been debated for some time, and I would argue that induced demand, although not separately estimated, is inherently accounted for in the combined generation-distribution effects. In using trip-generation procedures that consider increases in income and/or car ownership, induced travel is partially accounted for by increases in mobility (trips) that result from increases in vehicle supply. Similarly, as travel-time savings occur in the highway network, trip lengths increase and again induced travel is indirectly accounted for.

In conclusion, I recommend the paper to any student of travel demand forecasting but suggest that the problems of survey error can be and are overcome through the use of appropriate calibrating strategies. The results of well-calibrated forecasting models, when tested against measured travel volumes, are adequate for most planning applications.

Vanpool Energy Efficiency: A Reevaluation and Comparison with a Brokered-Carpooling Concept

AXEL B. ROSE

Since the first employer-operated vanpools began operating in 1973, much has been made of the considerable energy savings possible through vanpooling and it has been generally accepted that vanpools are the most efficient commuter transportation mode available. The analyses that formed the bases for these conclusions have seldom involved more than simple comparisons of the line-haul energies of vanpools and average commuter automobiles; rarely, if ever, have vanpools been compared with other innovative and efficient commuting modes. Based on data available through a recent survey of vanpool riders in Chattanooga, Tennessee, a more detailed calculation of vanpool energy intensities is presented that incorporates the line-haul, access-egress, and indirect energy uses of vanpools as well as a calculation of the energy uses arising from the use of pool vehicles for private purposes. The resultant energy intensity of vanpools is calculated at 1508 kJ/passenger-km (2300 Btu/passenger mile), which represents an increase of more than 100 percent over the line-haul energy intensity. Concurrently with the calculation of the vanpool energy intensities, values are calculated for an alternative commuting mode essentially identical to vanpools with the exception that efficient subcompact and compact automobiles are used instead of vans. In the final analysis it is shown that efficient brokered carpools could save up to 60 percent of the energy used by vanpools and also offer significant advantages over vanpools in ease of implementation and possible penetration of the commuting market.

In recent years, it has become a widely accepted conclusion that vanpools are the most efficient mode of commuter transportation and that consequently they should play a major role in any petroleum conservation program. Unfortunately, these conclusions have been largely based on incomplete or dated investigations of vanpool energy use; rarely, if ever, have vanpools been compared with other innovative commuter transportation modes. Within this context, this paper presents a more complete analysis of vanpool energy use and then compares the resultant energy uses with those of an alternative commuter transportation mode that has the potential of considerable energy savings over vanpool operations.

A vanpool can be described as a commuter ride-sharing transportation mode in which a group of people who live and work in proximity to each other commute together in an 8- to 15-passenger van. In return for a free ride and limited personal use of the van, one person in the group, typically the driver, assumes responsibility for the vehicle and its operation. The other pool members (and in some cases the employer and/or the government) share the costs of the whole operation. Three general types of vanpools are currently in operation: (a) employer-sponsored vanpools, in which the employer purchases the vans, furnishes them to the employees, and over time recovers the costs through the fares; (b) third-party-sponsored vanpools, in which a third party purchases the vans and acts as a broker between employees and employers; and (c) individually owned and operated vanpools.

The first employer-sponsored vanpool program became operational in April 1973 at the Minnesota Mining and Manufacturing (3M) Company in St. Paul, Minnesota. By April 1979, 4382 vanpools were known to be operating in addition to the 3000-5000 privately owned vanpools believed to be in existence (1, p. 6). From the first to the third quarter of 1980, the Tennessee Valley Authority (TVA) expanded its vanpool operations from 219 to 413 vans. By 1990, 1.15 million vanpools are forecast to be in operation in the United States (2, p. 10). Substantial government programs are under way to further ridesharing and vanpooling. Investment tax credits are being granted for the purchase of vans for pooling purposes, Highway Trust Fund money is available for the purchase of vans, and special lanes, to be reserved for high-occupancy vehicles, are being constructed in several areas. In summary, it can be stated that vanpooling has made substantial headway in the past few years toward penetrating the commuting market and that a variety of programs have been implemented that are aimed at increasing the growth of vanpooling in the future.

The impetus behind the movement can be found in a variety of perceived vanpool benefits frequently cited in the literature. Vanpool riders enjoy reduced commuting costs and the freedom of not having to drive, employers and/or localities need to provide and maintain fewer parking spaces, and everybody benefits from a reduction in congestion, vehicle emissions, and gasoline consumption. Of these benefits, lower commuting costs and energy savings are usually considered the most important. In comparison with traditional U.S. commuter transportation modes, a typical vanpool is generally credited with saving approximately 18 925 L (5000 gal) of gasoline per year, reducing emissions by 1.81 Mg (2 tons) per year, and removing six to nine vehicles from the road.

