transit subsidies and fare reduction are already part of most mode-choice models. Transit subsidies improve the quality of the transit system, and this in turn will be reflected in the travel time by the transit mode. Encouragement of paratransit, such as vanpooling, can be modeled in the case of an energy shortage in the form of an additional mode with its own peculiar characteristics and surrogate variables. A disaggregate modal-choice model of the logit formulation can conceivably accept another mode with little modification.

Changes in land-use patterns have always been an integral part of the demand-forecasting process, although usually as exogenous input to the other models. Unless changes in land use occur in conjunction with changes in the availability of transit, it is unlikely that such changes will, by themselves, result in substantial mode shift. An exception to this is where substantial redevelopment occurs around existing transit facilities, but this is likely to occur only over a relatively long period of time.

Finally, policies that change travel patterns (i.e., modified workweek or staggered work hours) can be expected to have a slight, but uncertain, impact on mode choice. The impact is dependent on the relative quality of transit vis-à-vis automobile and on the impact of the changes in reducing congestion. At the current time, the effects of such policies on mode choice cannot be modeled.

CONCLUSION

Various levels of government may implement many different policies to combat a gasoline shortage. Each of these policies may produce one or more travel responses. Modeling these responses in order to predict travel behavior and system performance as a result of these policies is a relatively new area for research in urban transportation demand forecasting. Modal shift is one of the most probable and highly important responses. Previous work has attempted to address this response and at least one study has attempted to model modal choice as a result of limited fuel availability. However, more work is required to improve the sensitivity of these mode-choice models to energy-conservation policies and to integrate the improved models into the total transportation demand-forecasting process.

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**Mr. Mufti is also affiliated with the Delaware Valley Regional Planning Commission, Philadelphia.*

Survey and Analysis of Energy Intensity Estimates for Urban Transportation Modes

Kenneth Chomitz, School of Social Sciences and Institute of Transportation Studies, University of California, Irvine

Current interest in energy conservation has resulted in a spate of divergent estimates of the energy intensiveness of urban transit modes. This paper critically reviews the methodologies and data sources employed by these estimates. It is shown that a very small repertory of sources and methodologies underlie the energy intensity estimates and that variance among them is primarily attributable to contradictory load-factor assumptions. Energy intensity estimates for bus and rail transit are developed, and the inadequacies of automobile data are discussed. Bus transit is shown to be more efficient than rail transit, and it is shown that the energy advantage of light rail over heavy rail lies in construction, not operation.

During the past few years, researchers have devoted considerable effort to the estimation of the energy intensiveness of various transportation modes. As a result, a plethora of energy-intensity (EI) values, which are often widely divergent, have been published. This report focuses on principal modes of urban passenger transportation and reviews some of the standard methodologies and data sources employed by EI researchers in an attempt to reconcile, or at least explain, the varying results. Emphasis is on aggregate statistical measures of EI rather than on disaggregate engineering analyses. In some cases where new or expanded data have become available, this paper presents new EI estimates.

PROBLEMS OF DEFINITION

EI may be ambiguously defined as energy input per transportation output. Ambiguity results unless the boundaries of the energy supply and the transportation system are delineated precisely. Different boundaries may be chosen to serve different analytic purposes. A recent Senate report (28) presents an excellent hierarchical framework of EI definition. A modification of that schema is given below.

Components of Energy Input	Measures of Transportation Output
Vehicle propulsion—revenue operation	Vehicle kilometers or seat kilometers offered
Auxiliary power—revenue operation (e.g., heating and lighting)	
Vehicle operation—nonrevenue service	Passenger route kilometers
Vehicle operation—inactive service	
Power to stations, shops, and other fixed facilities	Passenger straight-line kilometers
Energy used to construct vehicles, guideways, and stations	
Energy used by subsidiary modes (e.g., feeders or distributors)	Passenger straight-line kilometers, door-to-door

Energy consumption is outlined in the left-hand column. At the top of the column is vehicle propulsion energy, which is the most narrowly construed boundary of energy input possible. Going down the column, other components of energy use are added successively, incrementally widening the scope of the energy input. The right-hand column works in the opposite direction. Starting with the broadest interpretation of transportation output, vehicle kilometers offered, scope is increasingly narrowed down to door-to-door straight-line passenger kilometers. Thus, to unambiguously specify EI, it is necessary to pick a specific level in the right-hand column and a cutoff point in the left.

The hierarchical EI scheme enforces consistency and has the attractive feature of distinguishing between fixed and variable energy costs. Too often an average EI value is employed in policy analysis where a marginal EI value would be more applicable and vice versa. For instance, it is inappropriate to consider sunk energy costs (such as guideway construction) in the evaluation of potential mode shifts between existing transportation systems. However, such costs become relevant in the evaluation of new transit systems.

Thus, a hierarchical scheme of EI definition allows the energy analyst a great degree of flexibility. Unfortunately there is a paucity of information about station, maintenance, and construction energy costs, and about trip circuity. Therefore, this report concentrates on vehicle operating energy—energy used to propel, heat, and light vehicles in active and inactive operation.

AUTOMOBILES

Automotive EI is determined by both vehicle fuel economy and average occupancy (load factor). Methodologically, these two aspects of EI are distinct and will, therefore, be treated separately.

Fuel Economy

Attempts to estimate nationwide average automobile fuel economy fall into three categories, each of which has severe drawbacks:

1. Those based on Federal Highway Administration (FHWA) compilations of aggregate gasoline consumption and vehicle kilometers traveled,
2. Those employing weighted averages of U.S. Environmental Protection Agency (EPA) fuel-economy ratings for individual models, and
3. Those based on the selection of a representative automobile.

FHWA Statistics

Highway Statistics, an annual FHWA publication (32), presents data on gasoline consumption and vehicle kilometers traveled. The fuel-consumption data, based on state reports on fuel-tax revenue, cover all domestic nonmilitary consumption for highway purposes. These data appear to be reliable.

Calculation of total U.S. vehicle kilometers traveled is a formidable task. FHWA's procedures for estimating nationwide vehicle kilometers traveled were the subject of a recent study by Transportation and Economic Research Associates (26). The report found that

1. The FHWA's role is limited to reporting estimates of vehicle kilometers traveled that are prepared by the individual state highway departments and
2. There is no uniformity of methodology among the states.

Two principal approaches are used by the states:

1. Traffic count—By monitoring the highway system with manual or automatic counters, it is theoretically possible to establish a rate of traffic flow that, integrated over a year's time, yields annual vehicle kilometers traveled. Since the U.S. highway system is more than 6 million km (3.7 million miles) long, the monitoring effort is diffuse and sporadic. Typically states rely on a mixture of continuous monitoring of a few primary routes, statistical sampling, and slowly rotating coverage of all road sections over a cycle of up to a decade. The states pursue traffic-count programs with varying degrees of enthusiasm.
2. Fuel-consumption method—Many states lack the resources to undertake comprehensive traffic counts, so they rely on the fuel-consumption method, which consists simply of multiplying an assumed average fuel economy (kilometers per liter) figure by fuel consumed. In many cases, the fuel-economy figure was generated by dividing FHWA-reported vehicle kilometers traveled by highway fuel consumption.

Evidently the FHWA vehicle-kilometers-traveled figures are of dubious usefulness in the estimation of average fuel economy, since the vehicle-kilometers-traveled estimates merely reproduce state assumptions about fuel economy, nor is there much reason to trust the breakdown of driving between urban and rural highways. A predominantly rural state, by using the fuel-consumption method of estimating vehicle kilometers traveled, will, for instance, err in its estimate of rural vehicle kilometers traveled by nearly as large a percentage as its assumed kilometers-per-liter figure differs from the actual value.

Method of Weighted Averages

Given a profile of the U.S. automobile fleet and the EPA fuel-economy ratings for each automobile model, it is tempting to try to compute a weighted average of automobile fuel economy. This approach is attractive because it seems to offer the possibility of easy annual updating with new registration and fuel-economy statistics. In practice, however, there are complications.

A general formulation of the weighted average is as follows:

$$\text{Average fuel economy} = \sum_{i,y} n_{iy} m_{iy} [r_{iy} R_{iy} + (1 - r_{iy}) U_{iy}] \div \sum_{i,y} n_{iy} m_{iy} \qquad (1)$$

where

i = the index of automobile model (or, for a less disaggregate approach, automobile size or weight class);
y = the index of model year or age of automobile;
n_{iy} = the number of registered automobiles of model (class) i, vintage y;
m_{iy} = the corresponding average annual kilometers traveled;
r_{iy} = the proportion of kilometers driven on rural highways;
R_{iy} = the average rural (highway) fuel economy (km/L); and
U_{iy} = the average urban fuel economy (km/L).

The computation requires five data values for each automobile type. Of these five values, the first is known or can be established, the last two are known with modest reliability for recent vintages, and the other two are not known at all. The following data are all that is actually available:

$$m_y = \sum_i n_{iy} m_{iy} / \sum_i n_{iy} \qquad (2)$$

as estimated by the Nationwide Personal Transportation Study of 1969-1970 (31). R_{iy}, U_{iy} is as estimated by EPA dynamometer tests, which are subject to correction.

Obviously there are severe problems in using these data. First, the applicability of the EPA tests can be questioned. Some understanding now exists of the relation between dynamometer measurements and actual road tests that use a particular driving cycle, but the extent to which the EPA driving cycles are typical of urban and rural driving is unknown. For this reason empirical data on automobile use would be preferable. Second, it is not known how much covariance exists between vehicle weight and kilometers traveled, or proportion of rural driving. Do city dwellers tend to buy smaller automobiles? Are larger automobiles driven further, on the average? Data from the Nationwide Personal Transportation Survey (31) might be used to answer these questions.

Method of the Representative Automobile

Given the lack of aggregate data on vehicle kilometers traveled, it is reasonable to change strategy and merely choose a typical automobile model as a point of comparison. The method of the representative automobile seeks to go a step further and choose the automobile whose fuel economy approximates the national average. Selection of this representative automobile is equivalent to computing the weighted average detailed in the previous section, which is impossible, given existing data. Some authors have made the mistake of equating the national average fuel economy with the fuel economy of the national median-sized automobile.

Load Factor

Load factor, or average occupancy, is the other determinant of automotive EI. Load factor varies with trip purpose and length, geographic area, size of automobile, and a host of other variables.

Urban Load Factor

The literature on urban load factors includes a few studies of specific cities and two comprehensive studies. Specific city studies include Boyce and the Institute for Transportation Studies. Boyce and others (3) studied journey-to-work trips from three suburban New Jersey counties in 1970. Data from the 1970 census urban transportation planning package were used to compute a passenger kilometers-vehicle kilometers ratio of 1.14.

The Institute of Transportation Studies has for some years conducted surveys of San Francisco-bound commuter traffic that originates in the East Bay area. The surveys are disaggregate, based on screenlines at the

Caldecott Tunnel and the Bay Bridge. A fall 1977 survey (14, 15) yielded the following observations of vehicle occupancy:

Survey Area	6:30 a.m.-6:30 p.m.		7:30 a.m.-8:00 a.m. (peak half-hour)	
	Westbound	Eastbound	Westbound	Eastbound
Caldecott	1.26	1.28	1.22	1.20
Bay Bridge	1.51	1.40	1.73	1.23

The Nationwide Personal Transportation Study of 1969-1970 attempted to characterize the driving habits of the entire civilian (noninstitutional) population. Automobile load-factors data for households located in incorporated areas were reported as (31):

Item	To and From Work	All Purposes
Passenger kilometers-vehicle kilometers	1.5	2.2
Occupants per trip	1.4	1.9

The passenger kilometers-vehicle kilometers measure is simply occupants per trip weighted by trip length. The former is skewed upward by the high average occupancy of long trips—2.6 occupants per trip for trips of over 64 km (40 miles). Since many of these long-distance trips are undoubtedly vacation or other intercity journeys, the all-purpose urban load factor is more accurately estimated by the occupants-per-trip measure. A second Nationwide Personal Transportation Study is currently in the final stages of processing.

The National Transportation Study (30) suggests 1971 load factors of 1.3 (peak hour) and 1.5 (daily) averaged over all standard metropolitan statistical areas (SMSAs). These figures are based on compilations of local agency estimates.

In sum, adoption of an overall peak-hour estimate of 1.3 or 1.4 people per automobile would not be inconsistent with the specific city studies. It is not so easy to reconcile the disparate estimates of average daily occupancy. The NationwidePersonal Transportation Study estimate of 1.9 (31), although high, is the most authoritative.

TRANSIT BUSES

EI is codetermined by vehicle kilometers per liter and load factor. We examine each separately.

Fuel Economy

The standard statistical source for both vehicle kilometers traveled and fuel consumption is the American Public Transit Association (APTA). APTA surveys its members annually and publishes data for individual systems (2). APTA also published estimates of aggregate energy consumption statistics (1). The aggregate estimates are based on the responses of about 125 systems, which represent approximately 75 percent of total vehicle kilometers traveled. Fuel consumption for the missing systems is estimated on the basis of number of buses owned, adjusted differentially based on the service area population.

APTA data are not perfectly reliable. An Urban Mass Transportation Administration (UMTA) study reports (33)

> The data's main limitations lie in the basic structure of the reporting elements, a lack of conformity by data suppliers to the (APTA reporting) system with regard to data submissions. In other words, the APTA system does not provide the scope, uniformity, consistency, and accuracy that would be desirable for current and future requirements.

Project FARE, developed by UMTA in association with APTA, attempts to provide a consistent base of information about transit operations. Until FARE is fully implemented, the APTA data are the best available.

In scope, the APTA data are meant to cover all U.S. transit systems, both public and private. Excluded are school buses, jitneys, sightseeing buses, and intercity buses. Vehicle kilometers traveled includes all passenger vehicle kilometers, both revenue and nonrevenue (1). Fuel consumption is not precisely defined and has probably not been interpreted consistently.

Calculation of megajoules per vehicle kilometer is straightforward, given the APTA data (1 L = 0.26 gal; 1 km = 0.62 mile; 1 MJ/vehicle-km = 1525 Btu/vehicle mile) (1, pp. 30, 40):

Year	Fuel Use (000 000s L)			Vehicle Kilometers Traveled (000 000 000s)	Megajoule per Vehicle Kilometer
	Gasoline	Diesel	Propane		
1971	111	972.0	100	2.213 2	19.9
1975	19.0	1 381.8	9.69	2.455 3	22.1

The energy content of the fuels in the above table is as follows: gasoline—34.84 MJ/L (125 000 Btu/gal); diesel—38.66 MJ/L (138 700 Btu/gal); and propane—25.53 MJ/L (91 600 Btu/gal).

It is of interest to compare these results with the engineering estimates presented elsewhere (19)—1.5-1.7 km/L (3.6-4.0 miles/gal), depending on load, for a 50-seat diesel bus. This corresponds to 22.6-25.2 MJ/vehicle-km (34 500-38 500 Btu/vehicle mile), which is somewhat higher than the estimates derived above. The disparity could be due to errors in the APTA data, or the engineering estimates may posit a bus with air conditioning.

APTA is unable to disaggregate vehicle kilometers and energy consumption by fuel type or bus size.

Load Factor and Passenger Kilometers

There are two methods of estimating passenger kilometers. One method assumes an average load factor and multiplies by vehicle kilometers traveled; the other assumes an average trip length and multiplies by the number of passengers. These methods can be applied at either an aggregate or disaggregate level. The only comprehensive set of disaggregate estimates available is contained in the National Transportation Study (NTranS) (30). This study, which was based on a survey of state transportation departments, presents estimates of passenger distances by mode for each SMSA. Despite its shortcomings, NTranS data contain the best available guesses about passenger kilometers, load factor, and average trip length. NTranS is consistent with APTA with regard to vehicle kilometers traveled and total passengers (1 km = 0.62 mile) (2, pp. 26, 30; 30, Tables SD-6, SD-15):

Study	Vehicle Kilometers (000 000 000s)	Passenger Trips (000 000s)
NTranS	2.202 4	4285
APTA	2.213 2	4699

Comparison of APTA fuel-consumption data and NTranS passenger-distance data to generate an EI estimate is therefore reasonable. For 1971 we find (30, Table 20-23):

Energy consumption = 44.016 PJ (41.721 × 10 trillion Btu).
Passenger kilometers traveled = 27.125 billion passenger-km (16 858 × 10 million passenger miles).
EI = 1.6 MJ/passenger-km (2500 Btu/passenger miles).

This estimate is consistent with an average load factor of 12.25 or an average trip length of 5.8-6.3 km (3.6-3.9 miles). Other assumptions about load factor or average trip length will yield proportionately different estimates of EI.

HEAVY RAIL

Aggregate Estimates

Several attempts have been made to estimate average EI of all 10 U.S. heavy rail systems combined. All are ultimately based on the energy-consumption statistics published by APTA (1). APTA statistics are comprehensive but flawed. APTA no longer separates light rail and trolley coach energy consumption because the combined heavy and light rail systems do not do a good job of this in their own internal accounting. Also, the systems have not interpreted "electricity used to operate vehicles" in a consistent fashion. Some systems have reported total energy consumption, including station heating and lighting; others have reported traction energy only. These inconsistencies become evident when data reported in another APTA report (2) are compared with other detailed analyses (3, 7, 23, 24). If these sources are used together, it is possible to separate traction energy from station and other energy for six systems, which together account for 95.2 percent of heavy rail vehicle kilometers traveled (1). These calculations are performed and documented in Table 1 (2, 3, 7, 23). In addition, Stanford Research Institute (SRI) (24) has made or obtained a best guess of average trip length on each system and derived passenger distance estimates, which are also presented in Table 1. As in the case of buses, the EI estimate will be very sensitive to assumptions about average trip length.

