In promoting fuel efficiency rather than efforts to reduce personal travel through traffic restraint or taxation, it must not be assumed that this is necessarily a more equitable approach for lower-income groups just because we found them to be more fuel efficient now. The mechanisms for promoting these policies (tax incentives and pool subsidies) may be out of reach, and lower-income groups may be trapped (especially with older cars) at efficiency levels that will become more burdensome as gasoline goes up in price.

A further development of this policy-analysis technique would be to introduce independently measured factors into the scenario definitions, such as the personal characteristics of those revealed by marketing studies to be willing to buy a smaller car or certain trip attributes that are associated with successful carpools of different sizes. The MDES data base has been constructed to facilitate this. In our view, the collection of sample data of this kind should become a routine matter in the monitoring of energy use and the planning of energy-conservation policy.

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Abridgment

How Much Fuel Does Vanpooling Really Save?

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Opinions vary as to how much fuel is actually saved by vanpools. Estimates range from an optimistic 49 210 L/year (13 000 gal) to a conservative estimate of 5700 L/year (1500 gal). A reliable estimate is required by policy planners so that preferential treatment for vanpools with regard to fuel allocation can be justified. During the fall of 1978, drivers of 211 vans provided the information necessary to compute values for average trip length by van and automobile and vehicle occupancy rates for the van and automobile. Late in the following spring, 211 van passengers responded to a questionnaire designed to obtain estimates for van and automobile fuel-efficiency rates and the use of vehicles formerly used for commuting. Fuel savings were determined by substituting the values into a modified version of a model developed for the U.S. Department of Energy. The results indicate that the most probable saving per van is 17 400 L/year (4600 gal). This is based on 11.2 occupants/van, a previous vehicle occupancy of 1.47, an 86.6-km (53.8-mile) commute distance, vehicles left at home being driven 9.8 km/day (6.1 miles/day), 4.25 km/L (10 miles/gal) for the van, and 6.8 km/L (15.9 miles/gal) for the previous vehicle. If the vanpoolers formerly drove by themselves in gas guzzlers that were disposed of immediately, the optimistic savings estimate is 30 280 L/year (8000 gal). If they drove the average fleet, carpooled some, and gave their previous cars to teenagers, a more pessimistic estimate of savings is 5700 L/year (1500 gal).

In Texas, vanpooling is a highly visible, and somewhat controversial, energy-conservation measure under the State Energy Conservation Plan (SECP). Because of their energy-saving potential, vanpools were given some preferential treatment during the gasoline shortage in the summer of 1979 and will be given higher priority during future emergency situations. In order to justify this position, fuel-allocation officials and conservation planners need reliable estimates of the fuel demand and the fuel savings created by the vanpool fleet. This study grew out of a need to establish a reliable estimate to replace current rules of thumb.

Almost everyone agrees that vanpools save gasoline, but opinions vary as to exactly how much. The Texas vanpool program has previously used 18 900 L (5000 gal) per van annually to make savings estimates. Most Texas vanpool programs (1) claim savings between 18 900 and 30 300 L (5000 and 8000 gal). The original SECP, which used guidelines developed by the Stanford Research Institute (SRI) (2) for the Federal Energy Administration (3), used a conservative figure of 5700 L (1500 gal) per van annually. The enthusiastic support given to the

30 300 L figure by various employer programs makes the 18 900 L figure appear too conservative and the 5700 L one look ridiculous.

The SRI methodology used to develop the original SECP estimates was the study's starting point. An extensive vanpool driver and rider survey produced a Texas data base to replace the national averages used in the original effort. These values were then substituted into a modified form of the SRI methodology.

The results show that an average van saves 17 400 L/year (4600 gal). The 1109 vans in operation at the end of 1979 save 73 700 L/day or 1 597 000 L/month. These vans are located at 76 sites and provide 987 000 passenger-km (613 300 passenger miles) of service per day--more than any single metropolitan transit system in the state.

MODEL DEVELOPMENT

Some of the standard techniques for estimating vanpool fuel savings are based on the following idea:

$$\text{Fuel saving} = \text{fuel used by automobiles before vanpooling} - \text{fuel used by automobiles left at home} - \text{fuel used by vans} \quad (1)$$

The assumption is that any fuel used to run after-hours errands is offset by a gain from the elimination of lunch-time travel. This concept also assumes that the number of vanpoolers diverted from transit is very small. The maximum potential saving can be realized if employees originally commuted alone in gas guzzlers and sold their second car immediately. More realistically, broken-up carpools and extra use of the vehicle left at home often dilute this potential substantially.