As stated, vanpool benefits have been calculated against a historical status quo. In view of the rapidly rising energy costs that tend to move people toward more efficient means of transportation and the significantly improved fuel economies for current and future automobiles, it is highly questionable whether the energy and cost advantages of vanpooling will remain at the levels implied by past studies. Furthermore, many studies, such as the one recently carried out by the Congressional Budget Office (3, p. 39), which concludes that "vanpool displays the best performance on all measures," do not take into account many of the operational factors that tend to degrade a vanpool's performance, nor do they compare vanpools with other innovative, alternative commuting modes. The remainder of this paper is devoted to a more rigorous quantification of vanpool energy intensities and to a comparison with an alternative concept that allows for substantial additional energy savings under a variety of operating conditions while offering many of the advantages of vanpools.

BASELINE DEFINITIONS AND ENERGY USES

The logical starting point for any analysis of energy use by vanpool and alternative systems is a more detailed examination of the methodologies used in arriving at the aforementioned yearly fuel savings per van of roughly 18 925 L (5000 gal). These savings are derived from a simple comparison of the line-haul energy use of a van that carries 11.2 passengers at 4.25 km/L (10 miles/gal) and a car that carries 1.4 passengers at 6.38 km/L (15 miles/gal) over an 80.45-km (50-mile) round trip. The resultant weekly fuel savings of 410.05 L (107.05 gal) are then aggregated over 47 weeks, accounting for vacations and holidays, and, in recognition of the simple nature of the calculations, are rounded to 18 925 L/van/year.

Of these data, those relating to automobiles will not be considered further since they are not germane to the subject of this paper. Since few hard data concerning the aggregate of vanpool operations are available, the assumptions concerning vanpools could only be verified through informal telephone contacts. Conversations with personnel at TVA and the U.S. Department of Energy revealed that assumptions of 11-12 riders/van and fuel economies of 3.82-4.25 km/L (9-10 miles/gal), though somewhat optimistic, would not be unreasonable. TVA added the caveat that, although these fuel economies fell within the range of their past experience, the new 15-passenger vans, obtained from a different manufacturer, were realizing fuel economies more in the range of 2.55-3.83 km/L (6-9 miles/gal). The average round-trip length for the TVA fleet of 413 vans was calculated at 75.8 km (47.1 miles) for the second quarter of 1980. From this, for the purposes of this paper the baseline vanpool was defined as carrying 11.5 passengers at a fuel economy of 4.04 km/L (9.5 miles/gal) over a round-trip length of 75.8 km.

The resultant line-haul energy intensity of the baseline vanpool as defined above is 750 kJ/passenger-km (1144 Btu/passenger mile). Any alternative system that can improve on this line-haul energy intensity should be able to realize energy savings over vanpools, provided that access-egress and other energy requirements are also roughly equivalent. When operated with a high load factor, virtually any mass transit vehicle is capable of bettering the line-haul energy intensity. However, due to the large number of riders required, the peak loading problems, and the high capital investments involved, such systems cannot be considered viable alternatives in most cases. One vehicle that does have the capacity for low line-haul energy intensities and also alleviates the problems associated with larger vehicles is the automobile when it is used for carpooling. Figure 1 compares the line-haul energy intensities of carpools and vanpools with varying automobile fuel economy.

At first glance it seems that the realized on-road fuel economies necessary for carpools to be competitive are sufficiently high that any further analysis is a waste of time. This is not necessarily true, however, since the long trip lengths involved in vanpool operations and the preponderance of highway driving conditions in the line-haul portions of such movements will enhance the automobile fuel economies considerably over the values they would realize under average operating conditions.

The long trip lengths involved in vanpool competitive operations will, to a large extent, alleviate the warm-up fuel-economy penalties incurred under the much shorter average U.S. automobile trip lengths of 14.2 km (8.8 miles) (4). From data provided by Scheffler and Niepoth (5), it is readily calculated that, over the average U.S. trip length, cars achieve roughly 85 percent of their fully warmed-up fuel economy in contrast to the 94 percent achieved over the 37.8-km (23.5-mile) trip lengths characteristic of vanpool operations. Thus, automobiles can be expected to achieve an 11 percent improvement in fuel economy over their normal use due to the longer trip lengths alone.

In general terms, driving conditions can be typified as either city, with frequent stops and low speeds, or highway, with substantially higher speeds under more or less free-flowing conditions. Typically, the fuel economies of automobiles obtained under highway driving conditions will be about 50-100 percent greater than those obtained in the city, depending on the particular definitions one uses for city and highway driving. At the national level, it is estimated that 55 percent of vehicle kilometers of travel occur in cities and 45 percent occur on highways. However, in vanpool-type operations typified by long line-haul portions, one would expect highway driving to account for closer to 60-70 percent of vehicle kilometers of travel, which would result directly in fuel-economy improvements of 6-30 percent, depending on the exact nature of the routes involved.