The left side of the equations below represents electric consumption as metered at the rail system; the right side includes energy used to generate the electricity and assumes a 30 percent efficiency in generation and transmission (i.e., 10 J at the power station yields 3 J of delivered electricity). The New York City Transit Authority is, however, supplied electricity at only 25 percent efficiency (24). Allowance for this would increase overall EI values by 15 percent (1 MJ = 947.8 Btu; 1 km = 0.62 mile).

Traction Energy Only

0.141 kW•h/passenger-km = 1.7 MJ/passenger-km
3.45 kW•h/vehicle-km = 41.4 MJ/vehicle-km

Total Operating Energy

0.173 kW•h/passenger-km = 2.0 MJ/passenger-km
4.22 kW•h/vehicle-km = 50.8 MJ/vehicle-km

The overall average EI values presented above are somewhat misleading and must be used cautiously. These averages reflect the efficient performance of the New York subways, which account for the bulk of heavy rail passenger kilometers traveled. Modern heavy rail systems tend to use more energy-intensive vehicles in less heavily populated regions, which results in much higher EIs. A disaggregate approach to heavy rail EI is therefore desirable.

Individual System Estimates

There is a great deal of diversity among heavy rail systems. Detailed energy profiles of three systems have been prepared by Fels (7), whose results are given below.

For Port Authority Transit Corporation of Pennsylvania and New Jersey (PATCO) and Port Authority TransHudson (PATH), almost all of the traction energy is used in active operation of the vehicles. By contrast, Bay Area Rapid Transit's (BART's) policy of keeping all cars hot (i.e., idling) at all times results in a substantial component of energy devoted to inactive operation. Fels estimated that BART cars consumed only 8.28 MJ electric/car-km (3.7 kW•h/car mile) in active operation but drew 26 kW during inactive hours of service, so that fully 46 percent of traction energy consumption is incurred by inactive operation. Table 2 gives the energy consumption of three heavy rail systems. As BART expands service hours and increases car utilization, the proportion of inactive operation will decrease, probably resulting in thriftier EIs.

Table 1. Heavy rail data aggregation.

System	Vehicle Kilometers (000 000s)	Passenger Kilometers (000 000s)	Electricity Consumption (TJ)		Notes
			Traction[a]	Total[b]	
Chicago	79.045	1 735	824.04	936.55	65.52 TJ lost in AC-DC conversion
New York	487.21	12 137	6 045.5	7 375.7	
PATH	17.147	296	201.38	228.87	SRI lists 27.47 TJ to auxiliaries (24); Fels and Smith (7, 23) make clear that this is actually fixed installation and is therefore excluded from traction energy
PATCO	6.747	152.1	122.54	145.89	Traction derived from total energy applying Boyce's ratio of 0.84 (3)
BART	34.523	751	559.76	788.4	
Southeastern Pennsylvania Transportation Authority (heavy rail)	23.427	674	257.062	402.682	Energy consumption derivation from SRI (24)
Total	639.10	15 745.1	8 010.282	9 878.092	

Note: 1 km = 0.62 mile; 1J = 0.000 9 Btu.

[a] Includes all energy drawn by cars–propulsion, heating, air-conditioning, and lighting, in active service or on standby. For the most part, available data do not specify whether the traction energy reported refers to DC or AC electricity use. Because of conversion losses, about 5 percent more current is purchased as AC than is actually used in DC form. It is assumed here that the systems have reported DC usage.

[b] Includes traction energy, energy used by stations shops and offices, energy used to heat rails and ventilate tunnels, and AC to DC conversion losses. This is electricity as metered by the rail system; transmission and generation losses are not included.

LIGHT RAIL VEHICLES

Operating data on light rail vehicles (LRVs) are scarce. APTA reported aggregate U.S. light rail energy consumption until 1973 but no longer does so because of problems with data reliability. The problem lies mainly with the Massachusetts Bay Transportation Authority's (MBTA's) inability to account separately for light and heavy rail components of energy use. The MBTA generates a large fraction of total U.S. LRV vehicle kilometers traveled, so no meaningful average can be made without it.

Lacking a useful aggregate average, there is no alternative but to use the operating statistics of individual systems or to rely on engineering estimates. Of the six remaining light rail systems, four are described below. Unfortunately it is not clear whether the energy consumption reported for these four systems was total energy or traction energy (1 km = 0.62 mile; 1 J = 0.0009 Btu) (2, 24).

System	Energy Consumption (TJ electric)	Car Kilometers (000 000s)	MJ Electric per Car, Derived
Cleveland RTA	16.2	1.67	9.69
Newark TNJ	10.22	0.93	11.10
Philadelphia, Red Arrow	50.4	2.49	20.20
Pittsburgh Port Authority of Allegheny County (PAT)	54.3	3.38	16.13

The high energy per car kilometer value for Philadelphia's Red Arrow line may be due to heavier than average cars. The Red Arrow cars range in weight from 9.5 to 27.2 Mg (21 000 to 60 000 lb), but Cleveland Regional Transit Authority's (RTA's) cars all fall within the 16.3- to 19.0-Mg (36 000- to 42 000-lb) range (24).

Table 2. Energy consumption of three heavy rail systems.

Measure	BART	PATCO	PATH
Car kilometers (000 000s)	37.6	6.8	17.7
Passenger kilometers (000 000s)	751	148	294
Total electricity consumed (TJ)	788	144	248
Traction (%)	71	85.5	89
Station (%)	24	12.5	5
Maintenance (%)	5	2	6
Total energy (MJ/car-km)	21.0	21.3	14.3
Traction (MJ/car)	14.8	18.1	12.5
Total EI[a] (MJ/passenger-km)	3.51	3.25	2.82
Traction EI[a] (MJ/passenger-km)	2.49	2.75	2.49

Notes: 1 km = 0.62 mile; 1J = 0.000 9 Btu.
These figures are based on the systems' billing records for energy and the systems' own estimates of car kilometers and passenger kilometers.

[a] Includes energy used to generate electricity, 30 percent efficiency assumed.

SRI also reports estimates of passenger kilometers. EIs derived from these estimates are given below. For the Transport of New Jersey (TNJ) system, the average trip length is 3.54 km (2.20 miles) and the average number of passengers is 2.408 million (1 MJ/km = 592 Btu/mile) (3, 24).

System	Energy Consumption (TJ electric)	Passenger Kilometers (000 000s)	EI (MJ/passenger-km)
Cleveland	16.2	44.2	1.21
Red Arrow	50.4	44.4	3.77
TNJ	10.22	8.5	4.00

From the energy analyst's viewpoint, Cleveland is a showcase system. Its very success in achieving a high average load factor makes it inappropriate as a guideline for the typical EI of light rail operations. On the other hand, the poor showing of TNJ and Red Arrow (twice the EI of old heavy rail systems) are not necessarily representative either.

However, bear in mind that the above data refer almost exclusively to cars of 1940s vintages and older. The new generation of light rail vehicles, more sturdily constructed than their predecessors and equipped with air conditioning, are likely to be more energy intensive. Tests of the new Boeing LRV in Boston yield an average value at 21.3 MJ/car-km (9.52 kWh/car mile) for combined subway and surface runs (4).

Thus if the existing cars on the three systems mentioned above were replaced by the new Boeing LRV cars and the former load factors were continued, then the new EIs would be 2.65, 7.28, and 4.29 MJ/passenger-km, respectively.

The main point of interest here is that the new generation of light rail systems will have EIs in the range of 2.6-6.6 MJ/passenger-km (4000-10 000 Btu/passenger mile), which is higher than the comparable EI for new heavy rail systems of about 2.6 MJ/passenger-km (4000 Btu/passenger mile). Thus the energy savings associated with light rail lie in the lower construction energy, not in lower operating energy.

COMMUTER RAIL

APTA recognized 15 commuter railroads at the end of 1976 (1, p. 46). According to NTranS, the commuter rail system produced 206.9 million vehicle-km (128.6 million vehicle miles) of travel and 9311 million passenger-km (5787 million passenger miles) in 1971 (30, tables SD-6, SD-23).

Energy consumption by commuter railroads is not regularly published. The Interstate Commerce Com-

Table 3. Commuter rail EI.

Measure	Northwestern	Burlington Northern	Milwaukee Road
Fuel consumption (L diesel/train-km)	7.8	10.1	6.8
Total traction energy, including deadheading and electric standby (equivalent L diesel/train-km)	8.9	10.6	7.8
MJ per coach kilometer	72	85	98
Average seats per coach	159	134-146	152
Passenger kilometers per seat kilometer	0.29	0.42-0.46	0.41
EI (MJ/passenger-km)	1.6	1.4	1.6

Notes: 1 km = 0.62 mile; 1 L = 0.26 gal; 1 MJ = 947.8 Btu.
Walbridge's raw data are directly from the railroads. Walbridge uses an electric efficiency of 34 percent; reconversion to the 30 percent factor used in this report would not make a difference at the two-significant-figure level that Walbridge employs. These estimates do not include energy used for stations and maintenance.

mission (ICC) requires each railroad to report annually on fuel consumption by motive power units. SRI's energy analysis of commuter rail operations is largely based on these reports. It would be possible to aggregate these data and attempt an overall average EI figure. However, Walbridge (35) demonstrates that an important component of energy consumption is not reflected in locomotive fuel consumption alone. A substantial amount of electricity is used to keep coaches and locomotives hot during the winter. The results of Walbridge's detailed analysis of three Chicago commuter roads are worth reproducing (Table 3) as guideline examples of commuter-rail energy intensity.

CONCLUSIONS

The best evidence available indicates that buses are substantially more energy efficient than is heavy rail transit; existing rail transit systems consume an average of 24 percent more operating energy/passenger km than do buses. Modern heavy rail systems consume approximately 100 percent more energy/passenger-km than do buses, not even taking into consideration the huge construction costs (16). Light rail systems, on limited evidence, seem to have no advantage over heavy rail in operating energy efficiency, but there may be some savings in construction costs. From the point of view of energy efficiency, bus is the preferred transit mode.

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Foreign Oil Dependence: State-Level Analysis

Richard A. Margiotta*, University of Tennessee, Knoxville
Lawrence J. Reilly*, Harvard University, Cambridge, Massachusetts
David T. Hartgen, New York State Department of Transportation, Albany

This paper discusses the dependence of New York State on foreign sources of petroleum products. The paper defines dependence to include direct product imports and imported crude oil that is domestically refined into such products. By use of a generalized allocation procedure that is applicable to all states, the original foreign sources of petroleum products are traced back from major East Coast and Gulf Coast refineries to the particular countries that supplied the imported crude oil. Known imports of refined products are then added to these estimates to obtain estimates of total dependence. Four products are studied: residual oil, distillate, gasoline, and jet fuel. Results show that, overall in 1976, New York is 72 percent dependent on foreign oil, compared with 43 percent for the United States. For residual oil, New York is 96 percent foreign dependent; major suppliers are Caribbean and South American countries, particularly Venezuela, Virgin Islands, and the Netherlands Antilles. For distillate, gasoline, and jet fuel, New York is between 54 and 58 percent dependent on foreign sources; supplies come mainly from African and Middle Eastern countries, particularly Nigeria, Algeria, and Saudi Arabia. The United States' dependence pattern is similar but less severe and broader in base. Although New York, like many states, gets its oil from many countries, it relies primarily on a relatively small number of suppliers for most of its petroleum products, making it particularly vulnerable to supply curtailments. A number of actions are suggested to broaden New York's base of sources, to cut foreign dependence, and to reduce petroleum use.

The technology and lifestyle of America has been predicated on the availability of cheap, unlimited energy, particularly petroleum. In its various forms, petroleum powers our atuomobiles and airplanes, heats many of our homes, runs our factories, and generates our electricity. Its presence pervades our society. Recent shortages, however, have demonstrated the finiteness of this resource, its uncertain availability, and its volatile price. The overall problem may vary widely in individual states. New York has no indigenous petroleum supplies and gets all of its petroleum from other states and foreign countries. Refined petroleum products come to New York primarily from three sources (see Figure 1):

Flow	Description
A	Direct from foreign refineries
B	Direct from petroleum administration for defense district (PAD) 1 (U.S. East Coast) refineries
C	Direct from PAD 3 (U.S. Gulf Coast) refineries

Figures for 1975 (New York State energy plan) show that 40 percent of New York's refined petroleum products came from foreign sources (A), and that the remainder came from U.S. refineries (B and C).

However, the entire picture is not so simple, since crude oil flows must also be taken into account. For instance, crude (unrefined) oil is often imported to Gulf Coast (flow D) and to East Coast (flow E) refineries from foreign countries and then is refined into petroleum products and sent to New York. Domestic crude from PAD 3 is also sent to PAD 1, refined there, and sent to New York (flow F). [This assumes that no refined product arrives in New York from PAD 2, which understates by about 1 percent New York's domestic dependence (1).] Thus, the degree of total dependence of New York on foreign sources is likely to be much greater than 40 percent. Since not all countries or states produce all refined products, New York's foreign dependence for certain products (e.g., residual oil) may be greater than for others (e.g., gasoline). Detailed breakdowns by country can show exactly which nations or states New York depends on for what products.

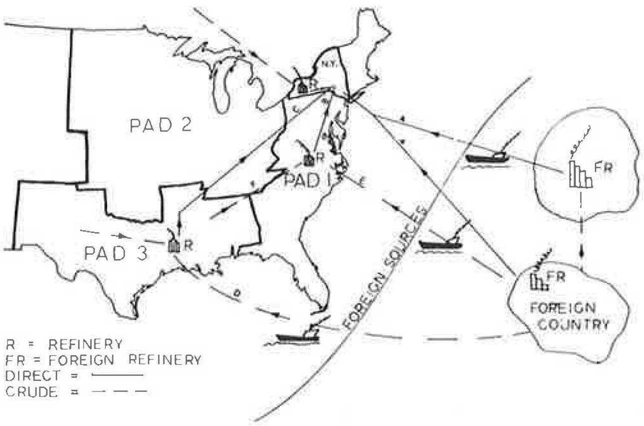
This paper estimates and describes New York's dependence on both domestic and foreign sources for refined petroleum products. The following key questions are addressed:

1. To what extent is New York more or less dependent on foreign petroleum than is the United States?
2. On what countries and states is New York most dependent and for what petroleum products?
3. How is New York's profile of dependence different from that of the United States?
4. What are the implications of such dependence on New York's energy policies?

METHOD

The procedure for estimating New York's oil dependence is described in detail elsewhere (1). Basically, the total volume of petroleum products refined in the United States (e.g., gasoline refined in PAD 1) are allocated

Figure 1. Schematic of petroleum products flow.



backward to country or state of origin, based on the shares that those countries or states have of imported crude oil to the refining site. Then these amounts are added to the refined product from these countries sent directly to New York. [Readers interested in applying the method are urged to contact the authors.]

Following the schematic (Figure 1) and letting RP be a refined product (e.g., gasoline) we have

Dependence of New York on Texas
= total RP directly imported from Texas (Flow C)
$-\sum_{\text{nations}}$ indirect sources via Texas (Flow D)
+ Texas' RP to New York via PAD 1 (Flow F)

The equation is also applied for Louisiana data.

Dependence of New York on foreign source
= amount RP directly imported from foreign source (Flow A)
+ amount RP indirectly imported via Texas and Louisiana (Flow D)
- amount RP indirectly imported via PAD 1 (Flow E)

The New York State Energy Office (2) feels that the above procedure tends to overstate foreign dependence by (a) ignoring U.S. oil from PAD 2 and other lesser (but considerable) U.S. sources (e.g., Alaska) and (b) by assuming that the only PAD 3 refining states are Texas and Louisiana. These assumptions were made to speed the analysis and are not likely to influence the overall conclusions of this report.

RESULTS

Data from the New York State Energy Office showing New York's 1976 energy use by fuel source and demand sector are shown in Table 1. Petroleum is a central component of New York State energy, accounting for more than 65 percent of consumption. In contrast, the U.S. (3) relies on petroleum for 47 percent of its consumption; the difference is taken up by heavier reliance on coal and natural gas. As may be observed, different refined products are important for different sectors. Residual oil, for instance, is primarily used in electric-power generation and residential and commercial, but distillate fuel is used almost entirely within the residential and commercial sector, primarily as home heating oil. Gasoline and jet fuel are used exclusively for transportation. These figures imply that foreign dependence on petroleum products must be considered against the ways that products are used.

The results of this analysis are summarized in Table 2. Most refined products reach New York from the U.S. Gulf Coast (PAD 3) and East Coast (PAD 1) refineries; only a small amount is shipped directly from foreign sources. However, adjustment for the source of crude oil (direct and indirect in Table 2) shows a decrease in the significance of the U.S. Gulf Coast states, and increases in foreign sources. PAD 1 is eliminated as an ultimate source because it produces no crude oil itself. On this adjusted basis, New York appears to be 72.1 percent dependent on foreign oil and the United States, 42.8 percent dependent.

