benefits of using this new package, which is considerably more complex than the original FHWA car-pool matching program. Ride-sharing agencies contemplating the use of CIS should obtain and carefully study the CIS user's guide before requesting the computer program tape.

SUMMARY AND CONCLUSIONS

The Commuter Information System is a state-of-the-art ride-sharing tool. It includes an advanced car-pool matching capability, an improved van-pool planning package, and a new transit information system to inform commuters of transit routes that can serve their commuting needs.

CIS is highly user oriented because it is modular and has a great number of user-selectable options. Thus, it is applicable to the wide range of local circumstances that were identified in the extensive survey of ride-sharing projects conducted at the beginning of the design effort. The entire package was pilot tested by a typical user agency, the city of Dallas, who felt that the system met their needs and worked well and will voluntarily continue using it. A small number of applicants were also surveyed; they felt that the printouts were easy to understand and that there were no significant errors or omissions.

CIS is distributed and supported by the Federal Highway Administration with the anticipation that it will become a standardized data-processing tool for ride-sharing projects nationwide. These efforts toward increased vehicle occupancy are required in many urban areas by U.S. Environmental Protection Agency regulations. Ride-sharing efforts will also be a major part of transportation system management projects as well as transportation-related energy-conservation efforts.

Providing high-quality information to commuters about their ride-sharing opportunities is "a link in the chain." It is a necessary but not a sufficient condition for making better use of existing transportation facilities by increasing vehicle occupancy.

Impact of Dial-A-Ride on Transportation-Related Energy Consumption in Small Cities

William R. Hershey, Sverdrup and Parcel and Associates, Inc.

Dial-a-ride is a door-to-door public transportation concept similar to taxi service except that passengers share the vehicle (usually a 12 to 20-passenger bus) with other riders. This paper examines energy consumption of dial-a-ride systems in three small Michigan cities. Fuel consumption per effective passenger kilometer (shortest distance between a passenger's origin and destination) is derived from aggregate fuel and ridership data and average trip-length data in the test cities. The analysis also predicts dial-a-ride user behavior and energy consumption in the absence of dial-a-ride. Results show that the introduction of dial-a-ride into test communities in Michigan has caused a net increase in transportation-related fuel consumption. Inducement of new trips, low vehicle occupancies, circuitous routing, poor vehicle fuel economy, and diversion of passengers from more energy-efficient modes are seen to be principal reasons for the significant energy costs of dial-a-ride. The future potential of dial-a-ride is discussed in the context of increasing energy prices, and several methods of reducing its energy intensiveness are presented. Despite the pessimistic estimates presented, energy consumption is only one of many factors that must be considered in determining the feasibility and desirability of dial-a-ride for a particular site.

Dial-a-ride is increasingly suggested as an effective public transportation option for suburban areas. As with any publicly financed venture, local policy makers must carefully weigh the costs and benefits of this popular and rapidly proliferating door-to-door transportation service. Monetary costs are usually thoroughly considered, but energy costs are often ignored. (Throughout this paper, energy cost is intended to mean the quantity of energy consumed and not the monetary cost of energy.) It is important to consider energy in terms other than present dollar costs because future energy prices and availability are highly unpredictable. Energy prices will almost certainly rise faster than such general economic indicators as the wholesale and consumer price indexes.

Other papers have technically assessed dial-a-ride's use of energy, but the news media and the public remain generally misinformed (1, 2). Many people assume that because dial-a-ride is public transportation it is energy efficient. A recent Associated Press release in California (3) stated:

> The aim of Dial-A-Ride is twofold: First, to save fuel by convincing people who normally would drive that they can switch to public transit without inconvenience. Second, to provide transportation for people who don't have a car and don't want to take a taxi.

In typical installations, however, dial-a-ride does not save fuel. On the contrary, the introduction of dial-a-ride into test communities in Michigan has resulted in a net increase in transportation-related fuel consumption. The principal reasons for this are the inducement of trips that would (or could) not have been made without the new service, the low average load factor (number of passengers per vehicle), circuitous routing, poor vehicle fuel economy, and the diversion of passengers from more energy-efficient modes.