The largest amount of internally consistent data relating to automotive fuel economy is the Environmental Protection Agency (EPA) certification data, which contain city, highway, and composite fuel economies for virtually every car model sold in the United States. In the past, it has been shown that EPA composite fuel-economy values overestimate considerably the average on-road fuel economies of vehicles and that the discrepancies increase with increasing vehicle fuel economy. The discrepancy for an estimated fuel economy of 17 km/L (40 miles/gal) is 23 percent or 3.9 km/L (9.2 miles/gal). However, if we recall that the long trip lengths and highway driving conditions typical of vanpool operations would enhance automobile fuel economy by 18-44 percent over normal operating conditions, it becomes quite reasonable to assume that automobiles used in vanpool-type applications could attain their EPA composite fuel economies in spite of the 4-8 percent fuel-economy penalty incurred due to higher passenger loads. In any case, it will become evident that the assumptions concerning realized on-road automobile fuel economies are not critical to the outcome of the analysis. Table 1 (6) gives the highest and the 90th percentile EPA composite fuel economies for 1980-model-year automobiles by vehicle size class.

Before we delve further into comparisons of vanpools and carpools, it is necessary to define more closely how the carpools to be analyzed are to function, since this is going to affect the outcome of the analysis. A more apt name for this mode would be a brokered carpool, since its operation is envisaged to be identical to that of a vanpool. An

Figure 1. Brokered-carpool and vanpool line-haul energy intensities.

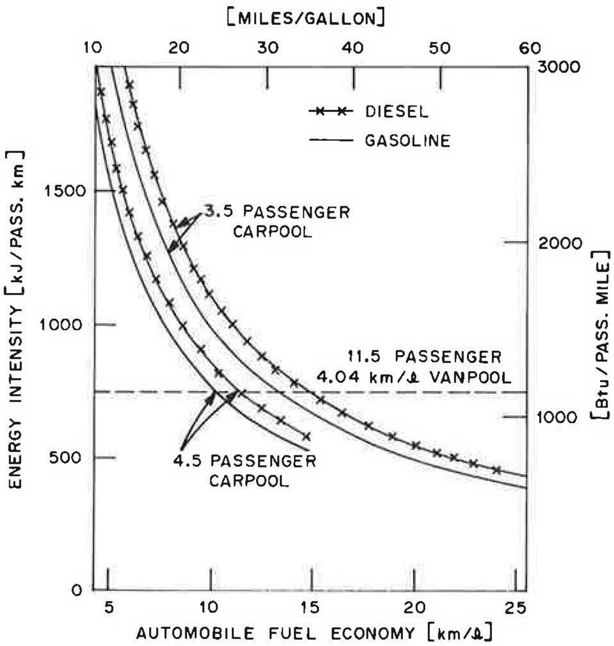


Table 1. EPA composite cycle fuel economy for 1980-model-year, high-fuel-economy automobiles.

Automobile Class	Fuel Economy (km/L) Highest Gasoline	Diesel	90th Percentile
Minicompact	17.34	-	15.64
Subcompact	18.02	20.15	14.62
Compact	13.35	13.86	11.65
Midsized	12.37	11.22	11.22
Large	9.22	11.22	8.50
Station wagon			
Small	15.09	17.47	14.79
Midsized	11.90	13.43	9.69
Large	8.16	10.29	10.29

Note: 1 km/L = 2.35 miles/gal.

employer, a third party, or a private individual will purchase the vehicle, which is to be dedicated to commuting trips, assign a driver to be responsible for its operation, and collect the fares that, barring subsidies, will cover the purchase and operational costs of the vehicle. In return for his or her services, the driver will not be charged a fare and to a limited extent will be allowed to use the vehicle for private purposes. The only differences between a van as used in a vanpool and an automobile as used in a brokered carpool will arise out of the differences in size, carrying capacity, and fuel economy of the two vehicles.

For the purposes of this analysis, it was assumed that highly efficient fourand five-passenger automobiles would be purchased for use in the brokered carpools. The average occupancies of 3.5 and 4.5 reflect that at any given time there will be a turnover in the membership of the brokered carpools and that some vehicles may be operating in lower-density areas. Surveys of TVA vanpool riders in Chattanooga and of the State Employee Vanpool Program in Lansing, Michigan (7), showed that only 7.2 and 5.4 percent of the respective vanpool trips were missed. Therefore, any effects of riders missing trips were neglected for vanpools and brokered carpool alike.

ENERGY USES OTHER THAN LINE-HAUL

In addition to an analysis of the energy used in the line-haul portion of the movements, any comprehensive comparison of energy intensities should also attempt to capture the energy use arising from the access-egress portions of movements and from possible additional uses of the vehicle as well as the indirect energy use associated with the construction and maintenance of the vehicles and their right-of-way. In particular, for the case of vanpools versus brokered carpools, these energies are nontrivial and will influence the outcome of the comparisons to a significant extent.