For all products combined (total column in Table 2) New York shows greater dependence than the United States on all sources except Asia and North America. Specific countries important to New York and the United States are shown in Table 3. New York's profile of sources shows greater concentration in fewer major sources than the United States. New York is more dependent than the United States on oil from Venezuela, Saudi Arabia, Nigeria, Virgin Islands, Netherlands Antilles, Algeria, Bahamas, and Iran and less dependent on Canada, Indonesia, and Libya.

Residual Oil

Residual oil is a relatively heavy multipurpose product used primarily for generation of electricity, space heating, and industrial-process heat. It is the single largest fuel source to New York's economy and accounts for 25 percent of New York's energy consumption. New York is 96.1 percent dependent on foreign sources for residual oil; the United States is 71.0 percent dependent. Table 2 shows that Texas and Louisiana account for approximately 42 percent of distillate, gasoline, and jet fuel consumed in New York, but only 3.9 percent of New York's residual supply comes from these domestic sources.

New York receives 35.4 percent of its residual oil from the Caribbean. This is by far the Caribbean's major contribution as far as petroleum product source is concerned. The same holds true for the U.S. source, where the Caribbean accounts for 21.5 percent of the total. Thus, the Caribbean is a major source of residual oil for both the United States and New York. All of the residual oil that comes to the United States (and New York) from the Caribbean is imported directly [i.e., no crude was shipped from the Caribbean to the United States (Table 2)]. The specific major sources of residual oil are shown in Table 4. New York generally relies on the same nations as does the United States, but its dependence is more concentrated than is that of the United States. Thus, from New York's view, the residual oil source problem is essentially an international one.

Distillate

Distillate oils, a group of relatively light refined products, are used for residential and commercial space heating, industry, and transportation (as diesel fuel). They account for 16.9 percent of New York's total energy consumption.

Domestic production accounts for a greater percentage of both New York's and the United States' supplies for distillate oils. Table 2 shows that only 9.8 percent of New York's distillate arrives in the United States in refined form, but that another 48 percent comes here in crude form. Overall, considering direct and indirect sources, 57.8 percent of New York's supply of distillate and 41.5 percent of the United States' supply is ac-

Table 1. 1976 New York State energy use by source and sector.

Energy Source	New York State: Electric Utility (PJ)	Residential and Commercial (PJ)	Industrial (PJ)	Transportation (PJ)	Total (PJ)	Percent	United States: Total (PJ)	Percent
Hydro	321.4				321.4	7.5	3 233	4.1
Nuclear	175.9				175.9	4.0	2 144	2.7
Petrol								
Residual	562.8	363.9	59.5	60.6	1 046.8	65.4	36 860	47.3
Distillate	31.9	583.2	25.9	67.2	708.2			
Gasoline				817.4	817.4			
Jet fuel				181.4	181.4			
Kerosene		35.9	5.2		41.1			
LPG		15.4	5.8	1.5	22.7			
Coal	151.2	5.3	198.2		354.7	8.2	14 505	18.6
Natural gas	5.7	510.3	124.9		640.9	14.9	21 328	27.3
Total	1 253.0	1 514.0	419.6	1 128.1	4 310.5			
Electric	-1 113.6	690.2	296.4	27.0				
Total	135.1	2 204.3	815.9	1 155.1	4 310.5	100.0	78 069	100.0

Note: 1 PJ = 947.8 billion Btu.

Table 2. Sources of New York State petroleum—summary for 1976.

	Residual (%)			Distillate (%)			Gasoline (%)			Jet Fuel (%)			Total (%)		
	New York			New York			New York			New York			New York		
Source	Direct Only[a]	Direct and Indirect[b]	U.S. Total[b]	Direct Only	Direct and Indirect	U.S. Total	Direct Only	Direct and Indirect	U.S. Total	Direct Only	Direct and Indirect	U.S. Total	Direct Only	Direct and Indirect	U.S. Total
United States															
PAD 3	8.1	3.9		61.9	42.2		67.0	42.3		75.5	45.9		43.9	27.9	
PAD 1	11.0	-		28.3	-		31.1	-		14.7	-		20.9	-	
Total	19.1	3.9	28.3	90.2	42.2	58.5	98.1	42.3	63.7	90.2	45.9	55.8	64.8	27.9	56.7
North America	1.5	1.9	3.7	-	1.3	3.2	-	1.5	3.1	0.7	1.8	3.4	0.6	1.6	3.2
Central America-Caribbean	35.3	35.4	21.5	8.2	8.0	3.5	4.3	4.5	1.6	6.9	6.9	3.5	17.3	17.1	6.5
South America	34.2	35.7	23.9	1.4	5.8	3.5	0.3	5.4	2.8	3.6	7.0	4.4	13.7	17.1	7.4
Europe and Soviet Union	6.0	6.1	3.8	-	0.3	0.3	0.1	0.4	0.4	-	0.2	0.4	2.3	2.1	1.1
Middle East	1.1	5.6	6.9	0.2	17.7	13.1	-	20.2	12.1	-	14.5	13.0	0.5	14.0	10.3
Asia	-	0.4	2.1	-	1.3	3.9	-	1.5	3.6	-	1.1	5.1	-	1.0	3.1
Africa	2.3	9.4	9.1	-	20.2	13.8	-	23.4	12.7	-	17.0	13.5	0.8	16.8	11.2
Other	0.5	1.6	0.7	-	3.2	0.2	-	0.8	0	-	5.6	-	-	2.4	-
Total foreign	80.9	96.1	71.7	9.8	57.8	41.5	4.7	57.7	36.3	11.2	54.1	43.3	35.2	72.1	42.8
Total accounted for	100.0	100.0	100.0	100.0	100.0	100.0	102.8[c]	100.0	100.0	101.4[c]	100.0	100.0	100.0	100.0	100.0
Organization of Petroleum Exporting Countries (OPEC)		40.7	33.5		42.2	32.2		47.8	29.5		34.3	31.6		42.9	29.0

Notes: Total residual energy = 1 046.7 PJ (992.2 trillion Btu); total distillate energy = 708 PJ (671.3 trillion Btu); total gasoline energy = 817.4 PJ (774.8 trillion Btu); total jet fuel energy = 181.4 PJ (172 trillion Btu); Total energy = 2 753.9 PJ (2 610.3 trillion Btu).

[a] Shipment of refined products.

[b] True dependence.

[c] Some of New York's supply is shipped to PAD 1.

counted for by foreign sources. Africa and the Middle East are the major foreign sources of distillate, supplying 20.2 percent and 17.7 percent of New York's total, and 13.9 percent and 13.1 percent of the U.S. total; virtually all of this oil arrives indirectly (i.e., it is shipped to the United States in crude form). Major countries that provide New York and the United States with distillate are shown in Table 5.

Middle East and African dependence dominates both profiles, but, as with residual oil, New York's dependence is concentrated in fewer nations. New York depends more on Saudi Arabia, Nigeria, the Virgin Islands, Algeria, Venezuela, and Iran than does the United States and less on Indonesia, Libya, and Canada.

Gasoline

Gasoline is used exclusively for transportation purposes. It accounts for 19.5 percent of New York's energy consumption. Considering both direct and indirect sources, foreign sources of gasoline account for 57.7 percent of New York's supply and 36.3 percent of the U.S. supply. Both the Middle East and Africa supply a greater percentage of gasoline than they do distillate to New York—20.2 and 23.4 percent, respectively; however, all of this comes to the United States in crude form. OPEC nations provide New York with 47.8 percent of its gasoline (5.5 percent more than do domestic sources); OPEC provides the country as a whole with 29.5 percent of its gasoline. This is the largest difference for a refined product between OPEC oil supplied to New York and that supplied to the United States. Primary sources of New York and U.S. gasoline are shown in Table 6.

Saudi Arabia, Nigeria, and Algeria head both profiles, and New York's dependence is more heavily concentrated. Beyond that, New York depends more on Venezuela, Iran, and the Virgin Islands than does the United States and less on Canada and Indonesia.

Jet Fuel

Jet fuel is used exclusively in air transportation and accounts for 4.3 percent of New York's energy consumption. Only 9.8 percent of jet fuel is imported directly (in refined state); but an additional 44.3 percent is imported in crude form. Thus, foreign production accounts for 54.1 percent of the jet fuel consumed in New York. In contrast, foreign production accounts for 43.3 percent of U.S. consumption.

Again, the Middle East and Africa are the largest

Table 3. Overall petroleum dependence—major sources.

New York State		United States	
Source	Percent	Source	Percent
United States		United States	56.7
Texas	18.1	Saudi Arabia	6.9
Louisiana	9.8	Nigeria	5.7
Total	27.9	Venezuela	4.7
		Indonesia	3.2
Venezuela	12.4	Virgin Islands	3.0
Saudi Arabia	9.7	Canada	2.7
Nigeria	9.1	Libya	2.6
Virgin Islands	8.2	Algeria	2.5
Netherlands Antilles	5.6	Netherlands Antilles	2.0
Algeria	4.2	Trinidad	1.8
Trinidad	4.1	Iran	1.7
Libya	2.4		
Bahamas	2.3		
Iran	2.2		

Table 4. Major sources of residual oil.

New York State		United States	
Source	Percent	Source	Percent
United States	3.9	United States	28.3
Venezuela	26.4	Venezuela	16.1
Virgin Islands	14.7	Virgin Islands	8.9
Netherlands Antilles	13.8	Netherlands Antilles	8.4
Saudi Arabia	4.0	Trinidad	5.2
Nigeria	4.0	Saudi Arabia	4.5
Algeria	2.7	Nigeria	4.1
		Bahamas	3.6
		Algeria	2.2
		Libya	2.0
		Indonesia	2.0

Table 5. Major sources of distillate.

New York State		United States	
Source	Percent	Source	Percent
United States		United States	58.2
Texas	28.6	Saudi Arabia	8.5
Louisiana	13.6	Nigeria	7.1
Total	42.2	Indonesia	3.8
		Libya	3.1
Saudi Arabia	12.6	Algeria	2.8
Nigeria	11.4	Virgin Islands	2.7
Virgin Islands	5.9	Canada	2.6
Algeria	4.9	Iran	2.1
Venezuela	4.2	Venezuela	2.1
Iran	2.8	United Arab Emirates	1.8
Libya	2.8		

Table 6. Major sources of gasoline.

New York State		United States	
Source	Percent	Source	Percent
United States		United States	63.7
Texas	26.2	Saudi Arabia	7.9
Louisiana	16.1	Nigeria	6.6
Total	42.2	Indonesia	3.5
		Libya	2.9
Saudi Arabia	14.5	Algeria	2.6
Nigeria	13.3	Canada	2.5
Algeria	5.5	Iran	1.9
Venezuela	3.8	United Arab Emirates	1.7
Libya	3.3	Venezuela	1.6
Iran	3.2		
Virgin Islands	3.0		
United Arab Emirates	2.0		

Table 7. Major sources of jet fuel.

New York State		United States	
Source	Percent	Source	Percent
United States		United States	55.8
Texas	22.8	Saudi Arabia	8.4
Louisiana	23.1	Nigeria	7.0
Total	45.9	Indonesia	3.7
		Libya	3.1
Saudi Arabia	10.3	Algeria	2.8
Nigeria	10.2	Canada	2.8
Trinidad	4.3	Iran	2.1
Algeria	3.6	Venezuela	1.9
Netherlands Antilles	3.4	Netherlands Antilles	1.8
Virgin Islands	2.7	United Arab Emirates	1.8
Venezuela	2.4		
Libya	2.4		
Iran	1.9		

exporters. The Middle East accounts for 14.5 percent of New York's total and 13.0 percent of the United States' total, all in the form of crude oil. Africa accounts for 17.0 percent of New York's total and 13.5 percent of the United States' total. Not surprisingly, Saudi Arabia and Nigeria are the countries with the largest amount of exports to both the United States and New York. Saudi Arabia provides 10.3 percent of New York's total and 8.4 percent of the United States' total. Nigeria provides 10.2 percent of New York's total and 7.0 percent of the United States' total. Other important suppliers are shown in Table 7. New York depends more on Trinidad, Algeria, Netherlands Antilles, and Virgin Islands and less on Indonesia, Libya, Canada, and United Arab Emirates than does the United States.

SUMMARY AND POLICY ACTIONS

The above analysis shows the following key findings:

1. New York's dependence on foreign oil is much greater than that of the United States: 72 percent versus 43 percent in 1976. Of this foreign petroleum, however, 35 percent is directly imported, and another 37 percent is imported in crude form and refined in the United States.

2. This dependence varies by petroleum product. For residual oil, New York is 96.1 percent foreign dependent; for other products (distillate, gasoline, and jet fuel), New York is between 57.8 and 54.1 percent dependent.

3. For residual oil, New York depends heavily on the Caribbean and South American countries. For distillate, gasoline, and jet fuel, New York depends first on Texas and Louisiana, next on Middle Eastern and African countries.

4. For residual oil, both the United States and New York are dependent on three major sources (Venezuela, Virgin Islands, and Netherlands Antilles). For distillate, gasoline, and jet fuel, both the United States and New York are dependent on three major sources (Saudi Arabia, Nigeria, and Algeria). The United States also relies on Canada and Indonesia, but New York has few imports from these nations.

5. New York's pattern of dependence is generally similar to that of the United States; however, it is also different in the following ways: (a) dependence is concentrated in fewer sources rather than spread among many sources and (b) it is generally more dependent than the United States on Venezuela, Virgin Islands, Netherlands Antilles, Saudi Arabia, Nigeria, Algeria, and Trinidad and less dependent on Canada and Indonesia.

Overall, New York appears to be in a significantly tighter position than the United States generally with respect to petroleum dependence. Its dependence on all products is higher, and its pattern of dependence, although similar to that of the United States, is generally more concentrated.

New York appears particularly vulnerable with respect to residual and gasoline because of (a) the extremely high foreign dependence of residual, (b) the large spread (18.3 percent) between New York's and the United States' gasoline dependence, and (c) its exclusive use in the transportation sector.

Such a finding has profound implications, for it reflects the sensitivity of New York's transportation energy supply to an embargo. It would necessarily mean that New York would be affected to a greater degree than would the rest of the country in the event of such an embargo. Such an embargo would also affect New York's supplies of other refined products greater in relation to the rest of the country, but the greatest rift would be in gasoline supplies.

It would be easy to say that New York should cut down on its imports from OPEC nations, but the situation is not so simple. Most petroleum products from OPEC nations arrive in New York indirectly (i.e., they are refined in Texas, Louisiana, or PAD 1 refineries). Thus, as far as the state's policy goes, it would have to rely on these refineries to import less OPEC crude. Such a move implies that the crude oil would have to come from different sources, unless, of course, conservation efforts permit an absolute drop in foreign oil imports.

Based on the above, we suggest the following policies for consideration as ways by which New York State can cut its overly high foreign-oil dependence.

Foreign oil supplies could be shifted from one source to another; however, total foreign dependence cannot be reduced unless (a) the U.S. demand for petroleum is reduced through conservation and (b) present U.S. reserves are used and expanded to a greater extent. Generally, supply policies are outside the realm of any one state to influence significantly, but each state can take unilateral or joint actions to reduce demand.

1. Concentrate energy-conservation actions in the residential-commercial and transportation sectors. These two sectors use the greatest percentage of residual oil and use all gasoline, the two most vulnerable products. Conservation efforts in New York's industrial sector, although important, would impact primarily coal and natural gas use, and may slow the state's economic recovery. Such actions would be most effective if coordinated among states, since present federal policies (e.g., allocation plans) unfairly burden states that are already relatively energy efficient, such as New York.
2. Substitute flexible-source fuels for inflexible-source fuels where possible, to reduce pressure on less flexible sectors, such as transportation. Encourage national actions to achieve these ends. Examples of such conversions would be residual oil to coal or additional small hydro plants for the generation to electricity and substitution of renewable fuels, such as wood or plant-based alcohols, where feasible. Coal gasification or liquefication, although expensive and in an infant industry state, could also provide significant amounts of liquid or gaseous fuels in the intermediate future.
3. Encourage the conversion of existing residential and commerical structures to non-oil-based heat and the construction of new structures with attendant heat sources. Such a move would accelerate the introduction of these new energy sources into New York's economy.
4. Encourage consumers, through incentives, to purchase automobiles that meet the energy-conservation standards of the federal government. If the efficiency of New York's motor vehicle fleet reaches 11.7 km/L (27.5 miles/gal) average by 1990, about 18 percent of the gasoline could be saved (4). This is the single most effective action to conserve gasoline that New Yorkers can take.
5. Support actions to increase aircraft load factors, thereby reducing the jet fuel required to serve a given number of air passenger kilometers. Jet fuel use is a small percentage of the present energy use, but its use is increasing rapidly and its use should be conserved.

Generally, New York is limited to acting in concert with other similarly positioned states and the United States in influencing energy supplies. Such actions are intended to reduce the overall energy dependence of New York on foreign countries and to make maximum use of its own resources. Such actions alone cannot solve the energy crisis or make it energy independent: Only by acting with other states, by maximizing use of new technology, and by reducing demand can progress be made toward these goals. Although we cannot yet control our energy future, we can influence it in certain ways. The thrust of this paper is that such actions as we can take are wisely viewed against New York's unique energy supply picture.