The original SRI model required two modifications to adapt it to the Texas situation and to expedite data collection. First, the number of cars replaced by a van should be expressed as a ratio of the vanpool occupancy rate divided by the automobile (used prior to vanpooling) occupancy rate. This accounts for the fact that some programs use 15-passenger vans and some use 12-passenger vans and that some programs attempt to fill every seat but others do not. Second, vanpool fuel consumption is computed directly by dividing the van trip length by the vehicle's fuel efficiency instead of indirectly from an adjusted average automobile trip length.

The equation used to calculate daily fuel savings for each Texas vanpool program is

$$GS(VP) = V\,[(VPOR/AOR)\,(F - H) - (L/VKPL)] \quad (2)$$

where

GS(VP) = daily gasoline savings,
V = number of vanpools in each program,
VPOR = vanpool occupancy ratio,
AOR = automobile occupancy ratio,
F = liters per day consumed by the average commuter automobile,
H = liters per day consumed by the average automobile left at home,
L = van roundtrip commute distance (km/day), and
VKPL = van fuel efficiency (km/L).

Savings for a specific program can be calculated by substituting appropriate regional values into this equation. If none of the regional values are appropriate, the statewide averages should be used. The statewide savings is the sum of all program savings.

DATA COLLECTION

In November and December 1978, a questionnaire was sent to all 23 vanpool managers in the state for distribution to their drivers; 14 responded and gave data for 211 vans out of 325 (65 percent). Where a program responded, all vans were included; at least one program responded from every geographic area. Survey results are given in Table 1.

The statewide average vanpool roundtrip length is 86.2 km (53.6 miles). The trips are shortest in the Houston area and longest in the rural areas. The fuel efficiency of vans averages 4.25 km/L (10 miles/gal). The relatively high prior automobile occupancy rate for the vanpools (1.47 as compared to 1.25 for the average Texas work trip) indicates that many vanpoolers are former carpoolers.

Statewide, van occupancy averages 11.2 persons/van; however, this is somewhat misleading. Included in this average are both 12- and 15-passenger vans. All San Antonio and rural area vans held 15 passengers. The remainder were 12-passenger vans. Taken separately, the average occupancy for 12-passenger vans is 10.2 persons and for 15-passenger vans, 13.4 persons. Both operate at approximately 90 percent capacity with two empty seats, counting the driver as a passenger.

Preliminary energy savings, computed by using national averages for automobile kilometers per liter and fuel used by the vehicle left at home, tended to support the 18 900 L/year figure. Later, it became apparent that an accurate determination of fuel savings hinged on the accuracy of the estimate for the actual amount of gasoline saved by not commuting in the vehicle left at home. Some vanpool program managers thought that the estimates for the fuel efficiency for this vehicle were too high and that its use was greatly exaggerated. The effect of this error would be to underestimate actual fuel saving.

In order to put this issue to rest, another survey was conducted in May and June of 1979. A second questionnaire was distributed to a Houston and a Dallas vanpool program. At the time of the survey, Aramco Services operated a 22-van, 227-person program in Houston; 178 passengers (78 percent) responded. In Dallas, Texas Instruments had a 16-van program that served 178 passengers; 157 passengers (89 percent) responded. Survey results appear below.

1. Automobile fuel efficiency = 6.76 km/L (15.90 miles/gal),
2. Automobile roundtrip length = 86.50 km (53.75 miles),
3. Distance driven by vehicle left at home = 9.80 km (6.09 miles), and
4. Automobile occupancy ratio = 1.40.

Prevanpool Commute Vehicle	Aramco and Texas Instruments (%)	State Average (%)
Large vehicle	39.9	40.7
Mid-sized vehicle	39.6	39.3
Compact vehicle	15.8	14.6
Subcompact vehicle	4.6	5.4

The number of liters per day consumed by a commuting automobile (F) is calculated by dividing the number of kilometers the automobile is driven by its fuel efficiency. By dividing the average automobile commute distance (86.5 km) by the average automobile fuel efficiency (6.76 km/L), the F-value is found to be 12.8 L/day. Because the average commuter roundtrip by automobile and by van is almost the same, F can be calculated from the

Table 1. Results of statewide vanpool survey.