In the vast majority of cases, the riders will not live sufficiently close to the pool driver that they can all walk to the departure point, and some energy will be used in the access portion of the trip. Typically, either the pool will pick up the riders at their homes or the riders will drive to one or more pickup points to meet the vehicle. If the pool vehicle is used to pick up the riders, a circuity will be incurred over the direct trip length, since it is highly unlikely that all pool members will live on the direct route between the driver's residence and the place of work. If round-trip length (RTL) is defined as the mean round-trip distance from the poolers' residences to the place of work and circuity (C) is defined as the mean fraction of the round-trip length that must be covered to pick up one rider, the energy intensity (EI) of a pool trip involving circuity and N riders can be calculated as

$$EI = [RTL(1 + N \cdot C) \cdot k]/(FE \cdot N \cdot RTL) \quad (1)$$

where FE is the fuel economy of the pool vehicle and k is the energy content per unit volume of the fuel being consumed. Figure 2 shows the effects of circuitous movements on the relative energy intensities of vanpools and brokered carpools. Since no data concerning the circuity of movements are available, the analysis was carried out parametrically for values of C and resulted in total circuities for van movements (VCIR) of 0.2-0.4.

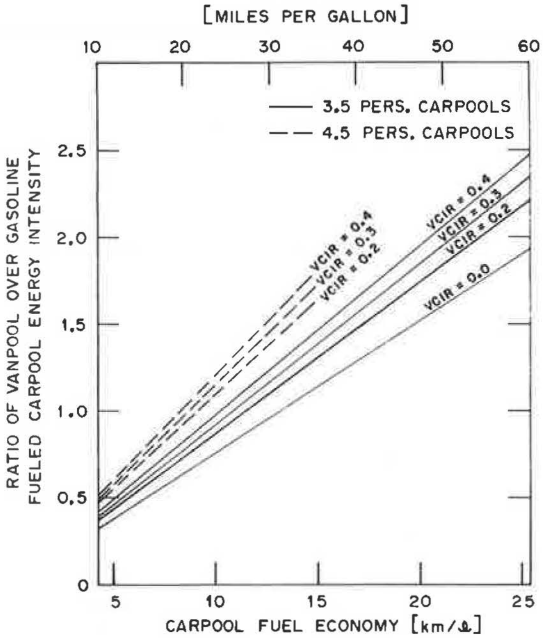
Evaluating the effects of pool members' driving to common pickup points is somewhat more complicated, since the relative positions of the pickup points, the driver's residence, and the riders' residences all exert an influence on the efficiency of the system as a whole. For the purpose of this analysis, we will assume the favorable interpretation that the pickup point is located between the pool members' residences and the work location and that consequently the movements to and from the pickup point result in a net productive transportation movement. Under this assumption, the energy intensity of the vanpool system can be calculated as

$$EI_v = [(RTL/VFE) + (ACC/VFE) + (N_v ACC/AFE)]/[RTL \cdot (N_v + 1) + 0.75 \cdot ACC \cdot (N_v + 1)] \quad (2)$$

where

- RTL = round-trip length of the van movement from the pickup point to the place of employment,
- VFE = fuel economy of the van,
- ACC = mean round-trip distance from the poolers' residences to the pickup point, and
- AFE = harmonic mean fuel economy of the vehicles used by the riders in driving to the vanpool.

Figure 2. Effect of circuity on relative energy intensities of vanpools and brokered carpools.



Thus, the numerator terms correspond to the fuel used by the van between the pickup point and the workplace, the fuel used by the van between the driver's residence and the pickup point, and the fuel used by the riders' vehicles between their residences and the access point, respectively. Similarly, the denominator terms correspond to the passenger kilometers generated by the van movement between the access point and the place of work and the passenger kilometers generated in the movements to and from the access point, respectively. The coefficient of 0.75 in Equation 2 was included on the generous assumption that three-quarters of the access-egress mileage would be in a direct line between the riders' residences and the place of work.

Substituting the efficiency of the brokered-carpool vehicles (CPFE) into Equation 2 in place of the van fuel economy allows the calculation of brokered-carpool energy intensities under identical operating conditions. However, considering that under the brokered-carpool concept roughly three times as many pool vehicles would be used to serve the same passengers, it is quite probable that a door pickup of the passengers would become possible and this would alleviate the need for pool members to drive to a common pickup point. Evidence supporting this assumption is given in an as yet unpublished survey of 439 TVA vanpool riders in Chattanooga, Tennessee, conducted in April 1980. Of the 189 respondents who drove or were driven to the pickup point, 117 had an access distance to the pickup point of 4.8 km (3 miles) or less. Thus, it appears that it is not the distance but the time involved in making 10.5 pickups that is the main reason common pickup points rather than door pickups are used in vanpools. This would not be the case for brokered carpools, since only 2.5 or 3.5 pickups, depending on the car size, are needed to fill the vehicle. If door pickups are to be considered for brokered carpools, then Equation 1, with slight modifications to reflect the longer trip lengths, must be used to calculate their energy intensity.