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Vehicle Kilometers Traveled: Evaluation of Existing Data Sources

Leon M. Rudman, Research and Special Programs Administration, Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts

Vehicle kilometers traveled is the total kilometers traveled by motor vehicles on the highway system during a given period of time. Vehicle kilometers traveled by passenger automobile is an important variable in the analysis of fuel efficiency, fuel consumption, environmental quality, and highway safety. Changing patterns of future vehicle kilometers traveled have significant applications for energy conservation and economic stability. This report evaluates existing data sources for vehicle kilometers traveled and gasoline consumption. Collection, reporting, consolidation, and estimation procedures are addressed. Since direct measurement of vehicle kilometers traveled has never been made, the available information consists of indirect estimates based on various sets of assumptions. The type of assumptions and the reliability of the data determine the models and types of hypotheses that can be meaningfully tested. Historically, the importance of vehicle kilometers traveled accumulation has been directed toward highway planning and included such areas as traffic density, highway safety, and other non-energy-related areas. For these nonenergy endeavors, the traffic-counting methodology has been the procedure used most widely by the individual states to estimate vehicle kilometers traveled. However, since the 1973 energy crisis, the Federal Highway Administration has requested that the states estimate vehicle kilometers traveled based on average fuel efficiency rated for different vehicle classifications. This alternative methodology may be a more appropriate way in which to solve energy-related issues because energy efficiency is one of the predetermined variables. However, fuel-consumption rates involve many heterogeneous inputs, and it has been difficult to arrive at a meaningful state average for fuel economy. The Federal Highway Administration has not developed and selected one specific methodology to estimate vehicle kilometers traveled. No single procedure has been established to collect, report, and consolidate vehicle kilometers traveled data. Each state and every region within a state selects its own process for gathering these data. Therefore, an accurate and reliable estimate of vehicle kilometers traveled from heterogeneous inputs cannot be obtained.

Vehicle kilometers traveled is the total kilometers traveled by motor vehicles on the highway system during a given period of time. Vehicle kilometers traveled by passenger automobile is an important variable in the analysis of fuel efficiency, fuel consumption, environmental quality, and highway safety. Unless otherwise specified, vehicle kilometers traveled henceforth will refer to passenger automobile vehicle kilometers traveled. Changing patterns of future vehicle kilometers traveled have significant implications for energy conservation and economic stability (1). The transportation sector uses 53 percent of the total petroleum consumed in the United States, and the passenger automobile accounts for 53 percent of all transportation energy as well as 69 percent of the highway energy (2).

This report evaluates the existing data sources for vehicle kilometers traveled and gasoline consumption. Collection, reporting, consolidation, and estimation procedures are addressed. No direct measurement of vehicle kilometers traveled has ever been made; the available information consists of estimates based on various assumptions. The assumptions and the reliability of the data determine the models and types of hypotheses that can be tested.

Historically, the importance of vehicle kilometers traveled accumulation has been directed toward highway planning and included such areas as traffic density, highway safety, and other non-energy-related areas. Since 1973, attempts have been made to use vehicle kilometers traveled statistics to address problems of fuel efficiency, fuel consumption, and energy conservation. Accordingly, many states are currently evaluating their methodologies and are considering changes in their estimating procedures for travel distances in order to reflect more properly these energy-related problems.

GENERAL METHODOLOGIES OF TRAVEL-DISTANCE ESTIMATION

The quality of existing travel-distance data limits the reliability of future studies on fuel consumption. Mellman indicates (3), "There are no direct measurements of actual annual VMT [vehicle miles traveled] in the United States at any level of aggregation. Therefore, VMT analysis must rest on estimates of VMT. There are three sources of estimates of VMT, but each has limitations."

Only two national sources of information on automobile travel currently exist. The Federal Highway Administration (FHWA) publishes an annual report, Highway Statistics (4). In conjunction with the 1970 census, FHWA also sponsored the Nationwide Personal Transportation Study (NPTS), in which a sample of households were questioned about their travel behavior.

Nearly all current data on annual estimates of national travel distances are compiled by the FHWA. Highway Statistics, from which Table 1 of this study was derived, is the most widely cited of the travel distance data. It forms the empirical basis for highway planning and is now being used for fuel-efficiency studies. These statistics are taken from state estimates, which are based on gasoline-consumption records. By multiplying fuel sales by estimates of fleet fuel economy (L/km), the states compute vehicle kilometers traveled per year.

While gasoline consumption is accurately known from tax data, estimates of liters per kilometer are a major source of error. What liters per kilometer actually depend on, and whether these factors can be empirically measured, are complex problems. In principle, average fuel economy in a state depends on

1. The drive cycle (drive schedule, meteorology, and topography),
2. Spatial distribution of travel (urban versus rural travel) in each state, and
3. The mix of automobiles by age and weight.

However, Rabe states (5):

> It is theoretically possible, then, to start with independent information of fuel economy by weight class and age of vehicle and develop a composite weighted average fuel economy that accounts for the type of vehicle driven, driving cycles, and physical factors. Unfortunately, the precise influence of driving cycle, climate, and topography on fuel economy is not known, so that even the most careful estimates would introduce some error.

In practice, the situation is much worse. Each state produces its own vehicle kilometers traveled estimate by using any procedure it wishes. The procedures fall into three broad categories:

Table 1. Estimated motor-vehicle travel in the United States and related data.

		Passenger Vehicles										
		Personal Passenger Vehicles			Buses				Cargo Vehicles			
Item	Year	Passenger Automobiles[a]	Motorcycles[b]	All	Commercial	School and Other Nonrevenue	All	All	Single-Unit Trucks	Combinations	All	All Motor Vehicles
Motor vehicle travel (vehicle-km 000 000s)												
Main rural roads	1975			529 555	1 493	1 497	2 990	532 546	145 501	71 321	216 822	749 368
	1974			504 857	1 553	1 481	3 034	507 891	138 504	71 716	210 219	718 110
Local rural roads	1975			180 002	129	1 641	1 770	181 772	33 333	2 150	35 483	217 255
	1974			182 831	145	1 625	1 770	184 602	34 068	2 232	36 300	220 902
All rural roads	1975			709 558	1 622	3 138	4 760	714 318	178 834	73 472	252 305	966 623
	1974			687 688	1 698	3 106	4 804	692 492	172 572	73 948	246 520	939 012
Urban streets	1975			981 016	2 639	885	3 525	984 541	173 443	15 944	189 386	1 173 927
	1974			942 690	2 502	837	3 339	964 029	167 741	16 270	184 011	1 130 040
Total	1975	1 654 603	35 970	1 690 573	4 262	4 023	8 285	1 698 858	352 276	89 415	441 692	2 140 550
	1974	1 594 413	35 964	1 630 377	4 200	3 943	8 143	1 638 520	340 312	90 218	430 531	2 069 051
Number of vehicles registered (000s)	1975	106 712.6	4 966.8	111 679.4	93.8	368.3	462.1	112 141.5	24 644.7	1 131.0	25 775.7	137 917.2
	1974	104 856.3	4 966.4	109 822.7	90.1	356.9	447.0	110 269.7	23 545.2	1 085.0	24 630.2	134 899.9
Average distance traveled per vehicle (km)	1975	15 504	7 242	15 137	45 432	10 924	17 928	15 149	14 294	79 059	17 136	15 520
	1974	15 205	7 242	14 846	46 620	11 048	18 218	14 859	14 453	83 150	17 479	15 337
Fuel consumed (L 000 000s)	1975	287 729	1 692	289 421	2 093	1 295	3 388	292 809	82 779	36 960	119 740	412 474
	1974	279 250	1 692	280 942	1 987	1 260	3 247	284 189	79 967	38 236	118 203	412 549
Average fuel consumed per vehicle (L)	1975	2 695	341	2 593	22 319	3 517	7 332	2 612	3 358	32 679	4 645	2 990
	1974	2 665	341	2 559	22 058	3 532	7 264	2 578	3 396	35 242	4 800	2 983
Average distance traveled per liter of fuel consumed (km/L)	1975	5.75	21.26	5.84	2.04	3.11	2.44	5.80	4.26	2.40	3.69	5.19
	1974	5.71	21.26	5.80	2.11	3.13	2.51	5.76	4.26	2.36	3.64	5.14

Notes: 1 km = 0.62 mile; 1 L = 0.26 gal; 1 km/L = 2.35 mile/gal.
Cells may not add due to rounding.

[a] For the 50 states and the District of Columbia.

[b] Separate estimates of passenger automobile and motorcycle travel are not available by highway category.

1. Simple trend extrapolation based on socioeconomic changes;
2. Extrapolation of traffic counts, based on number of vehicles per kilometer of roadway; and
3. Some variant of the procedure outlined above, usually based on a very rough estimate of average fuel economy.

In short, the FHWA data represent the only time series currently available. Their accuracy is questionable because of nonuniform estimation procedures. Yet they are frequently cited since some data are better than none. FHWA has undertaken some new studies in order to improve the quality of existing information in this critical area.

STATE APPROACHES

An area in need of further study is the state inputs to the FHWA annual travel-distance statistics. An understanding of the ways in which travel-distance statistics are currently being compiled by individual states is needed.

The Transportation and Economic Research Association (TERA) surveyed all 50 states for the methodology each used to prepare annual estimates of travel distance (6). Basically, TERA found that there are two methods used by states in compiling travel-distance data—the vehicle-count method and the fuel-consumption method. These methods are used individually or in conjunction with each other.

Although vehicle counts offer a good alternative to the fuel-efficiency method, there is need for improvement. There is substantial diversity in the counting methodology with respect to persons responsible for the counting programs, how the programs are administered, and how the results are processed.

The second method used by the states to compute vehicle travel distances is the fuel-consumption method. Since the 1973 energy crisis, FHWA has requested that the states use the fuel-consumption method to estimate vehicle kilometers traveled. Unfortunately, most of the state estimates assume an existing fuel efficiency and thus lack usefulness for estimating the fuel efficiency of the national fleet. Estimates of vehicle kilometers traveled prior to 1973 have been directed mainly toward highway planning and have included such areas as traffic density, highway safety, and other non-energy-related areas.

All states cannot employ one single methodology to determine fuel-efficiency rates. Because drive cycles and drive schedules are heterogeneous, there is no simple solution. The Claffey model attempted to estimate vehicle kilometers traveled by using the fuel-consumption method without the problems inherent in that model.

Vehicle Counts

The most widely used technique for estimating vehicle kilometers traveled is the traffic-count procedure. This procedure assumes that the vehicle kilometers traveled in a state during a year can be estimated by counting the traffic on representative sections of roadway (links) during short periods of time and expanding these results to statewide totals.

The total vehicle kilometers traveled in a state during a year is then:

$$\mathrm{VKMT} = \Sigma C_{ij} L_i w_i t_{ij} \qquad (1)$$

where

VKMT = vehicle kilometers traveled,
C_{ij} = traffic volume (count) passing location i during period j,
L_i = length of the link (km) on which location i is located,
w_i = assigned weight (or expansion factor) to equate with L_i with the total set of links it represents, and
t_{ij} = assigned weight (or expansion factor) to equate the count during period j with the total annual count at location i.

A link is a section of roadway that has homogeneous traffic volume. It usually encompasses a section of roadway between two major intersections. Links on local streets range from 0.40 to 0.80 km (0.25 to 0.5 mile), arterials from 0.80 to 1.61 km (0.5 to 1.0 mile), and freeways from 1.61 to 3.22 km (1 to 2 miles) (7, p. iv).

No one standard procedure is used to estimate vehicle kilometers traveled. Each state and city traffic-counting program is, in essence, a different sampling procedure. As FHWA has indicated (7, p. 2),

> The most reliable method of developing vehicle-mile and traffic volume information is to count each location continuously throughout the entire year. These long-term counts—in both a spatial and temporal sense—would provide an accurate picture of the entire population of counts—since there would be no sampling errors. However, such a procedure is difficult and costly to achieve in practice. Consequently, a great variety of sampling methods have been employed.

All road systems are classified according to FHWA guidelines and broken down into section lengths that are then monitored, either manually or by a selection of automatic devices, for traffic volume. The reliability of this monitoring is based on equipment used, as well as on the location and on the frequency of the counts. Equipment is extremely costly to use on an extensive network of local roads that carry relatively light truck volumes.

There are three types of traffic counts: (a) a permanent or continuous traffic volume; (b) a seasonal-sample type of traffic count, which is a special count done either to indicate a seasonal variation or to represent a percentage of the state's roadways that can be expanded to represent the total; and (c) complete system coverage that may involve only one road classification or all road classifications in a state. In any case, the system is broken into section length. Complete coverage means that every kilometer of the system is included in the count and the vehicle kilometers traveled is actual rather than expanded from a sample.

The sampling procedures are designed to estimate link-volume counts in 24-h, 48-h, or 5-day periods. In some states, both a complete coverage over multiple-year cycles and sample counting over selected links are undertaken and the results of both are adjusted to reflect seasonal variations. Because the costs of undertaking complete or permanent counts of each kilometer of roadway are prohibitive, traffic sampling is necessary.

Permanent counting is necessary to verify traffic volume on local roads, which account for approximately 70 percent of roadways but for only 12 percent of total highway travel. In most states, the number of these monitoring stations is insufficient. Any extensive expansion of additional stations for local rural or urban roads would be too expensive for most states to undertake.

However, only at continuous (permanent or complete counts) monitoring stations and under perfect conditions can true average daily traffic (ADT) be determined with absolute accuracy. This assumes that there are no mechanical failures and that correct vehicle classification data are available when axle counts are converted to vehicles. Any count of less than one year must be regarded as a sample.

Every state has its own problems concerning traffic-volume information. There is no single procedure that will solve all problems. Nevertheless, there is a methodology that will produce appropriate answers concerning the location and number of stations, length and frequency of counts, and the accuracy of the results. Therefore, it is necessary to consider separately the counting and the estimation of traffic volumes on rural roads and urban streets.

The procedure that is presented for high-volume rural roads can be divided into three major steps (8, pp. 2-5):

1. Grouping continuous-count stations into similar patterns of monthly traffic volume variation,
2. Assigning road sections to groups of similar patterns of monthly variation, and
3. Locating and operating traffic-counting stations.

The major premise for high-volume rural roads, which carry approximately 500 ADT or more, is that it is possible to establish a series of consecutive continuous road sections that have similar patterns or monthly traffic volume variation and to assign road sections to groups of similar patterns of monthly variations. Stations of the same group usually fall along continuous routes. Thus, two fundamental assumptions of traffic volume measurement are that the pattern of monthly variations of traffic volume persist over long stretches of highway and over long periods of time.

After all road sections have been allocated to groups of similar monthly patterns of traffic variation, it may be possible to eliminate or relocate some of the continuous-count stations. This decision, however, should be made only after careful determination of all purposes served by these stations. These considerations should include (7, pp. 14-15)

1. Continuous-count stations, in addition to providing adjustment factors for expansion of coverage counts, may be needed for long-range determination of traffic trends at a particular point;
2. Determination of accurate peak-hour counts at a particular station may be desirable;
3. Other local information may be used;
4. The road sections for which records are not available should be studied (either permanent or seasonal control stations should be located on these sections in future years to enable the proper classification of these road sections by groups; if seasonal count stations are operated, each count should be for a one-week duration);
5. Retention of continuous-count-station locations may be desirable to determine the rates of change of travel; and
6. In general, a minimum of six continuous-counting stations should be located in each group of road sections with an independent set of monthly factors.

Rural roads that carry less than 500 ADT must be treated differently from roads that have higher traffic volumes. Past studies have shown that the standard error of estimate increases at a much greater rate when the traffic volume ranges from 25 to 500 ADT (7, p. 16).

A total of 4111 continuous permanent counting locations have been established nationwide. The number of automatic-traffic-recorder (ATR) locations varies by state. For example, Alaska has only 32 ATRs, but each 1.6 billion VKMT (1 billion vehicle miles traveled) is covered by 11.7 counters. On the other hand, Texas has the largest number of ATRs at 255; yet each 1.6 billion VKMT is based on 2.9 ATRs.

Urban ATR locations account for only one-third of all continuous counts, yet represent 55 percent of nationwide vehicle kilometers traveled. The remaining two-thirds of the counters are located in rural areas, which account for 45 percent of all vehicle kilometers traveled on 83 percent of total highway roadway (9). Since the number of urban ATRs in proportion to urban vehicle kilometers traveled is small and the larger number of rural ATRs are distributed over an extensive rural highway system, the possibility exists that significant changes in traffic could take place and not be detected.

Vehicle monitoring is only as good as the traffic-counting equipment. Unfortunately, some of this equipment is too expensive for state and local governments. Some, such as the ultrasonic overhead detector, are very accurate; but their disadvantages must be weighed against their positive features. The main assets are freedom from deterioration caused by traffic wear, snow, and ice and ability to provide accurate counts of vehicle by lanes. The main parallel lanes of automobiles pass simultaneously on multilane roads, which causes biases in distinguishing individual lane volumes and overcounting when a vehicle changes lanes. The best and the most accurate counter appears to be overhead measures, but these have a very high initial cost.