This analysis consists of two main parts. The first part is based on empirical data from dial-a-ride operations in three small Michigan cities—Holland, Ludington, and Mt. Pleasant. Data on aggregate ridership, fuel consumption, and average trip length are used to derive effective passenger kilometers (shortest road distance between boarding point and destination) per liter of gasoline burned. The second part of the analysis starts with the hypothesis that riders are deprived of dial-a-ride service. How would they get where they need to go (or would they really go there) if dial-a-ride were unavailable? Alternate travel behavior is predicted on the basis of answers to on-board surveys conducted in the three Michigan cities. Energy-consumption data are presented for each alternate travel mode. The results are directly comparable to the data computed for dial-a-ride energy consumption in the first part of the analysis. Such a comparison reveals the energy-related implications of implementing dial-a-ride: More energy is consumed with dial-a-ride than without it.

Despite such pessimistic estimates, it must be emphasized that energy consumption is only one of many factors that must be considered in determining the feasibility and desirability of dial-a-ride for a particular site. The social benefits of providing mobility to the elderly, the poor, and the disadvantaged would be judged by many people to far outweigh the energy costs of dial-a-ride service. Other benefits that are often mentioned are reduction of parking problems and traffic congestion, greater personal safety, creation of new jobs, and relief for parents from chauffeuring their children. Furthermore, this study applies only to local-circulation dial-a-ride service in small cities. Demand-responsive feeder service to more efficient public transit modes involves other energy-consumption and mode-choice implications that are beyond the scope of this paper.

Finally, the paper concludes by using the data analysis to show how dial-a-ride energy consumption can be improved while certain social goals are maintained. The main objectives are to create an awareness of the energy costs of dial-a-ride and to inform decision-makers about the energy implications of various operating policies.

APPROACHES TO ESTIMATING TRANSPORTATION-RELATED ENERGY CONSUMPTION

Fels (1) has estimated the energy required for various urban transportation modes by adding together the energy used in manufacture and in operation (fuel), i.e., vehicle operation, vehicle manufacture, and guideway construction. Others (4, 5) have used economic input-output analyses to estimate total automobile-related energy costs. The latter approach includes indirect energy costs for items such as insurance, retailing, and taxes as well as the direct energy costs of fuel and manufacture. Accordingly, estimates based on input-output analyses are higher than those of Fels for automobile transportation.

This paper analyzes only the energy required to operate vehicles, that is, the energy represented by fuel consumed. The energy cost of manufacturing dial-a-ride vehicles, the allocated energy cost of the street network, and indirect energy costs are ignored although they would measurably increase the already high estimates of energy intensiveness presented here for dial-a-ride. Fels has estimated that approximately 90 percent of the energy consumed in providing motorized urban transportation goes into operation of vehicles (1). Most of the remainder is consumed in manufacturing the vehicles.

DIAL-A-RIDE FUEL CONSUMPTION

How much fuel does dial-a-ride consume in transporting a passenger 1 km (0.62 mile)? In theoretical approaches to this question, entire analyses have been based on a few key assumptions related to load factor and vehicle fuel economy. An empirical approach is favored here because of the many unpredictable vehicle movements that contribute to dial-a-ride fuel consumption.

The most useful quantities in an analysis of fuel consumption in passenger transportation are the energy expended to move a passenger over a given distance and, alternatively, the number of passenger kilometers traveled per unit of energy (such as a liter of gasoline) expended. Energy consumption per kilometer is calculated by counting the effective distance that a passenger travels and not the total distance, which includes kilometers traveled in collecting and distributing other passengers. Effective trip length is defined here as the shortest road distance between the passenger's boarding point and destination. For example, if a passenger rides 1.7 km (1 mile) in a dial-a-ride vehicle but the distance between his or her origin and destination is only 1 km (0.62 mile), that passenger will have ridden 1 effective passenger·km. A common error is to use actual rather than effective passenger kilometers in comparing the energy intensiveness of dial-a-ride with that of other, more direct transportation modes.