Figure 3 shows the results of a parametric investigation of the effects of trip length in conjunction with access mode on the relative efficiencies of brokered carpools and vanpools. The lower bands in this figure result when one assumes that all carpool and vanpool passengers alike drive to common pickup points for variations in ACC of 9.65-16.09 km (6-10 miles) and in RTL of 64.36-80.45 km (40-50 miles). The individual lines correspond to the cases in which vanpool riders drive to common pickup points and members of brokered carpools are picked up at their residences with a per-person VCIR of 0.3. The base fuel economy of the access vehicles in all cases was assumed to correspond to the U.S. mean of approximately 6.38 km/L (15 miles/gal). This fuel economy was subsequently degraded by factors of 0.74 and 0.87 for round-trip access distances of 9.65 and 16.09 km, respectively, to account for the increased warm-up effects in relation to the U.S. mean trip length of 14.2 km (8.8 miles).

The wide range of possible relative energy intensities shown in Figure 3 can be narrowed down considerably through data available from the Chattanooga vanpool rider survey. Of the 439 riders surveyed, 47.8 percent were picked up at their homes and 43.1 percent drove or were driven to a common pickup point at an average round-trip access distance of 14.12 km (8.78 miles). The remaining 9.1 percent of the riders have been assumed to consume no energy in meeting the vanpool. When these data are used in conjunction with the TVA system's average round-trip length of 75.8 km (47.1 miles), a base fuel economy of 6.38 km/L (15 miles/gal) for the access vehicles, and a per-passenger pickup circuity of 0.0286 (VCIR = 0.3), they result in a calculated vanpool energy intensity of 1250 kJ/passenger-km (1906 Btu/passenger mile), which represents an increase of 66 percent over the line-haul energy intensity. Figure 4 relates the energy intensity of "average" vanpools to that of "equivalent" brokered carpools (i.e., carpools in which the riders gain access to the pool vehicle in a manner identical to the way in which vanpool riders gain access to their pool vehicle) and to that of "full-service" brokered carpools (i.e., carpools that pick up all passengers at their residences).

As stated in the introduction, limited personal use of the van, and hence of the brokered car, by the driver is often permitted as an additional incentive for people to become pool drivers. Thus, any differences in energy use between the pool vehicle and the vehicle that would otherwise have been used must be included in the analysis of energy use. By letting OF be the fraction of the pool-use mileage for which the driver is allowed personal use of the vehicle and OFE the fuel economy of the vehicle that would otherwise have been used, the change in energy use due to personal use of the pool vehicle by the driver can be calculated as

$$E = \left\{ [(RTL \cdot OF)/FE] - [(RTL \cdot OF)/OFE] \right\} \cdot K \quad (3)$$

The argument that the personal use of pool vans generally applies where only a van would suffice found little substantiation in the 1980 Chattanooga survey, where only 5 out of 123 responses indicated that the person became a vanpool driver in order to have a van for personal use. Within the TVA system, the average OF was 0.165 during the first quarter of 1980. If the fraction of personal use of total van mileage exceeds 20 percent, the purchase of vans for pooling is no longer eligible for any federal investment tax credits. Figure 5 shows the new relative energy intensities that result when an OF of 0.165 at OFE = 6.38 km/L (15 miles/gal) is incorporated into the analysis of Figure 4.

The indirect energy uses of a transportation mode

Figure 3. Effect of access mode on relative energy intensities of vanpools and brokered carpools.

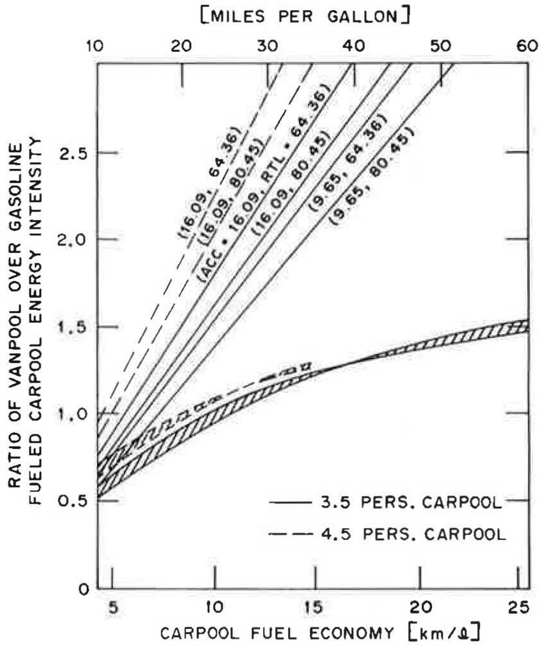
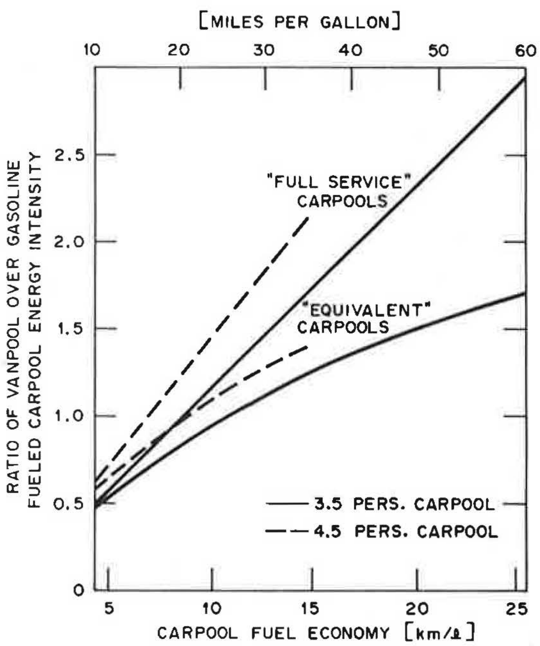