Fuel-Consumption Method

The fuel-consumption method is the second procedure that the states use to compile vehicle kilometers traveled data. This method assumes that vehicle kilometers traveled in a state during a year is a function of the fuel-consumption rate and the number of liters of motor fuel consumed by vehicles in one year.

$$\mathrm{VKMT}_s = (\mathrm{km/L}_s)\,(\mathrm{FC}_s) \qquad (2)$$

where FC = gasoline consumed, s = state, and $\mathrm{km/L}_s$ = average fuel efficiency. It has been assumed that the fuel-efficiency rate for each state is determined independently from the national fuel-consumption rate. According to TERA (6, p. 50)

> The source for fuel consumption data is most often the fuel tax receipts, and the average mile per gallon figure is either suggested by FHWA and adjusted by the state based on judgment, or generated from state studies in the past which enables calculation of trend values for the current year.

Table 2 is a state-by-state summary, compiled by TERA, that is used to estimate vehicle kilometers traveled every year (15, p. 52). A combination of traffic counts and fuel-consumption estimates are used by 23 states. Only 12 have made an independent empirical investigation of kilometers per liter, 4 use FHWA guidelines, and 7 use an unspecified method. FHWA guidelines imply that the states may use the computed national figure for kilometers per liter to determine the individual state vehicle kilometers traveled.

Indeed, causality becomes a major issue because

Table 2. Comparative summary of state practices to estimate travel distance.

					Fuel-Consumption Method						
	Traffic-Count Method				Fuel-Consumption Estimate				Estimate (km/L)		
State	Permanent Station[a]	Seasonal Sample[b]	Complete System Coverage[c]	Manual or Automatic[d]	Tax Records	Ratio to National	Whole-sale Figures	Other	Empirical Study	FHWA Guideline	Other
Alabama	X	X		A							
Alaska	X	X	X		X				X		
Arizona		X		A				X		X	
Arkansas	X	X	X	A							
California	X	X		A	X						X
Colorado	X	X		A							
Connecticut			X	A				X			
Delaware		X		A							
Florida	X	X		A							
Georgia	X	X	X	A							
Hawaii	X	X		A	X				X		X
Idaho		X		A	X						
Illinois	X	X		A	X					X	
Indiana	X	X		A	X					X	
Iowa	X	X	X	A							
Kansas		X	X	A							
Kentucky	X	X		A	X				X		
Louisiana	X	X	X	A							
Maine		X	X	A	X					X	
Maryland		X	X	A							
Massachusetts	X	X		A							
Michigan					X				X		
Minnesota	X	X	X	A							
Mississippi		X	X	A				X			X
Missouri	X	X	X	M,A				X			X
Montana	X	X		A	X				X		
Nebraska	X	X	X	M,A				X			X
Nevada	X	X		A							
New Hampshire	X	X		A	X						X
New Jersey	X	X	X	M,A	X				X		
New Mexico	X	X	X	A							
New York								X			
North Carolina		X		A				X			
North Dakota	X	X		M,A							
Ohio	X	X		A	X				X		
Oklahoma	X	X		A	X				X		
Oregon		X	X	A				X	X		
Pennsylvania		X	X	A		X			X		
Rhode Island		X		M,A							
South Carolina		X		A	X				X		
South Dakota	X		X	A							
Tennessee	X			A	X				X		
Texas	X	X		A							
Utah	X	X	X	A							
Vermont		X	X	A							
Virginia		X	X	A				X			X
Washington	X	X		A							
West Virginia		X	X	A							
Wisconsin		X		A	X				X		
Wyoming	X	X		A							
District of Columbia	X	X		M,A							

[a] A permanent counting station is placed at one location for a year and continuously monitors traffic volume.

[b] The seasonal-sample type of traffic count is a special count done either to indicate a seasonal variation or to represent a percentage of the state's roadway that can be expanded to represent the total.

[c] Complete system coverage traffic counts may involve only one road classification or all in a state. In either case, the system is broken into section lengths, each of which is monitored and for which an ADT is calculated. Complete coverage means that every kilometer of the system is included in the count and the vehicle distance traveled is actual rather than expanded from a sample.

[d] There are two ways to perform an actual count, either manually (M) or by automatic traffic recorders (A).

FHWA then uses national vehicle kilometers traveled data to compute national fuel consumption.

$$\mathrm{km}/L_n = VKMT_n/FC_n \tag{3}$$

$$\sum_{1}^{50} VKMT_s = VKMT_n \tag{4}$$

where n = nation. Surprisingly, no one state has been using only the fuel-consumption method to estimate vehicle kilometers traveled. The Claffey method (10, p. 3), an improvement in the fuel-consumption method, has been used in New York, is being considered by Michigan, and has been used to verify the results of Oklahoma's methods. The remaining states used some form of traffic counting.

All states cannot employ one single methodology to determine fuel-efficiency rates. Because drive cycles and drive schedules are heterogeneous, there is no simple solution. Also, other variables, including automobile accessories, tires, and vehicle weight, add to the complexity of the problem. If every state in the United States were identical, many of these problems that are critical to this study would be eliminated.

For example, meteorology and topography, which have an impact on the drive cycle, have widely different characteristics. Maximum fuel economy is achieved at 21°C (70°F). For the full city and highway cycle, the fuel economy penalty ranges from 8 to 16 percent for -7°C (20°F) operation and from 0 to 5 percent for 38°C (100°F) operation (11, p. 29). Hills cause increased fuel consumption: The steeper the hills, the greater the increase in fuel consumption and the greater the rate of increase. This is true for both urban and highway cycles and for large and small automobiles. On a national basis, urban fuel consumption is increased by 6.6 percent and the highway fuel consumption is increased by 5.5 percent.

Furthermore, the drive schedule presents varying trip characteristics and behavioral differences to include origin and destination of trip, road design, traffic congestion, and stop-and-go frequency. For operation at an ambient of 21°C, an automobile is warmed up to the point where it will give 95 percent of its fully warmed-up fuel economy after a trip of about 6-8 km (4-5 miles). However, for that trip, the average fuel economy is only 70 percent of its warmed-up potential. Trips shorter than 8 km constitute 64 percent of all trips and consume 31 percent of all fuel, yet account for only 15 percent of vehicle kilometers traveled, as can be seen in Table 3, which is summarized below (1 km = 0.62 mile).

Trip Length (km)	Trips (%)	Fuel (%)	Vehicle Kilometers Traveled (%)
0-8	64	31	15
8-16	22	17	17
0-16	86	48	32

Disaggregation by purpose or location of trip is appropriate, because these travel characteristics influence other facets of analysis and because these travel sensitivities could vary with the type of trip (e.g., work versus leisure and urban versus rural or suburban). More than half of all workers (52 percent) live 8 km or less from the job; and 20 percent travel longer distances of 24 km (15 miles) or more from work. The average home-to-work trip length by automobile is 15.1 km (9.4 miles). Trip lengths are generally longer in unincorporated areas [17.9 km (11.1 miles)] and incorporated places of 1 million and larger [22.7 km (14.1 miles)]. In the latter areas, 53 percent of all home-to-work vehicle kilometers of travel is generated by workers who commute more than 33 km (21 miles) to work. The automobile accounts for three-fourths of all home-to-work travel (12).

Finally, stop-and-go frequencies account for such variables as speed, accelerations, decelerations, idle, and cruise. In short, fuel-efficiency rates are so heterogeneous that is misleading for FHWA to use one estimate for kilometers per liter throughout the nation. State and regional variations do occur and their inputs are required to determine the true fuel-economy values.

In sum, no test-procedure drive schedule was found to have been adequately correlated with actual in-use driving (13, p. 5-4). EPA test errors are possible through a number of variability factors. The EPA drive schedules, determined by dynamometer fuel-economy testing, do not accurately present urban and rural highway driving. Recent field studies that have attempted to determine in-use vehicle drive schedules have not had a favorable outcome. Since several variables affect a drive schedule for a particular trip, specific values for each may not be duplicated for other trips.

FHWA METHOD OF ESTIMATING VEHICLE TRAVEL DISTANCES

The purpose of this section is to develop an understanding of the way in which FHWA estimates vehicle kilometers traveled. There are two major data sources. The first is the average fuel economy (km/L), and the second is the vehicle count. In each state the fuel economy depends on

1. The share of automobiles by age and weight,
2. The spatial distribution of travel, and
3. The drive cycle (climate, topography, and drive schedule).

The exact influence of the drive cycle on the fuel-consumption rate is assumed. The vehicle count is determined by a sampling of the number of vehicles per kilometer of road.

Table 1 stresses the fuel-efficiency approach and is derived from data principally submitted by state transportation departments. Average kilometers traveled per liter of fuel consumed is computed by dividing vehicle kilometers traveled by fuel consumed. Average kilometers traveled per vehicle is calculated by dividing vehicle kilometers traveled by vehicle registrations.

Several caveats should be noted. First, the approach used to prepare Table 1 is slightly different each year, depending on the data available and the analyst. The development and documentation of standardized procedure has not been accomplished by FHWA. Some intermittent values are developed by analyzing trends, but in other years empirical derivations are used. Thus, a precise explanation for the development of Table 1 is very difficult. The most complete description of these procedures is documented in the TERA reports and in an FHWA document dated January 5, 1978.

Second, the inputs used by FHWA to compute the data in Table 1 are often compiled by more than one source. For example, there is a recurring discrepancy between FHWA registration data compiled on a full calendar year approach and R. L. Polk estimates of vehicles in use on July 1 of each year (14). As Table 4 reveals, the percentage difference can range from 7.6 to 13.4 percent. Over the past 10 years, the average difference between FHWA and Polk estimates has been 11.2 percent.

The FHWA data are based principally on reports from state highway departments. States are instructed to

Table 3. Effect of trip length on fuel economy.

Trip Length (km)	Trips (%)	Vehicle Distance Traveled (%)	City Driving Warm-Up City Fuel Economy (%)	Incremental Fuel Economy (%)
1.6	17	1.5	47	47
3.2	16.5	2.8	61	75
4.8	13	3.5	69	85
6.4	10	3.6	74	89
8.0	7.5	3.7	77	89
Subtotal	64	15.1		
9.7	6.5	3.5	80	95
11.3	5.0	3.4	83	100
12.9	4.0	3.3	85	99
14.5	3.5	3.2	86	
16.1	3.0	3.1	88	
Subtotal	22	16.5		
Total	86.0	31.6		

Note: 1 km = 0.62 mile.

Table 4. Comparison of alternate estimates of automobile travel per year.

Year	FHWA Registrations (calendar year)	Polk Automobiles in Use (in use July 1)	Percentage Difference[a]	Vehicle Travel (km/year)	
				FHWA	Polk[b]
1960	61.7	57.1	8.1	15 202	16 433
1961	63.4	58.9	7.6	15 232	16 390
1962	66.1	60.9	8.5	15 184	16 475
1963	69.0	63.5	8.7	15 092	16 406
1964	72.0	66.1	8.9	15 155	16 504
1965	75.3	68.9	9.3	15 107	16 512
1966	78.1	71.3	9.5	15 297	16 750
1967	80.4	73.0	10.1	15 421	16 979
1968	83.6	75.4	10.9	15 493	17 181
1969	86.9	78.5	10.7	15 743	17 428
1970	89.3	80.4	11.1	16 058	17 841
1971	92.7	83.1	11.6	16 288	18 178
1972	97.1	86.4	12.4	16 390	18 422
1973	101.8	89.8	13.4	16 081	18 234
1974	104.9	92.6	13.3	15 279	17 312
1975	107.4	95.2	12.8	15 535[c]	17 523

Note: 1 km = 0.62 mile.

[a] Computed as [(FHWA data − Polk data)/Polk data] × 100.

[b] Computed as (FHWA VKMT/year) × [1 + (percentage difference/100)].

[c] Jack Faucett Associates estimate based on 1974-VKMT growth of 4.1 percent, reflective of traffic growth by all highway vehicles, as reported in Traffic Volume Trends.

eliminate from their totals any vehicles that have been reregistered during the year. Because of differences in registration plate transfer practices and state record-keeping procedures, some states may not remove all reregistrations, such as those attributable to interstate transfer of registration or those due to resale and reregistration of a vehicle. Adjustments are made by FHWA to correct for omissions of this sort.

The key difference between the sources is their conception. FHWA includes all vehicles that have operated on the roads during a calendar year, including vehicles that are retired during the year. Polk counts the vehicles that are registered to operate at one point in time. Polk data reflect adjustments for reregistered and scrapped vehicles. Consequently, the Polk estimate for registrations appears to be more accurate and should be a better measure for computation of the annual distance traveled per vehicle.

Next, although total vehicle kilometers traveled for all motor vehicles is submitted annually by each state according to a uniform reporting format, there is no single methodology applied by all states to derive and compile vehicle kilometers traveled data. FHWA is currently developing a uniform computational procedure based primarily on the analysis done by Claffey in 1972 for FHWA (10). The procedure is a computerized algorithm for use in estimating travel on non-federal-aid roads where vehicle counts are not available. Factors that affect motor vehicle fuel-consumption rates are incorporated into the analysis. These include roadway design, terrain, and meteorological conditions as well as vital distributions by highway system and vehicle type.

Once these individual state vehicle travel distances have been totaled into a nationwide figure for all motor vehicle travel, FHWA uses a variety of procedures to derive travel by vehicle type (15). Although the FHWA procedure appears to indicate that total vehicle kilometers traveled for passenger automobiles reported by FHWA is a residual figure obtained by successive deductions from the total highway vehicle kilometers traveled data reported by state transportation departments, the final estimate for passenger automobiles is checked by FHWA against data compiled and published by other sources.

In addition, the FHWA data on motor-fuel consumption are compiled from statistics provided by each state, based on motor-fuel tax receipts. The gross fuel consumption reported gasoline used for both highway and nonhighway purposes. Data on nonhighway uses of gasoline are not recorded in the same way in all states. In fact, except for Arizona, it is necessary to estimate a portion of all of the nonhighway use. FHWA adjusts nonhighway motor-fuel consumption from total use. The lack of reliability of nonhighway statistics is overshadowed by the fact that they constitute only a small fraction (3.2 percent in 1975) of the total gasoline consumption throughout the nation. Thus, the total highway fuel consumption given in Table 1 is fairly accurate. However, this type of data is very unreliable for select farm states.

The most significant off-highway use is agriculture (50 percent in 1975); next is marine use (23 percent). Since gasoline taxes were designed as a user tax collected to support the highway system, farmers may apply for refunds when gasoline is used solely for farming. The five states that had the highest percentage of agricultural gasoline use in 1975 were North Dakota (28 percent), South Dakota (18 percent), Iowa (11 percent), Wyoming (9 percent), and Nebraska (8 percent). Although the total farm use of gasoline is approximately 3 percent nationwide (which is insignificant) inclusion of these data for the above five states can give misleading results.

Finally, the process of arriving at a national fuel-efficiency rate is not a strict case of only dividing vehicle kilometers traveled by the number of liters of fuel consumed:

$$\mathrm{km}/\mathrm{L}_n = \mathrm{VKMT}_n/\mathrm{FC}_n \tag{3}$$

The fuel economy by vehicle class is based on the subjective evaluation and judgment of the respective analyst for a particular year (16, p. 27). The procedure for determining kilometers per liter figures in Table 1 seems to maintain the status quo; only small incremental adjustments are necessary to account for the year changes in vehicle registrations, fuel consumption, and vehicle kilometers traveled. Only when new information, such as an update of a major survey, becomes available are major changes made in the annual fuel economy figures.

However, state vehicle kilometers traveled estimates are based on an assumed knowledge of individual state fuel economy:

$$\mathrm{VKMT}_s = (\mathrm{km}/\mathrm{L}_s)(\mathrm{FC}_s) \tag{2}$$

$$\mathrm{VKMT}_n = \sum_{1}^{50} \mathrm{VKMT}_s \tag{4}$$

It has been theorized that the fuel-efficiency rate for each state is determined independently from the national fuel-consumption rate safety average. Nevertheless, for the 17 states that now use the fuel-consumption method in combination with the traffic counts, only 12 have made an independent empirical investigation of kilometers per liter; 4 use FHWA guidelines. Empirical investigations do not have a standard methodology and are made infrequently. FHWA guidelines imply that the states may use the computed national figure for fuel economy to determine the individual state vehicle kilometers traveled. Indeed, in this circumstance, causality is a major issue.

NPTS DATA

The major alternative for a national study of vehicle kilometers traveled is the NPTS. This is a cross-section study of 6000 households in 1969-1970. This study gained insight into the relation between demographic and economic characteristics and automobile travel. Some of the variables examined that were relevant to aggregate vehicle kilometers traveled considerations included the number of automobiles per household, origin and destination of trip, urban versus rural travel, discretionary versus necessary travel, age of automobile, income and vehicle kilometers traveled correlations, and annual kilometers of automobile travel. These microscale data might be used to overcome many of the impediments caused by the national level of aggregation of FHWA data.

Some comparisons of travel characteristics were done for urban and rural households. Within the urban trip classification, trip lengths tend to increase with urban size. For example, in cities that have a population of 25 000-49 000, 59 percent of all trips were less than 8 km (5 miles); in those cities that have more than 1 million people, only 44 percent of all trips were less than 8 km (12). Furthermore, the data showed that rural households consume more personal transportation and take longer and more frequent trips than do their urban counterparts.

Yet, there are many limitations to using NPTS statistics as a major source of information for vehicle kilometers of travel. First, vehicle kilometers traveled data are based on guesses of annual travel by individuals rather than on actual odometer readings. Nobody knows how accurately individuals can estimate their vehicle kilometers traveled, but these observations are bound to have large errors. NPTS estimates are 15 percent greater than those of FHWA for national vehicle kilometers traveled.