Average effective passenger kilometers per liter of gasoline can be computed by using the following formula:

$$E_k = PD/F \qquad (1)$$

where

E_k = fuel efficiency (effective passenger·km/L),
P = total number of passengers during the observed period,
D = average effective trip length per passenger (km), and
F = total fuel consumed during the observed period (L).

Fuel-consumption data were taken from fueling receipts, and ridership counts were taken from driver logs for a 1-month period during 1974 for each of the three Michigan dial-a-ride systems. This approach accounts for all fuel used—not only for carrying passengers but also for deadheading and for movement during fueling, cleaning, and maintenance. (These overhead fuel uses must be included in an honest appraisal of dial-a-ride energy consumption.)

Average effective trip length (D) was computed for the three Michigan dial-a-ride systems as follows:

1. Drivers recorded origin and destination addresses for each passenger during a period of 1 to 2 d. Sample sizes were 416 passengers in Holland, 210 in Ludington, and 351 in Mt. Pleasant.
2. Persons who were familiar with the area located each origin-destination pair on a map of the city and measured the road distance (the effective trip length) between the two points on the map.
3. Effective trip lengths for all sample trips in each city were averaged to produce a value of D for each city.

Table 1 gives calculations for the fuel-economy variables in Equation 1 for the three Michigan systems. The values of E_k are low, even when they are compared with customary fuel-efficiency measures for a full-size automobile occupied only by the driver: For example, fuel efficiency for the Holland system is 4.76 effective passenger·km/L (11.2 passenger-miles/gal), and that for Ludington is 3.76 effective passenger·km/L (8.8 passenger-miles/gal). Clearly, not all dial-a-ride passengers were riding around alone in full-size automobiles

Table 1. Fuel economy for three dial-a-ride systems.

City	Total Passengers for 1 Month	Total Fuel Use for 1 Month (m^3)	Average Trip Length (effective km)	Fuel Efficiency (effective passenger·km/L)	Gasoline-Equivalent Energy Consumption (kJ/effective passenger·km)
Holland	5876	4567	3.70	4.76	7.82
Ludington	5095	3928	2.90	3.76	9.91
Mt. Pleasant	5018	4578	4.02	4.41	8.44

Notes: 1 m^3 = 264 gal; 1 L = 0.26 gal; 1 km = 0.62 mile; 1 km/L = 2.35 miles/gal.
The energy equivalence of gasoline, 37.2 kJ/L (8900 large cal/L), includes the energy needed to refine the gasoline at 2.46 kJ/L (590 cal/L).

before dial-a-ride became available.

ENERGY CONSUMPTION WITHOUT DIAL-A-RIDE

Results of on-board surveys in the test cities have been used to predict the use of alternate transportation modes in the absence of dial-a-ride. The surveys were conducted in each city at the same time that other data-collection efforts were performed. Samples in each city included approximately 200 to 300 passengers. One of the questions asked was, If you were not riding with us today, how would you have reached your destination? Answers to this question have been interpreted to be an indication of the traveler's expected mode of transportation if dial-a-ride did not exist. The table below gives the percentages of survey respondents' modal preferences in such a case (percentages are normalized to exclude nonresponses):

	Preference (%)		
Mode	Holland	Ludington	Mt. Pleasant
Would not make the trip	21	16	16
Drive	6	6	10
Ride in an automobile with someone making a special trip	15	13	24
Ride in an automobile with someone going the same way	8	7	3
Taxi	21	22	12
Bicycle	5	3	3
Walk	24	33	32
Total	100	100	100

Bicycles and motorcycles were lumped into a single category on the survey form as were walking and hitchhiking. A similar survey of dial-a-ride passengers in Trenton, Michigan, indicated that 4 percent of passengers preferred bicycles as an alternate mode and a negligible number preferred motorcycles or motorbikes (6). The same survey found that 25 percent would walk and 6 percent would hitchhike. In this analysis, all responses in the bicycle-motorcycle category are assumed to be for bicycles and all responses in the walk-hitchhike category are counted as walkers. The amount of energy used for these modes is so small that slight errors will not affect the analysis.