Figure 4. Relative energy intensities of vanpools and brokered carpools with Chattanooga access modes.



are generally broken down as the energy embodied in the vehicle itself, the energy embodied in its guideway, and the energies needed to maintain the vehicle with its supporting infrastructure. Ranges of values for the embodied energies of the vehicles and guideways are given elsewhere (3). For vanpools, the "middle" estimates of 131 and 1180 kJ/vehicle-km (200 and 2000 Btu/vehicle mile) were used, respectively. For automobiles, it was assumed that the embodied energy of the vehicle is directly proportional to its weight, and a coefficient of 1.46 kJ/(kg/vehicle-km) [0.365 Btu/(lb/vehicle mile)], falling at the lower end of the range of values in the report of the Congressional Budget Office (3), was applied to vehicles weighing 816, 1134, and 1587 kg (1800, 2500, and 3500 lb). This yields energy-use values for vehicle construction of 433, 597, and 839 kJ/vehicle-km (660, 910, and 1280 Btu/vehicle mile) for 3.5- and 4.5-person carpools and "average" automobiles, respectively. Since guideway construction energies are relatively unimportant, a value of 79 kJ/vehicle-km (120 Btu/vehicle mile) was assumed for carpool vehicles and a value of 98 kJ/vehicle-km (149 Btu/vehicle mile) was assumed for "average" cars. Since no reliable methodologies, much less data, are yet available for the calculation of the maintenance and infrastructure energies for carpools and vanpools, these were not incorporated.

Incorporating the vehicle and guideway construction energies into the analysis of Figure 5 yields the final comparison of brokered-carpool and vanpool energy intensities. This is shown in Figure 6 and represents the most realistic estimate of the energy intensities of vanpools and brokered carpools that could be constructed from the available data. In absolute terms, the inclusion of the access-egress energies, the personal use of the vans, and the construction energies raised the energy intensity of vanpools to 1508 kJ/passenger-km (2300 Btu/passenger mile), which represents an increase in excess of 100 percent over the line-haul energy intensity. Corresponding energy intensities for 17-km/L (40-mile/gal), 3- to 5-person and 12.75-km/L (30-mile/gal), 4.5-person brokered carpools are 1079 and 1116 kJ/passenger-km (1646 and 1702 Btu/passenger mile), respectively, when they are operated in an equivalent manner. When door pickups are assumed for all brokered-carpool riders, these values drop further to 600 and 723 kJ/passenger-km (916 and 1103 Btu/passenger mile), respectively.

From these values, it can then be concluded that, under the operating conditions considered in this study, replacing the existing vanpools with readily available, high-efficiency brokered carpools would result in considerable energy savings. To be more exact, 17-km/L (40-mile/gal), 3.5-person brokered carpools would be expected to save between 37 and 60 percent of the vanpool system's energy use, the exact value depending on the passenger access modes. For the larger, less efficient, 12.75-km/L (30-mile/gal), 4.5-person brokered carpool, the potential savings are only slightly lower, falling in the range of 28-52 percent. More important than the absolute magnitude of the possible energy savings is the fact that every factor, except indirect energy use, furthered the energy-use advantages of the brokered carpools. The direct conclusion from this is that, as long as the sum of the line-haul and indirect energy intensities of brokered carpools remains below the corresponding value for vanpools, energy savings are guaranteed if the vanpools are replaced by brokered carpools.

NON-ENERGY-RELATED CONSIDERATIONS

Obviously, the viability and desirability of brokered carpools as a commuter ridesharing alternative to vanpools cannot be assessed on the basis of energy considerations alone. This is particularly true since many of the often-cited advantages of vanpools over alternative commuting modes are not directly based on energy considerations.

Of the considerations not directly related to energy use, the system's costs must be considered the most important, since it is ultimately the reduction in commuting costs that makes vanpooling

Figure 5. Relative energy intensities of vanpools and brokered carpools with Chattanooga access modes and personal use of pool vehicles.