Second, no data were collected on existing fuel prices for the consumers. Hence, only approximate measures of the cost of travel can be developed. In addition, this survey was made several years before fuel prices increased to their existing high levels. Accordingly, individual responsiveness to magnitudes of price increases may be somewhat different.

A third drawback is the purely cross-sectional character of the statistics. The data represent a picture of the situation existing at the time of the study, 1970. The implications of this static picture are dubious. Are the data characteristic of past years? Do they represent short-term or long-term responses?

Also, the published NPTS report does not reveal geographic locations of the respondents. Therefore, it is impossible to relate annual vehicle kilometers traveled per household to the spatial characteristics of the region or the city of residence and the average cost of gasoline.

Finally, long-range forecasts of vehicle kilometers traveled rely largely on estimates or how anticipated changes in real income affect the individual's driving habits. Unfortunately, the NPTS has a very small sample of upper-middle-income and upper-income households. It is not weighted toward the projected income distribution of the future. Thus, there is little evidence as to how increasing income influences vehicle kilometers traveled.

The impact of household family size (or number of drivers) on vehicle kilometers traveled per household is not discussed. It is wrong to impute the higher vehicle kilometers traveled associated with larger families exclusively to the higher average income of larger households. For the future, some economists are projecting higher household income but not larger households. Vehicle kilometers traveled analysis must isolate the impact of larger households on vehicle kilometers traveled from the impact of higher income on vehicle kilometers traveled.

Conversely, the greatest value of the NPTS data lie in their microlevel of disaggregation (3, p. 4). The national data of FHWA may be easier to use but they hide important behavioral relations of the individual consumer found at the microlevel. The NPTS household response represents a good, consistent base of socioeconomic information related to vehicle kilometers traveled and automobile ownership.

Another difference between the NPTS data and FHWA occurs in the annual kilometers traveled. Observed annual vehicle kilometers traveled are obtained from home interviews; however, the kilometers per vehicle value in Table 1 is a calculated value found by dividing total automobile travel by the number of registered vehicles. Since all registered vehicles are not operated by households during the entire year, the number of automobiles registered should be substantially greater than the number resulting from expanding the number in the sample households. In another case, a household would be classified as a two-automobile household if that were the number owned at the time of the interview for the NPTS. However, if both automobiles were scrapped and replaced during the year, that particular household would account for four registered vehicles in the FHWA computations. Double counting is not totally eliminated in the latter study.

Perhaps the new NPTS report, which is now in progress, will rectify some of the past inadequacies. The sample size, consisting of 20 000 interviews, will be much improved. The gasoline price is included in the questionnaire and regional information may be available in the analysis. Tapes are expected to be available in late 1978 and some analytical work should be released in late 1979. In the future, these cross-section studies may be undertaken at five-year intervals. Therefore, as the data collection for vehicle kilometers of travel improves, better estimates of the fuel efficiency of the automobile fleet will become available.

PROBLEMS AND IMPROVEMENTS

FHWA has undertaken many recent studies to improve the accumulation of vehicle kilometers traveled statistics. First, the Claffey report, which developed fuel-consumption rates for each state by vehicle type and highway system is the basis for the algorithm of RDTRAV (17). This computerized program uses an adjusted Claffey model. For example, RDTRAV employs 13 highway systems; Claffey has 6. RDTRAV used 10 vehicle classes; Claffey has 4.

Estimates of vehicle travel for the various highway systems are reported annually by each state in a report to the FHWA. These data are generally accurate for heavily traveled (high-level) road systems, where they are determined by traffic counts. However, they are often questionable for local (low-level) roads, where full coverage by traffic counts is impractical.

The need for accurate travel statistics led to a consideration of the use of fuel-consumption rates, known vehicle travel on high-level roads, and total statewide fuel consumption for determining travel figures for a low-level highway system. This approach has been implemented in the computer program RDTRAV (18).

The top-level logic of RDTRAV is straightforward. Known vehicle-travel figures for high-level roads (specified for the state as a whole or on a subarea basis) and estimates of average fuel-consumption rates for these road systems are used in subareas. These fuel-consumption figures are summed over all subareas and the result is subtracted from total fuel consumed statewide to produce fuel consumed on low-level roads throughout the state. This result, together with the fuel consumed on low-level systems, yields the desired travel figures for low-level roads.

A key element of this approach is the accurate estimation of average fuel-consumption rates. Vehicle fuel consumption on the various highway systems is affected by a variety of highway design features, vehicle characteristics, environmental conditions, and traffic-flow characteristics. A search of the literature reveals the lack of available engineering models for computing the effect of these parameters on fuel usage. However, extensive work has been accomplished in the past in the area of experimental tests to produce empirical estimates of fuel usage under a variety of operating conditions. Winfrey (19) and Claffey (20) did the initial work in this area. To this was added the work in vehicle mix and population of the Transportation Systems Center in Cambridge, Massachusetts, and also by Claffey (10), who developed fuel-consumption rates for each state by vehicle type and highway system, taking into account the motor vehicle population and design features on each system. These and other empirical studies are the basis for the inner algorithm of RDTRAV, which contains logic to compute average fuel-consumption rates for high- and low-level road systems (both individually and collectively) for a geographical area.

The basic user inputs required by this inner logic are baseline fuel-use rates for various operating conditions, distributions of travel among these operating conditions (see below), and fuel-rate adjustment factors supplied on a statewide basis or on a subarea basis; up to 99 subareas are allowed.

Baseline fuel rates for each subarea may be specified at any of six levels of detail, depending on which parameters and operating conditions are implicitly accounted for in the available fuel-use data. At one extreme, the user simply specifies average fuel-use rates for high- and low-level roads in the subarea. These rates must account for all highway, vehicle, traffic, and environmental characteristics that affect fuel use in the subarea. At the other extreme, the user supplies fuel-use statistics for each road system, vehicle category, traffic flow condition, and range of road gradient in the subarea. An example of such input would be the average fuel-use rate by small passenger automobiles in congested traffic on local rural roadways in rolling terrain at 0-2 percent range of road gradient. Four levels of data, which fall between these two extremes, are also allowed. Empirical data, extracted from the above referenced studies and included in the program documentation, may be used in the absence of other information.

Parameter adjustment tables may be supplied for operating conditions not accounted for in the baseline rates. Examples of such adjustments include

1. Travel in subfreezing temperatures,
2. Travel on snow- and ice-covered pavements,
3. Vehicle stops and slowdowns,
4. Operation of vehicle air conditioners,
5. Vehicle power-accessory equipment (e.g., power steering and power brakes), and
6. Recent changes in engine design for the control of emissions.

Empirical data for a variety of parameters are listed in the literature and in the program documentation.

Travel distributions are used to integrate (average) the corrected fuel rates to produce average fuel-consumption rate on high- and low-level road systems (both individually and collectively) in the subarea. The types of distributions required depend on the form of fuel-use data supplied. These distributions include

1. Distributions of travel among road systems,
2. Percentage of travel on each road system that is congested,
3. Distributions of travel among vehicle categories for each road system,
4. Distributions of travel among vehicle terrain types for each road system, and
5. Distributions of travel among ranges of highway gradient for each road system and terrain type.

Sources for this information are described in the program documentation.

A variety of options are accommodated in specifying the required input to the program. Different versions of a data table may be specified for different geographical areas, and a particular version may apply to more than one area. Sets of operating conditions for which fuel-use data are supplied (road, vehicle, traffic, terrain, and grade categories) may assume any fixed meanings the user desires for an area, so long as the category definitions remain consistent for all data supplied for that area. In a similar fashion, parameter-adjustment tables may represent any operating characteristic whose effect on fuel usage can be validly specified as a percentage increase or decrease in average fuel rate.

The program output from RDTRAV consists of a printed list of input error and warning messages and, assuming no fatal input errors, two printed tables of fuel-consumption, travel, and fuel-use statistics. The input editor messages contain the sequential number of the card image containing the error. The first statistical table contains fuel consumed, vehicle kilometers traveled, and average fuel-consumption rates for each road system in each subarea. The second table presents similar statistics for high-level roads, low-level roads, and all road systems (collectively) for each subarea and for the state as a whole.

In a second effort to improve the current methodology, FHWA is testing the vehicle kilometers traveled procedures in six cities. The preliminary manual (7) contains a technique for estimating daily average vehicle kilometers traveled based on a stratified random sample of street links (sections of roadway with homogeneous traffic volume). The primary objective of this study is to test the practicality of the methodology in the revised manual and to discover how to integrate the vehicle kilometers traveled estimation program into the traffic-counting program. Figure development includes sampling procedures that are required to subdivide the area vehicle kilometers traveled estimate into the various vehicle classifications (21).

Hamburg and Associates (22) will work in one of the six test cities. Their work program consists of four tasks. Task 1 includes the assembly of historical traffic-count data and estimation procedures for vehicle kilometers traveled. In task 2, the sampling procedure will be determined, the sample selected, and the specific links determined. In task 3, the actual collection of data will be undertaken. Task 4 will produce estimates of vehicle kilometers traveled for the subregion and measure the accuracy achieved. As part of this task the FHWA procedure (7) will be evaluated with respect to its statistical reliability and applicability.

For another project in May 1977, Hamburg and Associates submitted a proposal to study improved methods for vehicle counting and determining travel distance (23). The problem is one of organizing and integrating numerous specialized programs, which are sponsored by local, regional, and state agencies into one program designed for statewide application but having provision for disaggregating by system type and geography. A survey of current traffic-counting techniques will be undertaken to include design of plan, administration, interagency coordination, collection, processing, and analysis. Next, Hamburg will produce a cost-effective highway-traffic-volume information program. Furthermore, the ability of the improved traffic-volume method to compute vehicle kilometers traveled will be compared to other procedures, such as the fuel-consumption method.

In another study, Rabe (5) concluded that, although many problems in vehicle kilometers traveled modeling can be traced to scarce data, the available information could be used more judiciously than it has been in prior attempts. More complex and realistic hypotheses should be tested before oversimplified models are accepted. Although available data may support some of these tests, a federally sponsored data-collection program could substantiate greater strides in vehicle kilometers traveled forecasting accuracy by eliminating misspecified models.

In addition to the studies that have been detailed, other contracts and projects are being planned and have been undertaken. The studies being carried out are in response to legislative requirements, deficiencies in state and local planning methodology, and policy analysis needs for federal program evaluations. The changing nature of the planning process results in a flexible mixture of projects that vary according to needs in the planning methodology. The two federal agencies that are the principal sponsors for this research effort are the U.S. Department of Transportation and the U.S. Department of Energy.

FINDINGS AND OBSERVATIONS

This paper has evaluated the existing data sources for vehicle kilometers traveled. FHWA has not developed and selected one specific methodology to estimate vehicle kilometers traveled. No single procedure has been established to collect, report, and consolidate vehicle kilometers traveled data. Each state, and every region within a state, selects its own process for gathering these data. Therefore, FHWA cannot obtain an accurate and reliable estimate of vehicle kilometers traveled from such heterogeneous inputs.

Historically, the importance of the accumulation of vehicle kilometers traveled has been directed toward highway planning and included such areas as traffic density, highway safety, and other non-energy-related areas. For these nonenergy endeavors, the traffic-counting methodology has been the procedure used most widely by the individual states to estimate vehicle kilometers traveled. However, since the 1973 energy crisis, FHWA has requested that the states estimate vehicle kilometers traveled based on average fuel-efficiency rates for different vehicle classifications. This alternative methodology may be a more appropriate way in which to solve energy-related issues because energy efficiency is one of the predetermined variables.

State departments of transportation have been unable to furnish accurate traffic counts on non-federal-aid highway systems (local, rural, and urban roads). In order to better estimate vehicle kilometers traveled on the non-federal-aid systems, FHWA has been developing the RDTRAV computer program. The RDTRAV algorithm contains logic to compute average fuel-efficiency rates for high- and low-level road systems for a geographical area. The basic inputs required by this inner logic are baseline fuel use rates for various operating conditions, distributions of travel among the operating conditions, and fuel rate adjustment factors for parameters not incorporated in the baseline data.

Today, it is assumed that the fuel-efficiency rate for each state is determined independently from the national fuel-consumption rate. Nevertheless, for the 17 states that now use the fuel-consumption method in combination with the traffic counts, only 10 have made an independent empirical investigation of fuel economy and the other 7 use FHWA guidelines. Empirical investigations do not have a standard methodology and are made infrequently. FHWA guidelines imply that the states may use the computed national figure for kilometers per liter to determine the individual state vehicle kilometers traveled. Indeed, causality is a major issue.

Fuel consumption rates involve many heterogeneous inputs, and it has been difficult to arrive at a meaningful state average. In each state, fuel efficiency depends on

1. The share of automobiles by age and weight,
2. The spatial distribution of travel, and
3. The drive cycle (climate, topography, and drive schedule).

At the current time, such important characteristics as the drive cycle and drive schedule have not been fully evaluated. The drive cycle includes the physical environment in which the vehicle operates. This is comprised of meteorology, topography, and the drive schedule. The latter embraces such key factors as trip information (e.g., origin, destination, purpose, and length), demographic patterns, road type, congestion, and stop-and-go traffic. In addition, other factors that affect fuel consumption and efficiency, such as automobile accessories and vehicle registration classifications, must be considered. The values of these factors should be determined from trip and travel statistics and are the major factors in determining a vehicle's fuel economy.

Although the vehicle count approach offers a good alternative to the fuel-efficiency method, there is need for improvement. First, there is substantial diversity in the counting methodology. Second, the methodology used to expand the counts is not grounded in standard statistical procedures. Third, higher-volume roads are better represented in the counting methodology than the lower-volume facilities. Finally, more statistical evaluation should be inferred from the count program.

To sum up, the scope and accuracy of vehicle kilometers traveled data leave much to be desired. New methodologies (such as the RDTRAV algorithm) must be established and then substantiated through empirical testing in order to achieve the National Highway Traffic Safety Administration's (NHTSA's) objectives. NHTSA is interested in vehicle kilometers traveled and gasoline consumption by vehicle classification and geographic region in order to arrive at the estimate of the fuel efficiency of the passenger automobile fleet.

Some form of standardization is a necessity for computing vehicle kilometers traveled. Experimental programs being undertaken by FHWA are principally directed toward the establishment of average statewide fuel-consumption rates for the individual states. Traffic counts are expensive, sampling techniques can be subjective, and equipment use varies from one state to another.

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Multivariate Classification of Automobiles by Use of an Automobile Characteristics Data Base

Robin Dubin, Department of Geography and Environmental Engineering,
Johns Hopkins University, Baltimore
David L. Greene and Connie Begovich, Oak Ridge National Laboratory,
Oak Ridge, Tennessee

Interest in forecasting the fuel efficiency of the automobile population has led to the development of automobile market-shares demand models. The validity of these models depends on the automobile classification used, yet little rigorous attention has been given to the problem of classifying automobiles for demand analysis. All existing models use classifications that are heavily subjective and rely on only one or two vehicle characteristics for classification. A cluster analysis of 125 models of 1975 automobiles was conducted in order to aggregate the vehicles into homogeneous groups suitable for modeling the demand for automobiles by vehicle type. Eight variables extracted from an automobile characteristics data base developed by the U.S. Department of Transportation were employed: curb weight, wheelbase, engine displacement, roominess, passenger capacity, fuel economy, list price, and power-to-weight ratio. Several weighting schemes, two-distance metrics, and hierarchical as well as nonhierarchical clustering techniques were used. The analysis strongly indicated that two- and six-group configurations were important. Within the six-group clustering, the three groups that had the highest average seat kilometers per liter and seats per initial cost comprised more than 80 percent of sales in 1975. A comparison of the cluster-analysis grouping with another classification used in a recent econometric automobile-demand model showed that the multivariate clustering did a consistently better job of accounting for the variability of vehicle characteristics.

Perhaps the most significant recent advance in the state of the art of long-run automobile-demand modeling has been the development of market-shares models (1-5). Models that divide new automobile sales among vehicle classes have enabled the forecasting of changes in the composition of automobile populations in response to changing energy prices and other factors. This capability has greatly enhanced the utility of automobile- and gasoline-demand models as policy-evaluation tools. Equally important to the development of meaningful models as the shares methodology itself is the classification of vehicles into meaningful groups. Although classification is a necessary first step to the creation of a shares model, the subject has been given surprisingly little rigorous attention by researchers. This paper presents an investigation of the structure of the population of automobile types via cluster analysis. A data set that contains selected characteristics of 1975 model year automobiles sold in the United States was explored via techniques of cluster analysis to derive a vehicle typology useful for automobile- and gasoline-demand modeling.

PREVIOUS CLASSIFICATIONS AND THE AGGREGATION ISSUE

The first question that must be addressed in determining a typology for demand modeling is, What in economic theory allows commodities such as automobiles of various types to be aggregated and treated as a single commodity and what criteria are provided by which to judge the goodness of a classification? On an intuitive level it is apparent that one would like to aggregate automobiles that are as much alike as possible. One would like to ignore the superfluous distinctions among automobiles and group them into a few homogeneous classes. Economic theory enables us to place a more precise interpretation on these intuitive ideas.