The first mode category—would not make the trip—of course makes no contribution to the energy consumption of alternate modes. The significant number of persons who checked this answer in each city can be attributed to two commonly observed tendencies of dial-a-ride:

1. To provide needed mobility to those persons who have no other means of transportation and
2. To encourage people to make unnecessary trips.

The first of these is the one most often hypothesized as the reason for induced trips, and it is frequently substantiated by comments from poor and elderly users. The second tendency should not be ignored.

Energy consumption per effective passenger kilometer for each mode can be calculated by using the following formula:

$$E'_c = E_v C/WL \qquad (2)$$

where

E'_c = effective energy consumption (kJ/effective passenger·km),
E_v = energy for vehicle operation (kJ/vehicle·km),
C = circuity factor (vehicle·km/effective vehicle·km),
W = warm-up factor (efficiency for the trip length under study ÷ average efficiency), and
L = load factor (passengers/vehicle).

Values for E_v are taken from the results of another study (1); assumptions made for load, circuity, and warm-up factors are explained below for all modes.

Automobile use, which comprised four different answer categories in the surveys (including taxi), exhibits four different levels of energy intensiveness (Table 2). Load factor is based on the average number of passengers who would have boarded a dial-a-ride vehicle at each trip-origin address. Average load factor for the three test cities was 1.25 passengers/stop, which is somewhat lower than the 1973 national average automobile occupancy of 1.9 passengers/automobile (7). The load factor includes the driver for the drive mode only; for the other three automobile uses, the 1.25 passengers are additional to the driver.

The circuity factor is one of the quantities that differentiate the various types of automobile use. It indicates how many incremental kilometers the automobile must travel for every kilometer the passenger wishes to travel. The circuity factor for a driver who drives directly to his or her destination is 1.0. For the driver who rides in an automobile with someone making a special trip, the circuity factor is 2.0 (the driver must make a round trip for every one-way trip made by the passenger). For automobile passengers who ride with someone going the same way, it is assumed that the passenger's destination will be slightly out of the way and will require the driver to detour a distance equal to 20 percent of the length of the passenger's trip (the accuracy of this assumption is not critical; the affected passengers comprise only 3 to 8 percent of the total). The circuity factor is thus 0.2 for these passengers. Taxi riders are considered to be similar to passengers who necessitate a special automobile trip; the circuity factor is 2.0.

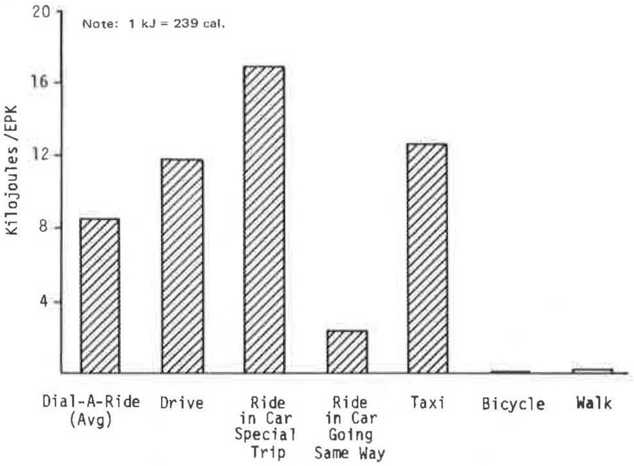
The warm-up factor also differentiates various types of automobile use. Automobile engines operate least efficiently when they are first started, and this poor efficiency would have a noticeable effect on fuel consumption during the relatively short trips in the range considered here [2.9 to 4.0 km (1.8 to 2.5 miles)]. Other factors that degrade automobile efficiency, such as low average speed and frequent stops, are also associated

Table 2. Fuel consumption for modes alternate to dial-a-ride.