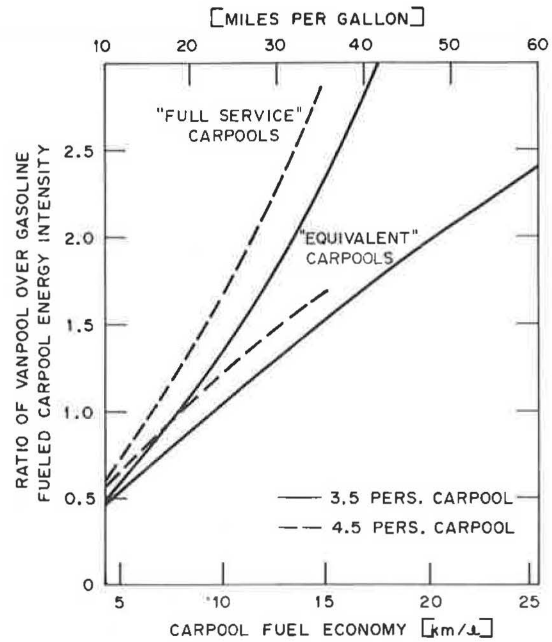
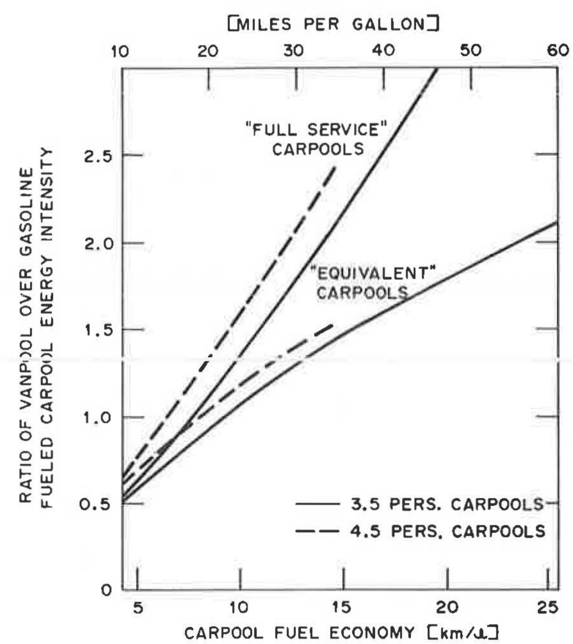


Figure 6. Best estimate of relative energy intensities of vanpools and brokered carpools.



attractive to riders and drivers alike. Table 2 gives the basic cost elements that will be used in developing system costs per rider. Suggested retail or POE prices were used on the assumption that the price reductions available through quantity purchases would equal the costs of any options installed in the vehicles. Tax credits and the like have not been included in the cost calculations, since they are reflections of the institutional environment and not of the economic merit of the systems being evaluated.

As given in Table 3, the total costs of vanpools and equivalent brokered carpools are very similar, whereas full-service pools have a cost advantage of roughly $100/month. However, due to the larger number of nonpaying drivers involved in the brokered carpools, the per passenger costs are considerably higher for equivalent brokered carpools than for the other systems. Although other benefits, which will be elaborated on later, may outweigh the cost disadvantages of the equivalent brokered carpools, it would be desirable to alleviate these cost problems. This may readily be accomplished by eliminating the free-ride policy for the driver and by rewarding him or her for driving by removing or slackening the restrictions on the driver's personal use of the vehicle. This would also result in further energy savings, since the vehicle the driver would otherwise use would almost certainly be less efficient. The low cost or free use of a highly efficient vehicle would certainly provide sufficient incentive for persons to become brokered-carpool drivers that an adequate supply of drivers would always be available.

Since each vanpool replaces several commuter automobiles, frequently cited benefits of vanpools, in addition to low commuting costs, are the reduced need for parking spaces, reduced congestion on the roads, and lower vehicle emissions. In terms of reducing congestion and the need for parking spaces, brokered carpools, while offering the advantages of historical commuting means, cannot compete with vanpools, since each van would be replaced by several brokered-carpool vehicles. In terms of reducing vehicle emissions, however, brokered carpools are roughly equivalent to vanpools, since emissions standards for light-duty trucks and vans are roughly three times as high as they are for automobiles.

Finally, one must consider the idea that, due to their smaller size and the smaller number of passengers carried, brokered carpools offer additional advantages over vanpools. It will, for example, be easier to find people willing to take on the responsibility of being a pool driver because of the reduced organizational burden of managing a pool of 2.5 or 3.5 persons versus managing 10.5 persons in the case of vanpools. In addition, the personal use of a highly efficient vehicle may very well turn out to be a formidable incentive for becoming a pool driver. Similarly, it should be easier to find passengers for the brokered carpools since lower trip times are possible due to fewer stops required for picking up and discharging passengers. An additional factor that should not be ignored is that brokered-carpool operations become possible in areas where there are simply not enough riders available to make a vanpool feasible. Seven persons are sufficient to form two small brokered carpools but would hardly suffice for even one vanpool. It is expected that all these factors would in the end result in a faster and deeper penetration of ridesharing into the commuter market than would be possible through vanpools.