According to the theory of the consumer, a group of commodities may be aggregated and represented as a single argument in a utility or demand function if and only if the marginal rate of substitution between any two variables in the group is independent of any variable in the utility function not in the group. This property, termed weak separability (6, Chapter 3), implies that trade-offs (purchase decisions) between group members are not influenced by variables outside of the group. To give a concrete example, expenditures on gasoline should not affect the consumer's choice between, for example, a Pinto and a Vega (assuming that these two automobiles are in the same group), but it may affect the choice between a Pinto (or Vega) and a Plymouth Fury. Therefore, the latter do not belong in the same group. The number of household members should also not affect the choice between smaller automobiles but, if it enters the household-utility function, it may influence the choice between a smaller or a larger automobile. Choices among automobiles within groups may be made purely on the basis of such factors as aesthetics (e.g., styling or response to advertising) that are, presumably, unaffected by other arguments in the consumer's utility function.

Clearly, then, it should be sufficient to divide automobiles into groups that are as homogeneous as possible with respect to those characteristics that might create dependencies between marginal rates of substitution for automobiles within a group and variables outside of the group. Unfortunately, this task is not entirely straightforward, since theory does not say precisely what characteristics are relevant. We have used our judgment in this and, as would be expected, the choice of variables greatly influences the aggregation.

The literature contains at least a dozen typologies. At least six classification schemes not developed for demand models have currency. The U. S. Environmental Protection Agency (EPA) classifies automobiles for the purposes of fuel-economy labeling and listing in the fuel-economy guide published jointly with the U. S. Department of Energy (DOE). The EPA system groups automobiles on the basis of interior volume. For model year 1977 automobiles, interior volumes ranged from under 21.3 m^3 (70 ft^3) for the smallest four-passenger vehicles to over 48.8 m^3 (160 ft^3) for the largest station wagons. Based on judgment and experimentation, the EPA distinguished four types of sedans and three station wagons plus a special class for two-seaters (7).

The other major nonmodeling classification schemes have been reviewed in detail elsewhere (8) and will only be mentioned briefly here. These classifications were developed for the purposes of domestic automobile manufacturers, largely to enable them to keep track of the production and sales of automobiles in competing size categories. As previous researchers have noted (8),

> While at least five distinctive industrial market classes existed, no formal industrial definition of classes has ever been created. Instead, criteria for classification developed through informal agreements based on a combination of vehicle size, price, and marketing intent.

The schemes have from five to eight automobile categories and vary considerably in the emphasis given to price and vehicle size (usually wheelbase). Given the manufacturers' intentions in developing classes consisting of competing vehicles, these classifications might be expected to approach the desired homogeneous grouping of vehicles. However (8),

> Unfortunately, marketing intent is difficult to define objectively and the criteria used to create market class specifications have varied considerably, depending on the purpose and user of the classification system.

At least six classifications developed for econometric-demand models are described in the literature (Table 1). At least two other models that use apparently different classifications have been published without descriptions of the criteria for classification (5, 11). Of the six classifications, three are variants of industrial classification schemes that consist of subdivision of wheelbase categories according to price. In general, the classification criteria for these schemes are not explicitly stated, though Schink and Loxley (4) come very close. The Wharton-model classification is apparently intended to be similar to the industrial-market classification. It is based on wheelbase, with all automobiles that cost more than a somewhat arbitrarily chosen cutoff price being grouped into a single luxury category, regardless of size. A good classification should be multidimensional; however, the Wharton study asserts (without substantiation) that "wheelbase plus any one of the other characteristics will very likely yield the correct classification" (4, Vol. 1, pp. 3-8 to 3-10).

The other three classifications consist of only three classes each. Two are unidimensional, one based on curb weight and the other on a roominess index, which is a simple sum of seven interior dimensions. In both, the class boundaries are arbitrarily defined by judgment and intuition. The third is an interesting approach that classifies according to a hedonic price index (HPI) (1). The HPI is appealing in that it allows more than one factor to contribute to the classification. However, it is a particularly inappropriate method for aggregating commodities from the point of view of demand theory. The hedonic technique is constructed so as to allow comparisons between apples and oranges based on the amount of quality embodied in them. Rather than ensuring that automobiles in a given group are homogeneous with respect to their characteristics, the hedonic approach allows very dissimilar automobiles to be grouped together, provided only that their quality indices are similar.

Recently, multidimensional classifications for demand modeling have been attempted by Resek and Kouo (12) and Springer (13) by use of principal-components analysis. Springer does not discuss his classification scheme in any detail, although it is apparently very similar in construction to that of Resek and Kouo. Data on wheelbase, length, engine displacement, weight, and list price were obtained by Resek and Kouo for about 1600 domestic automobiles. The researchers first tried multiple-discriminant analysis as a classification tool, starting with the industry-market classification but found that usable discriminant functions could not be obtained. They next turned to principal-components analysis and found interpretable patterns in the factor weights of the first two components (12).

Characteristic	Component First	Component Second
Latent root	3.94	0.51
Trace (%)	78.83	10.14
Variable (factor weights)		
Wheelbase	+0.22	+0.78
Length	+0.23	+0.61
Weight	+0.24	−0.06
Displacement	+0.22	−0.66
Price	+0.21	−0.72

"Clearly, the first factor represents size while the second is power or luxury" (12, p. 2). Given the structure they observed in the data, the authors elected to designate the top 10 percent of models in price as luxury. The remaining automobiles were classified into four groups based on their scores on the first component. Cut points were determined by judgment to achieve a final five-group classification similar to the industry-market classification. Oblimax rotation results of the first component scores are given below (12).

Variable	Factor Size	Factor Price
Wheelbase	+1.09	−0.18
Length	+0.98	−0.01
Weight	+0.46	+0.56
Displacement	−0.09	+0.99
Price	−0.15	+1.02

A closer examination of the Resek-Kouo classification scheme reveals several fundamental deficiencies. First, the selection of variables omits any direct measure of vehicle capacity. Intuitively, this would seem to be a critical vehicle characteristic for most consumers and one very likely to cause aggregation problems unless specifically taken into account. Fuel efficiency is also not considered. Less important is the omission of a direct measure of vehicle performance. Both engine displacement and power are very closely related to vehicle weight and, therefore, a relatively poor measure of performance. A second problem arises from the fact that the classification implemented discards the second component and substitutes price in its stead. Not only does this result in the loss of information but causes difficulty in interpreting a classification based on one component score and one raw variable. Finally the determination of cut points (both along the price and first component dimension) relies entirely on judgment—the only apparent objective of which was the replication of the industry-market classification. As a result, this classification should be considered as groundbreaking in the field of multivariate vehicle classifications but still exploratory.

For the purposes of constructing an econometric model of automobile demand, all of the existing classifications leave something to be desired. Schuessler and Smith (14, p. 4) have pointed out one reason: "It should be noted that an automobile is a multiattribute good, and any unidimensional classification scheme will be unsatisfactory for some models when viewed along an alternative dimension."

Most existing typologies are essentially unidimensional. Another major drawback of all existing classifications is that they rely on subjective judgment and

Table 1. Automobile classifications for econometric demand models.

Model	Criteria	Class
Transportation Systems Center (2)	Weight	Compact (<1134 kg) Intermediate-standard (1134 < 1814 kg) Luxury (>1814 kg)
Chase Econometrics[a] (9)	Wheelbase, price	Subcompact Compact Intermediate Standard Luxury
Energy and Environmental Analysis, Inc.[a] (10)	Wheelbase, price	Subcompact Compact Intermediate Standard Small luxury Large luxury
Interagency Task Force on Motor Vehicle Goals beyond 1980 (3)	Roominess index (sum of seven interior measurements)	Small (<671 cm) Medium (671-696 cm) Large (>696 cm)
Cato, Sweeney, and Rodekohr (1)	Hedonic index of weight and wattage	Small (<1610 kg) Medium 1610 <HPI <2381 kg Large HPI (>2382 kg)
Wharton EFA[a] (4)	Wheelbase, price	Subcompact (≤254 cm) Compact (254 <wheelbase ≤282 cm) Domestic mid-size (282 < wheelbase ≤ 300 cm) Domestic full-size (>300 cm) Luxury (price of specific models selected by judgment is used as lower bound, includes automobiles in all size categories)

Note: 1 kg = 2.20 lb; 1 cm = 0.39 in.

[a] Variant of industrial classification according to wheelbase and market intent.

intuition to establish the number of groups and dividing lines between groups. This is even true of the EPA classification, which is certainly the most rigorous in terms of statistically evaluating the consequences of different cut points for classes (8). What is clearly required is a method of classification that considers multiple attributes simultaneously and seeks out natural groupings of automobiles. Cluster analysis provides such a method.

AUTOMOBILE CHARACTERISTICS DATA BASES

A data set that contained extensive information on automobile characteristics and permitted the retrieval of this information by model names (e.g., Pinto, Chevette, or Dart) was required for the cluster analysis. Two data sets were considered as possible candidates: Fels (15) and The Automobile Characteristics Data Base (16, 17) [hereafter referred to as the Chilton-National Highway Traffic Safety Administration (NHTSA) data].

The Fels data set was compiled primarily for fuel-economy information, although it contains 11 additional descriptive variables. Automobiles included in the data set are identified by model name and number of cylinders or body style. For example, the data set contains three entries for the Cutlass model: Cutlass six cylinder, Cutlass eight cylinder, and Cutlass station wagon. Information on model years 1973-1978 is included.

The Chilton-NHTSA data were compiled by two different agencies under three different contracts. As a result, the Chilton-NHTSA data are actually composed of three smaller data sets. Each of these smaller sets contains its own set of descriptive variables as well as a unique identification system. For example, the 1955-1974 data identify automobiles by manufacturers and size [e.g., General Motors (GM) intermediate], but the 1975 data use manufacturer and model name (e.g., Ford Pinto) as the identifier. The three data sets combined cover the years 1955, 1960, 1965, 1968, and 1970-1977.

For the purposes of this paper, the primary differences between the Fels and the Chilton-NHTSA data are that the latter contain more extensive information on the interior volume of an automobile and a longer time series of data. For these reasons, we chose the Chilton-NHTSA data for input into the clustering procedure. This choice left two problems to be resolved—identification of the automobile and the size of the data set. As the desired output of the clustering procedure was an automobile-classification scheme in terms of model names, we decided to restrict our attention to data in which the automobiles were already identified by model. The only part of the Chilton-NHTSA data to meet this criterion were the 1975 data. The automobiles in the 1975 data were further classified by engine size, number of cylinders, and transmission. This is a greater level of disaggregation than that required for automobile-demand modeling, since data on new registrations are not available at such a fine level of detail. The data were aggregated to the level of detail available in the R. L. Polk new-vehicle registrations data (i.e., model year, make, series, sedan versus wagon). The resulting variable scores are sales-weighted averages of the disaggregated variable scores. The aggregated 1975 data set contained 125 observations.

In any classification scheme, the choice of variables included in the analysis influences the final categories obtained. It was thus important to select from the 50-odd attributes included in the data base those characteristics that capture the important ways in which one automobile differs from another. In particular, it was important that the automobile be accurately described in terms of its size, price, performance, and fuel economy. The variables that were chosen to reflect these aspects of automobiles are as follows:

1. Wheelbase—Wheelbase is defined as the distance between the centers of the front and rear wheels of an

automobile and is a measure of exterior size.

2. Curb weight—Curb weight is another indicator of size. It is defined as the operational weight of the automobile, i.e., the weight of the automobile with all tanks filled, spare tire, and optional equipment (if produced on 35 percent or more of automobiles in that model line).

3. Displacement—Displacement is a measure of the size of the engine and is defined as the number of cubic centimeters displaced by the pistons in an upward stroke.

4. Number of passengers—This is a measure of the passenger-carrying capacity of the automobile.

5. Roominess factor—The roominess factor is computed as the sum of the following seven measurements: legroom (front and rear), shoulder room (front and rear), headroom (front and rear), and front-seat height. These measurements are Standard Motor Vehicle Manufacturers Association measurements L34, L51, W3, W4, H61, H63, and H30, respectively. Both the roominess factor and number of passengers are indicators of interior size; however, the two measurements differ in that (a) the roominess factor is a continuous variable and (b) the roominess factor cannot distinguish between station wagons and sedans, as only the first two seats are counted. If a third seat is available in a station wagon, the number of passengers variable is incremented to reflect this.

6. Power—Power by itself is very closely associated with the size of an automobile. However, if size is accounted for by dividing motive power by curb weight, then a meansure of performance is obtained. Motive power divided by weight is the variable that is used in the analysis.

7. Fuel economy—The fuel-economy measurement used is a weighted average (55 percent urban, 45 percent highway) of the EPA city and highway fuel-economy tests.

8. Acceleration time from 0 to 96.5 km/h (0 to 60 mph)—Acceleration time is an additional measure of performance. Unfortunately, for the 1975 data, too many values were missing for this variable to be included in the analysis.

9. Price—Manufacturer's list price is the only measure of the cost of the automobile (other than fuel economy) contained in the data set. It is a less than perfect indicator of the true cost of an automobile, however. The primary problem is that very few new automobile buyers actually pay the manufacturer's list price for the automobile. Furthermore, the amount of discount is not constant but varies with price and other factors. Additionally, this price does not include the cost of options.

Three of the variables included in the analysis measure exterior size (wheelbase, curb weight, and displacement). Two of the variables measure interior size (roominess factor and number of passengers). Of the three remaining variables, one measures fuel economy, one measures price, and one measures performance (power per curb weight). The matrix of product-moment correlations (Table 2) between variables reveals that all of the size variables are closely correlated. Fuel economy is also strongly, though negatively, related to size. Price shows a somewhat weaker correlation, and the performance measure correlates poorly with all measures except price.

CLUSTERING METHODS

The term cluster analysis refers to a collection of statistical procedures designed to identify groupings or typologies of items based on their characteristics. Given a set of (usually measurable) characteristics for a population, cluster analysis attempts to divide individuals into groups that have similar characteristics. Similarity is measured by the distance between individuals in a multidimensional characteristics space. Many distance measures (or metrics) can be used, including Euclidean distance, which measures distance along a straight line that joins two points. Algorithms for determining clusters may be divided into two categories: hierarchical and nonhierarchical. Hierarchical algorithms begin by regarding each of n observations as a group. The two closest observations are then combined into a single group that is assigned the mean value of the characteristics of the two points. In the next step the closest of the n-1 remaining groups are combined, and so on, until all observations have been combined into one single group. Thus a hierarchy of n groupings is generated of sizes n to 1. A key feature of hierarchical algorithms is that, once two groups are joined, they may not be divided at a later step. Nonhierarchical algorithms, in contrast, are designed to find a prespecified number of groups by iteratively assigning and reassigning individuals to groups in order to maximize a chosen measure of group homogeneity.

Both hierarchical and nonhierarchical clustering methods were used. The hierarchical clustering program (DENDRO) (18) uses an algorithm based on Ward's method (19), which at each step combines clusters to achieve the minimum increase in error sum of squares. The Euclidean distance metric was used (a rank-score procedure was also tested and gave similar results) (20). The nonhierarchical method, MIKCA, uses a variation on an iterative K-means procedure (21). Unlike the hierarchical approaches, MIKCA finds a prespecified number of clusters. Starting with k randomly chosen seed points, the algorithm assigns each data point to the closest seed point, computes cluster centroids, and reallocates data points iteratively. This is done from start several times and the clustering that has the minimum within-group sum of squares is chosen. Once again, the Euclidean distance metric was used. Both clustering approaches use the same distance metric and optimization criteria. Differences in final cluster configurations are largely attributable to the fact that hierarchical algorithms are irreversible —that is, once two clusters have been combined no

Table 2. Correlation matrix of automobile characteristics, 1975.

Variable	Roominess	Curb Weight	Displacement	Power to Weight	Fuel Economy	Price	Number of Passengers
Wheelbase	0.93	0.95	0.93	0.24	-0.87	0.64	0.86
Roominess		0.89	0.86	0.26	-0.81	0.59	0.84
Curb weight			0.96	0.26	-0.90	0.69	0.86
Displacement				0.30	-0.88	0.64	0.81
Power to weight					-0.28	0.49	0.17
Fuel economy						-0.60	-0.78
Price							0.49

Note: Pearson product-moment correlation coefficients. All correlations are significant at the 0.01 level, except as noted.
*Significant at 0.1 level.

members of either cluster may be reassigned later.

Several methods were tried for preprocessing the data by standardization and weighting. Simply standardizing the raw data enforces equal variation on the variables that may reduce intergroup differences. It also disregards correlations between variables. Use of the first few principal-component scores helps to reduce the number of variables and provides an implicit weighting scheme that should reduce the importance of highly correlated variables. If the data are not well structured, however, the clustering on component scores will differ from that using the raw data (19, p. 49). This turned out to be the case for the automobile data.

When either standardized raw data or the first three component scores were used, the results from the hierarchical and nonhierarchical methods differed greatly (this was true whether the Euclidean or rank-score metric was used). An examination of the normalized between-cluster to total-sum-of-squares ratio for each variable indicated that variables that measure vehicle size dominated the classification. It appeared that the six highly correlated variables that measure size, wheelbase, roominess, curb weight, engine displacement, power, and number of passengers were so heavily weighted that the clustering algorithms were having difficulty discriminating among vehicle types.

The preprocessing approach finally adopted is based on the idea that there are five major, quantifiable dimensions that consumers use in making decisions about vehicle purchases:

1. Overall size—wheelbase, curb weight, and displacement;
2. Capacity—roominess and number of passengers;
3. Price—manufacturer's list price;
4. Variable costs of operation—composite fuel economy; and
5. Performance—power divided by weight.