Mode	Vehicle Operating Energy (kJ/vehicle·km)	Load Factor	Circuity Factor	Warm-Up Factor	Effective Energy Consumption (kJ/effective passenger·km)
Would not make the trip	0	–	–	–	0
Drive	7.15	1.25	1.0	0.47	12.2
Ride in an automobile with someone making a special trip	7.15	1.25	2.0	0.67	17.1
Ride in an automobile with someone going the same way	7.15	1.25	0.2	0.47	2.43
Taxi	7.15	1.25	2.0	0.88	13
Bicycle	0.09	1.0	1.0	1.0	0.09
Walk	0.14	1.0	1.0	1.0	0.14

Notes: 1 kJ = 239 cal; 1 km = 0.62 mile.
Automobile data are for a 1636-kg (3600-lb) 1973 automobile with a fuel efficiency of 5.24 km/L (12.3 miles/gal). Operation energy for walking and bicycling is derived from the difference between the energy burned by walking and bicycling and the energy burned when the body is at rest.

Figure 1. Energy intensiveness of dial-a-ride and the modes it replaces.



with short trips. Austin and Hellman (8) have developed curves that show fuel economy as a function of trip length, and the warm-up factors in Table 2 are derived from their data. It is assumed that taxi trips are made with warm engines and that all other automobile trips start with cold engines. The distance traveled riding in an automobile with someone who is making a special trip and in the taxi mode is assumed to be twice the distance for the drive mode and riding in an automobile with someone who is going the same way (Table 2).

Bicyclists and walkers are assumed to operate at uniform efficiency and to travel directly to their destinations. They are assigned circuity, load, and warm-up factors of 1.0.

Figure 1 compares the energy intensiveness of dial-a-ride with that of other modes available to dial-a-ride passengers.

Average energy consumption for a composite of all modes is calculated by weighting the value of E_c' for each mode by the appropriate survey response percentage. The sum of these weighted values represents the energy consumption of the average dial-a-ride passenger in the absence of dial-a-ride. The calculation was performed separately for each test city. The following table gives the results in the form of a comparison of dial-a-ride with the mix of alternate modes for each city:

	Energy Consumption (kJ/effective passenger·km)		
City	Dial-a-Ride	Mix of Alternate Modes (weighted average)	Difference (energy cost of implementing dial-a-ride)
Holland	7.8	6.3	1.5
Ludington	9.9	6.0	3.9
Mt. Pleasant	8.4	7.0	1.4

RESULTS

In all three of the study cities, dial-a-ride was shown to be more energy intensive than the mix of alternatives it replaces. The difference between the energy required for dial-a-ride and the energy required for the alternatives produces a rough measure of the energy impact of dial-a-ride. This impact, measured in gasoline, would total approximately 3200 L/month (850 gal/month) for the three cities.

How applicable are these results to other dial-a-ride systems? It is clear from the analysis presented here that many factors affect energy consumption. Dial-a-ride operators may want to do their own calculations to see how their systems compare with the examples presented here. The three cities chosen for this analysis are thought to be typical of most dial-a-ride service areas characterized by low density and single-family homes. Van-type vehicles show fuel economy midway between the 2.5 to 3.0 km/L (6 to 7 miles/gal) of 20-passenger, gasoline-powered vehicles and the 5.1 km/L (12 miles/gal) of small diesel buses. Populations of the cities range from 9000 (Ludington) to 26 300 (Holland). Average productivities for the relevant period ranged from 5.1 passengers/vehicle•h in Mt. Pleasant to 6.4 passengers/vehicle•h in Holland.