Item	Texas Average	Houston	Dallas	San Antonio	Rural
Vehicle characteristics					
Vanpool roundtrip distance (km)	86.2	79.0	94.0	90.7	106.2
Vanpool occupancy ratio[a]	11.2	10.3	11.3	13.4	13.4
Van fuel efficiency (km/L)	4.25	4.21	4.25	4.12	4.51
Automobile occupancy ratio	1.47	1.35	1.72	1.76	1.67
Prevanpool commute mode (%)					
Carpool with one other	18.6	17.7	13.2	23.3	20.0
Carpool with two others	15.4	9.9	8.0	15.2	35.5
Carpool with three others	15.8	12.7	40.4	28.0	8.6
Drive alone	48.2	56.7	38.4	32.0	35.9
Bus	1.9	3.0	0.0	1.0	0.0

Note: 1 km = 0.62 mile; 1 km/L = 2.35 miles/gal.
[a]10.3 for 12-passenger vans; 13.4 for 15-passenger vans.

Table 2. Comparison of assumptions and gasoline savings for various cases.

Item	Maximum Potential	Realistic	SECP	Survey Results
Vanpool occupancy ratio	12.0	11.0	9.0	11.21
Automobile occupancy ratio	1.0	1.4	1.4	1.46
Number of automobiles replaced by one van	12.0	8.0	6.4	7.7
Automobile commute distance (km)	72.4	72.4	25.9	86.6
Automobile kilometers per liter	4.25	4.25	5.19	6.76
Consumption by average commuter automobile (L/day)	17.0	17.0	5.0	12.8
Consumption by average automobile left at home (L/day)	0.0	0.0	0.46	1.44
Van roundtrip commute distance (km/day)	72.4	72.4	25.9	85.8
Van fuel efficiency (km/L)	4.25	4.25	0.06	4.25
Gasoline savings				
Liters per day	187.4	119.2	20.6	67.3
Liters per year	48 713.0	30 999.0	5340.9	17 487.5

Note: 1 km = 0.622 mile; 1 L = 0.264 gal; and 1 km/L = 2.352 mile/gal.

average van distance for a region rather than by using the statewide average value of 12.8 L if a more consistent estimate is desired.

Responses indicate that the vehicle left at home is driven, on the average, 9.8 km/day. Dividing this distance by the automobile's fuel efficiency (6.76 km/L) yields a value of 1.44 L for the liters per day consumed by a vehicle replaced by a vanpool (H). These vehicles, which are driven much more than was anticipated, represent a significant loss in potential savings.

RESULTS

The wide range of published estimates for yearly fuel savings from vanpooling is caused primarily by differing assumptions about how people commute before they joined a vanpool. To illustrate this, gasoline savings for the average 12-passenger van were determined for each of the following situations: (a) maximum possible potential, (b) more-realistic case advocated by Texas vanpoolers, (c) case stated in the Texas energy conservation plan by using the SRI methodology, and (d) savings by using the survey results. The modified SRI equation was used for all calculations except that of the state's energy conservation plan. Table 2 summarizes the assumptions made for each variable and the resulting daily and annual gasoline savings (3,5). The potential and realistic assumptions were made by using Murrell (5).

The primary differences between the assumptions made from the survey and those used by the others are the automobile and van roundtrip distances, the automobile fuel efficiency, and the amount of savings attributed to the vehicles left at home. The survey reveals that automobile and van roundtrip distances are slightly higher than the estimate for either the maximum potential or realistic cases and more than three times the estimate used in the SECP. The automobile fuel efficiency was also significantly higher than previous estimates. Another major difference lies in the liters per day used by the vehicles left at home. The maximum potential and realistic cases ignore this value altogether, and the value used in the SECP is low by slightly more than a factor of three.

CONCLUSIONS AND RECOMMENDATIONS

Vanpools save a significant amount of fuel. In Texas the 17 400 L/year per van saving is enough to justify preferential treatment in fuel allocation. Steps are being taken to ensure that vanpoolers will be able to get to work during the next period of severe shortage. This has become as important to the vanpoolers as the concept of money saved that was the primary consideration during the program's first stages. Employers see this as a technique for expanding their labor market in the face of increasing costs and shortages.