CONCLUSIONS

The principal findings of this paper can be summarized as follows:

1. Past studies have tended to neglect many of the operational aspects of vanpooling, such as the access-egress portions of the movements, which directly result in overestimates of the possible energy savings of vanpools by a factor of two.
2. Small, highly efficient automobiles, when used in brokered carpools, could save a substantial portion (up to 60 percent) of the energy consumed by vanpools.

Table 2. Basic cost elements for vanpools and brokered carpools.

Element	Cost ($) 17-km/L, $4000[a] Subcompact	12.75-km/L, $5150[a] Compact	4.04-km/L, $11 000[b] Van	6.38-km/L, $6300[c] Avg Car
Fixed costs per month				
Payments (11 percent, 4 years)	103.38	133.10	284.30	-
Discounted salvage value after 4 years (0.5 at 10 percent)	28.46	36.64	68.75	-
Licenses and registration	6.83[d]	6.83[d]	10.00[b]	
Insurance	23.08[e]	28.67[e]	56.25[e]	
Total	104.83	131.96	281.80	
Operating costs per kilometer				
Fuel ($0.317/L)	0.019	0.025	0.078[b]	0.039
Maintenance	0.010[c]	0.015[c]	0.016[b]	0.057
Tires	0.003[f]	0.004[f]	0.006[b]	0.034
Total	0.032	0.044	0.101	0.130

Note: 1 km/L = 2.35 miles/gal, 1 L = 0.264 gal, and 1 km = 0.62 mile.
[a]Manufacturer's suggested retail or port-of-entry (POE) price of a 1980-model-year car of the given fuel economy (8).
[b]From U.S. Department of Transportation (9).
[c]Maintenance costs for first four years allocated over 90 100 km (10).
[d]From American Automobile Association (11).
[e]All insurance costs apply to employer-owned vehicles and were provided by the Insurance Services Office, New York, and the Allstate Insurance Company office in Oak Ridge, Tennessee.
[f]Calculated by assuming a useful life for steel-belted radials of 64 360 km.

Table 3. Comparison of total costs of vanpools and brokered carpools.

Category	Cost ($/month) Access Vehicles	Pool Vehicles Fixed	Pool Vehicles Variable	Total	Per Passenger	Per Person
Vanpool	173.94	281.80	185.25	640.99	61.05	55.74
Brokered carpool[a]						
3.5 persons						
Equivalent	136.07[b]	344.44	173.86	654.37	79.66	56.90
Full service	0	344.44	193.00	537.44	65.73	46.73
4.5 persons						
Equivalent	148.17[b]	337.15	181.76	667.08	74.58	58.01
Full service	0	337.15	213.99	551.14	61.62	47.93

[a]Cost data are calculated for the number of brokered carpools needed to transport 11.5 persons.
[b]Access costs are not identical to those of vanpools, since it was assumed that the same fraction of riders would still drive to the access point and this implies that a fraction of the riders who would have driven to vanpool access points have become carpool drivers. Pool vehicle mileages were adjusted to reflect this shift in trip lengths.

3. Even if energy use is neglected, the advantages of brokered carpools over vanpools tend to outweigh their disadvantages by far, and hence their implementation should be easier than that of vanpools.

Based on these findings, the inescapable conclusion of this paper must be that efforts should be made to evaluate the brokered-carpool concept in practice through the actual implementation of several pools.

ACKNOWLEDGMENT

The research reported in this paper was sponsored by the U.S. Department of Energy under contract with Union Carbide Corporation.

REFERENCES

1. L. Pratch and R. Starling. Vanpooling...An Update. U.S. Department of Energy, DOE/CS-0031/1, Sept. 1979.
2. L. Pratch. Vanpools: Their Growth and Potential. U.S. Department of Energy, Draft Rept., April 1978.
3. Urban Transportation and Energy: The Potential Savings of Different Modes. Congressional Budget Office, 1977.
4. Nationwide Personal Transportation Study. Bureau of the Census, U.S. Department of Commerce, 1970.
5. C.E. Scheffler and G.W. Niepoth. Customer Fuel Economy Estimated from Engineering Tests. Society of Automotive Engineers, Warrendale, PA, Paper 650861, 1965.
6. J.E. Murrel, J.A. Foster, and D.M. Bristor. Passenger Car and Light Truck Fuel Economy Trends Through 1980. Society of Automotive Engineers, Warrendale, PA, Paper 800853, June 1980.
7. State Employer Vanpool Program Status Report. Michigan Department of Transportation, Lansing, 1979.
8. Ward's Automotive Yearbook 1980. Ward's Communications, Inc., Detroit, MI, 1980.
9. How Ridesharing Can Help Your Company. U.S. Department of Transportation, 1980.
10. Cost of Owning and Operating Automobiles and Vans: 1979. U.S. Department of Transportation, 1980.
11. Your Driving Costs. American Automobile Assn., Falls Church, VA, 1980.