For some trips, of course, dial-a-ride uses less energy than the preferred alternative. Automobile trips made especially for the passenger and taxi trips show particularly high energy consumption per effective passenger kilometer. Mean values have been used throughout this analysis; therefore, approximately half of all trips will be less energy intensive than the average. Subscription service, in which a group of passengers is collected daily in an efficient vehicle tour, is likely to show relatively low energy intensiveness, particularly if the line-haul portion of the trip is rather long.

As noted earlier, the energy expended in manufacturing the vehicle, which would be nearly 10 percent of the total energy if allocated on a per-kilometer basis, has been ignored. In a rigorous analysis of the energy impact of dial-a-ride, one would have to observe the buying patterns of dial-a-ride users to determine whether they bought fewer automobiles and bicycles because of the service or extended the lives of such vehicles by using them less. Then the energy required for manufacture of dial-a-ride vehicles and the vehicles they replaced could be added to the respective values of operating energy for a more complete comparison of dial-a-ride with alternate modes. Because only 10 percent of the total energy is involved in vehicle manufacture and because dial-a-ride has shown only a minimal propensity for replacing automobiles in most cases, such a calculation would almost certainly reinforce the conclusion that dial-a-ride is an energy-intensive means of moving people.

CONCLUSIONS

Policy makers must apply their own priorities to this analysis in attempting to assess the utility of dial-a-ride in specific applications. Clearly, the dial-a-ride style of transportation carries significant energy penalties that must be considered along with its amenities. As energy prices increase, it is doubtful that dial-a-ride will emerge as the ultimate public transportation substitute for the private automobile.

What should be dial-a-ride's long-term objective? In one scenario described by Ward (9), dial-a-ride would serve as a public transportation market development tool in suburban areas. Having coaxed people out of their automobiles (with substantial monetary and energy subsidies), dial-a-ride would eventually lead to a greater relative proliferation of lower cost, fixed-route elements as ridership density (riders per square kilometer per hour) increased. By that time many people would have recognized the considerable travel-time savings involved in foregoing the doorstep service and walking a few blocks to the nearest bus stop. Energy intensiveness would be much lower than for pure dial-a-ride service because, with a line bus, there is little or no marginal fuel consumption associated with serving additional passengers, up to the capacity constraint of the vehicle. (Each passenger added to a dial-a-ride vehicle does increase energy consumption because of the necessity to route the vehicle to his or her origin and destination.)

Certain improvements can be expected in the efficiency of dial-a-ride. Vehicle fuel economy should improve as the automobile and small-bus industries become more serious about designing more efficient vehicles. Diesel-powered dial-a-ride vehicles will probably become more common. Increased use of day-in-advance prebooking of trips would allow more careful consideration of vehicle routing and manipulation of customer requests than does a random influx of telephone calls for immediate service. Carefully structured fare policies can help discourage nonessential trips and encourage group riding. Tough policies on no-shows can help reduce unproductive vehicle movements. Drivers can play a major role by developing more conservative driving habits, thoroughly learning the service area to avoid unnecessary deviations, and turning off their engines while waiting for their next tours.

If these measures and others fail to produce significant improvements in energy efficiency, perhaps dial-a-ride will have to be reserved for those who need it most. Many operations are currently limited to designated user groups such as the elderly and the handicapped. Depending on the rate of increase in energy prices, dial-a-ride may be increasingly restricted to such groups. All dial-a-ride costs and benefits must be considered, of course, as such decisions are made.

The challenge to dial-a-ride operators is clear. By striving for higher productivity, choosing fuel-efficient vehicles, and instituting thoughtful operating policies, dial-a-ride operators may be able to reduce the energy (and dollar) costs of dial-a-ride and thereby make this popular service a more acceptable transportation option for the future.

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Methodology for the Analysis of Local Paratransit Options

Larry S. Englisher and Kenneth L. Sobel, Transportation Systems Division, Multisystems, Inc.

A system of models has been developed that is capable of predicting the performance characteristics of transit service for the purpose of analyzing a wide range of local transit-service alternatives. Patronage and demand forecasting issues are treated parametrically. Local transit is de-