The potential savings are not as high as some of the more enthusiastic vanpoolers would like to see. This is because of the increasing fuel efficiency (6.0 km/L in 1973 to 6.8 km/L in 1979) (5) of the vehicles replaced by the vans and because the vehicle replaced is used during the day for other purposes. When these vehicles are disposed of, it is hoped that they will not be replaced. However, if the prior mode included a significant percentage of transit ridership (very rare in Texas), the savings are overstated.

Finally, there is an admitted bias toward Houston vanpools since the majority of Texas vanpools are located in Houston. By actual count, 72 percent of the vanpools are in Houston, 11 percent in Dallas, 11 percent in San Antonio, and 6 percent in rural Texas. When the goal of 1500 vans is reached by the end of 1980, the growth of vanpooling in San Antonio and Dallas-Fort Worth will eliminate, or at least reduce, this bias.

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Evaluating the Costs and Benefits of Plans to Reduce Gasoline Queues

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The costs in terms of service station queuing of contingency plans designed to reduce gasoline demand during a shortfall in petroleum supply are analyzed. Queues are recognized as a response to market disequilibrium that will grow until the cost per gallon of queuing fills the gap between the equilibrium price and the price charged at the pump. The cost of queuing can thus be inferred from this price differential; the reduction in total queuing costs represents the benefits produced by the contingency plan. Benefits and costs of a contingency plan are measured relative to the alternative of rationing by queuing. The value of these benefits is measured for three such plans and compared with rough estimates of the costs of achieving them. Costs include the losses in consumer surplus caused by a plan and the expenses of implementing a plan. An economic model of the retail gasoline market is presented graphically to describe the theory that underlies the analysis. An important inference that can be drawn from the analysis is that, when more-efficient policies are precluded, restrictions on consumption may be designed that will yield benefits in excess of costs. The three plans analyzed in this paper are an employer-based plan to encourage more energy-efficient commuting travel, a sticker plan to require each household to give up use of all of its cars on a selected day of the week, and a ban on weekend use of off-road recreational vehicles, private boats, and aircraft. Estimates are based on data from secondary sources and a set of assumptions that include a 7 percent shortfall in the supply of gasoline in 1981. Benefits from all three plans are found to exceed their costs.

In the winter of 1973-1974 and again in the spring of 1979 the United States experienced shortages of gasoline. Not only did the supply of gasoline fall below consumers' demand, but also the price was not permitted to rise sufficiently to clear the market. The result was an excess of demand at the prices being charged at the pump. When prices fail to rise to the equilibrium level, some other mechanism perforce takes over to determine how limited supplies are allocated among competing users.

In the absence of any other type of rationing (for example, government-issued coupons), the tendency is for queues to form at gasoline stations. Under perfect market conditions (perfect information and absence of discrimination or product differentiation), queues will grow to be equal in length at all gasoline stations in a given market, and we would expect their length to be sufficient to cause the cost of queuing per gallon of gasoline to consumers to make up the difference between the dollar price at the pump and the price consumers would be willing to pay for the marginal gallons purchased. The cost of queuing will thus equilibrate the market when price is controlled. The queues' length will be determined by the excess of demand over supply.

Queuing is a real resource cost, in contrast to dollar payments, which represent transfers of purchasing power. They are what economists call a dead-weight burden. No one benefits from the use of resources employed in queuing nor can their cost be recovered through taxation. It is, therefore, a good idea to reduce or eliminate queues even at some cost to society at large. This paper concerns one method for doing so.

It is necessary at the outset to distinguish between queues that consumers join in order to stake a claim to a share of a product when there is not enough to go around at the current price and queues due to congestion caused by bottlenecks in distribution. The former phenomenon concerns us here. The latter can be eliminated by removing the bottlenecks (e.g., increasing the number of gasoline station pumps and attendants, having stations remain open longer, or instituting minimum purchase requirements); the former cannot. Speeding up the distribution system will merely cause the number of cars in line to grow to restore queuing time to its former level when queues serve as a price to bring demand and supply into equilibrium. It will also force stations to close sooner.

Barring an increase in the supply of gasoline, there are three ways to eliminate queues caused by a gasoline shortage:

1. Let the price rise to clear the market, via either market forces or a tax increase;
2. Substitute some other form of rationing that assures consumers a given amount of gasoline without queuing; and
3. Reduce demand for gasoline to the point where consumers are satisfied to purchase no more than the available supply at the price that is charged at the pump.