Each of these dimensions or factors was given a total weight of one-fifth. This weighting scheme produced greater equality in the normalized sum of squares explained by the classification as well as good consistency between the results of the two clustering algorithms. Therefore, this preprocessing method was selected.

The dendrogram in Figure 1 displays the results of the five-factor weighting. To compare the results of the dendrogram with the MIKCA results, each sample has an identifier Mn, n = 1, ... 6, which indicates its MIKCA group.

NUMBER OF CLUSTERS

The dendrogram indicates the separation between clusters by the length of the vertical lines that join clusters. Subjectively, it appears that divisions can be made at the two-, four-, and seven-group levels. Statistics described by Everitt (19) were tabulated for the MIKCA groupings (Table 3). The two-cluster grouping appears as the best overall, and six also appears to be a meaningful grouping if more than two groups are desired. A Monte Carlo clustering technique, which uses estimates of error in the raw variables, was also employed by using a probabilistic method for grouping data (22). The error estimates proved to be so large that only the two-group clustering was consistently found. These results suggested that the most significant distinction between automobiles is between two broad categories that may be described as large and small. Beyond that, a six-group classification appears to be best.

Although both the DENDRO and MIKCA algorithms produce acceptable classifications, the MIKCA typology seems preferable on grounds of efficiency. The six-group MIKCA and seven-group DENDRO classifications are compared in Figure 2 in terms of the normalized sum of squares explained by the classification for each variable. With one negligible exception, the MIKCA groups do a better job of capturing the underlying variability with fewer groups. Since, other things being equal, the percentage of variance of variables explained will increase with the number of groups, the MIKCA groups are clearly better by this criterion. In discussing the results of the cluster analysis below, we shall refer to the MIKCA six-group typology. The group numbers have no particular significance.

Group 1 contains 24 makes that have a combined market share (based on production and import figures) of 10.2 percent in 1975 (Table 4). Included in the group are the Ford Mustang, Buick Skyhawk, Toyota Corona, Mercury Capri, and Audi 100 LS. The values for the group centroid indicate that the typical member is a relatively small, four-passenger sedan or wagon with moderate performance and price and good fuel economy. The heaviest automobile in the group is the Chevrolet Camaro [1645 kg (3627 lb)]; the lightest is the Dodge Colt GT [1070.5 kg (2360 lb)]. The most expensive is the Volvo 245 ($6275, 1975 dollars) and the cheapest is the Mercury Bobcat Wagon ($3672). The Mercury Capri 2800 is most typical of the group, as measured by weighted distance from the group centroid.

The second group is comprised almost entirely of large domestic luxury automobiles. This group has only 10 members but captures 5.9 percent of the market. Cadillacs, Chryslers, and Lincolns dominate this cluster of the largest, heaviest, least efficient, and most expensive automobiles.

The next three groups might be thought of as the basic transportation group. Together they comprise more than four-fifths of the market (80.8 percent). These are the automobiles most Americans drive. Perhaps this is because automobiles in these groups give both the largest passenger-carrying capacity per dollar of purchase price and the greatest number of seat kilometers per liter of gasoline. Group 3 consists largely of domestic compact automobiles, such as the Plymouth Valiant, Chevrolet Nova, and American Motors Hornet. This has the lowest average value for power to weight but carries the greatest number of passengers per dollar of all the groups. Group 4 might be termed economy subcompacts. Automobiles such as the Volkswagon Beetle, Ford Pinto, Chevrolet Vega, and Datsun 210 make it the lightest, smallest, cheapest ($3573), and most fuel-efficient cluster of all [10.6 km/L and 41.25 seat-km/L (25 miles/gal and 97 seat miles/gal)]. The fifth group is the only one that consists entirely of domestic automobiles. Although not the heaviest group, it does have the greatest passenger capacity due to the large number of station wagons in this group. These large automobiles are the largest 1975 market share by far of all groups (42 percent). Though the vehicles themselves are relatively fuel consumptive [5.5 km/L (13 miles/gal)] they deliver the second highest level of seat kilometers per liter [39.1 seat-km/L (92 seat miles/gal)].

Group six, the smallest in terms of both members (7) and market share (3.2 percent), consists predominantly of high-performance, expensive small automobiles. The Datsun 280Z, Pontiac Firebird, and Fiat

Figure 1. 1975 automobiles—weighted and standardized clustering dendrogram.

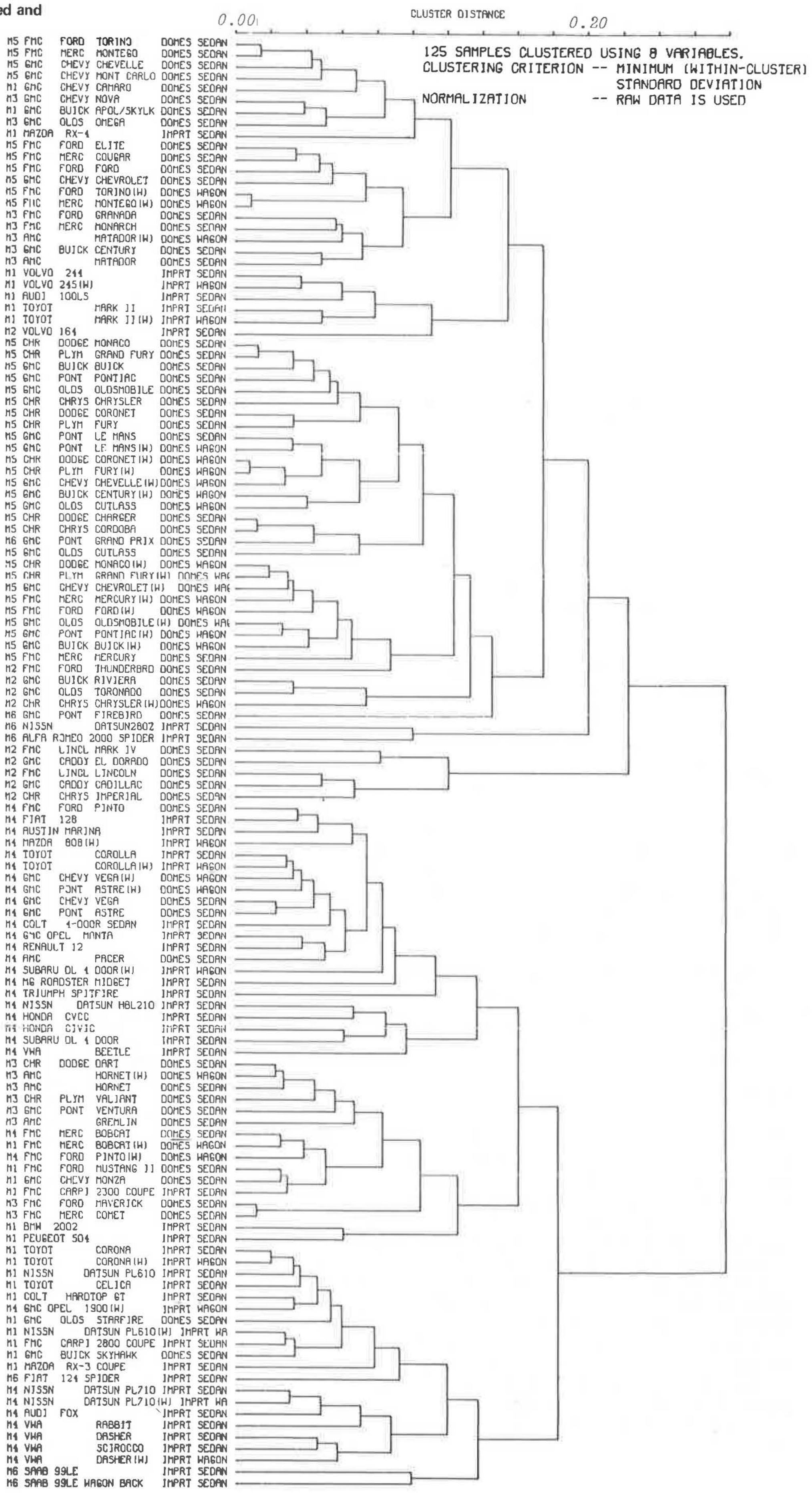


Table 3. MIKCA cluster analysis statistics.

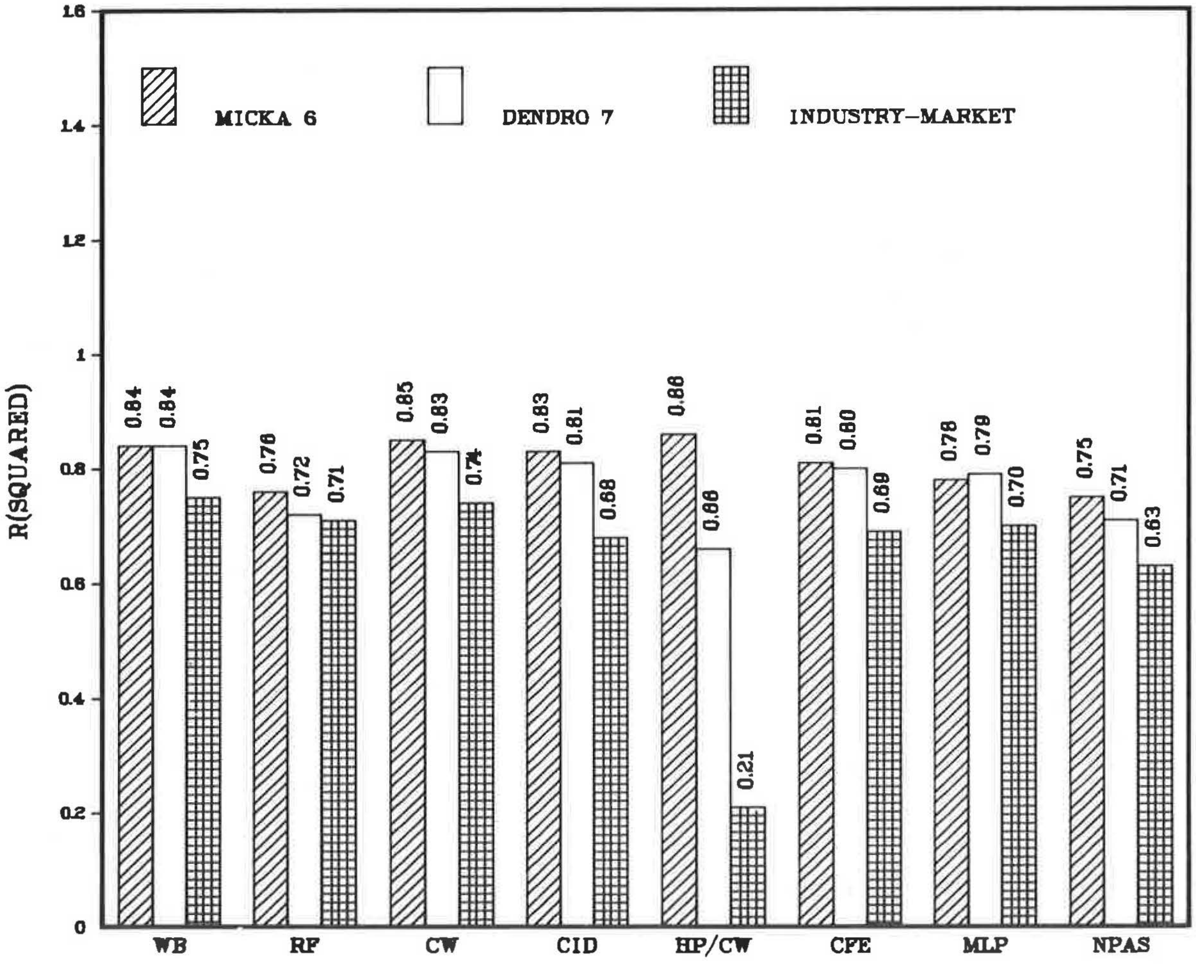
Number of Groups (g)	Trace W (total within-cluster sum of squares)	Trace B (total between-cluster sum of squares)	Calinski and Harabasz (Cg)[a]	F (g + 1, g)[b]
2	10.06	8.97	109.64	2.14
3	8.06	10.97	83.02	2.07
4	6.87	12.16	71.39	1.66
5	6.19	12.84	62.23	5.01[c]
6	4.72	14.31	72.16	2.63
7	4.19	14.84	69.65	

[a] C increasing monotonically with g suggests no cluster structure; C decreasing monotonically with g suggests a hierarchical structure; C rising to a maximum at g suggests g clusters.

[b] A significant result indicates that division into g + 1 clusters is significantly better than a division into g clusters.

[c] Significant at the 0.05 level. F (6, 2) however is not significant at 0.05, which indicates that it cannot be concluded that there are six but not two groups present.

Figure 2. Percentage of variance of variables explained by classification.



124 Spyder are typical of this group, which has the highest power-to-weight ratio of all clusters. Though comparable in size to group 1 automobiles, vehicles of this cluster typically cost $1000 more and have one-third more kilowatts per kilogram.

The ability of the MIKCA and DENDRO clusterings to capture the variability in vehicle characteristics along the eight dimensions is displayed in Figure 2. In no instance does the MIKCA typology account for less than 75 percent of the variance. Figure 2 also compares the multivariate clustering approaches to the approximation to the industry-market classification used in the Wharton model (in our opinion the most sophisticated classification used for modeling purposes). The multivariate clustering approaches do better in all cases but dramatically so in the case of performance. Performance appears to be the one factor that is virtually independent of size.

We were interested to see how well a simple three-group classification would perform. The classes used by the Interagency Task Force on Motor Vehicle Goals Beyond 1980 (3) based on the roominess index alone did a remarkably good job of capturing the underlying variability in all size-related variables: wheelbase (86 percent), roominess (82 percent), curb weight (83 percent), displacement (81 percent), and passengers (77 percent). It does slightly less well in accounting for the variance in fuel economy (73 percent), does poorly on price (37 percent), and virtually ignores performance (7 percent).

Clearly any classification that does not achieve a reasonable degree of homogeneity within classes with

Table 4. Centroid values for MIKCA six-group classification.

Variable	Variable Weight	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
Membership		24	10	15	32	37	7
Market share (%)		10.2	5.9	22.7	16.1	42.0	3.2
Wheelbase (cm)	0.33	253.2	310.4	279.6	238.2	303.8	248.7
Curb weight (kg)	0.33	1 288.6	2 221.5	1 597.6	1 036.5	2 043.1	1 294.3
Displacement (L)	0.33	2.6	7.1	4.5	1.8	6.2	3.3
Roominess factor (cm)	0.50	658.6	725.9	695.7	646.2	725.7	670.8
Number of passengers	0.50	4.25	6.10	5.33	3.88	6.92	4.43
Power to weight (kW/kg)	1.0	0.021 59	0.024 33	0.018 31	0.019 46	0.022 50	0.029 07
Composite fuel economy (km/L)	1.0	8.5	5.4	7.2	10.6	5.6	8.5
Manufacturers list price (1975 dollars)	1.0	4748	8455	4160	3573	5465	5792
Seat-kilometers per liter (seat-km/L)		36.4	33.3	38.2	41.2	39.0	37.6
Passengers per $1000		0.90	0.72	1.28	1.09	1.27	0.76
Model automobile		Mercury Capri 2800	Cadillac	Pontiac Ventura	Toyota Corolla Wagon	Pontiac Le Mans Wagon	Saab 99 Le Wagon

Note: 1 kg = 2.20 lb; 1 cm = 0.39 in; 1 L = 61.03 in^3; 1 km = 0.62 mile; 1 km/L = 2.35 mile/gal; 1 kW = 1.34 hp.

respect to price cannot satisfy the condition for aggregation of commodities since income may strongly influence substitutions between commodities within a group. Whether or not performance is critical for aggregation is not clear. Many consumers consider performance important, but styling and color are also important to many vehicle purchasers. To the extent that performance is a luxury characteristic, it would seem necessary to consider it in the aggregation process. The same applies to exterior size, although all the classifications do a reasonable job of capturing variation in the size variables.

CONCLUSIONS

This exploration of the structure of the 1975 automobile population has produced a classification into six groups that succeeds substantially in dividing the vehicles into homogeneous groups. It is not the only classification that can be obtained from cluster analysis. Considerable experimentation with other weighting schemes and distance metrics has shown that the clustering obtained is, not surprisingly, dependent on the variables included and the weights given to them. The classification scheme finally selected is based on an equal weighting of five factors measured by eight variables. The factors are interior capacity, exterior size, performance, fuel economy, and price. A simple one-dimensional, three-way classification based on either interior capacity or weight should create reasonably homogeneous groups with respect to interior capacity, size, and fuel economy. The Wharton-model five-group classification based on wheelbase and price gives a respectable performance on all but the performance variable. The nonhierarchical six-group clustering does better than the Wharton scheme on all variables and does considerably better on performance.

The cluster-analysis methodology employed here holds considerable promise for developing aggregations of automobiles for the purpose of market-share demand modeling. Additional research will be required, however, in order to develop a classification scheme that covers a time series of data. In particular, if the clustering is to be of use in forecasting work, it must include the scaled-down models of recent years. The work reported here takes the first step toward developing such a multivariate classification.

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