TRANSPORTATION RESEARCH RECORD 650

Paratransit Services

TRANSPORTATION RESEARCH BOARD

COMMISSION ON SOCIOTECHNICAL SYSTEMS
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1977

Transportation Research Record 650
Price $4.80
Edited for TRB by Mary McLaughlin

subject area
84 urban transportation systems

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Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board
Paratransit services.

(Transportation research record; 650)
Reports for the TRB 56th annual meeting.
1. Personal rapit transit—United States—Addresses, essays, lectures. 2. Urban transportation—United States—Addresses, essays, lectures. I. Title. II. Series.
TE7.H5 no. 650 [HE308] 380.5'08s [388.4]
ISBN 0-309-02679-2 78-11115

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Taxicab Feeder Service to Bus Transit

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The use of taxicabs as feeders to fixed-route transit is discussed. Reasons for involving privately operated taxicabs as feeders to publicly subsidized systems are presented and three existing systems are described to illustrate some of the benefits and problems associated with this innovative type of operation. The major questions about feeder service pertaining to economics, quality of service, and demand are reviewed, and the institutional issues that may inhibit using taxicabs as feeders are discussed. A proposal is outlined for an experimental demonstration for a large urban area.

In suburban areas and urban communities, there is often public and political pressure for broad public transportation coverage. In the United States, where many transit operations are supported by various forms of taxation on urban and suburban residents, this pressure has usually resulted in the conventional, radial-oriented, fixed-route bus service that extends far out into areas of low residential density. Because it is increasingly costly to operate transit systems at all, the high costs of operations in areas with low-density demand patterns (and low revenue) are difficult to justify. Thus, some transit authorities in large metropolitan areas are considering cutting back routes in suburban areas and reducing or dropping service during low-demand periods such as late at night and on weekends.

A novel way to provide broad coverage is to integrate dial-a-ride and subscription feeder service with fixed-route operation. Smaller vehicles would respond to telephone requests, pick up users at their homes, and take them to designated points for transfer to the scheduled transit service. On the return trip, these small vehicles would take transit users from the transit stop to their homes. In a well-integrated system, the transfers would be coordinated to minimize passenger wait time and the service would have convenient transfer mechanisms such as joint fares and sheltered transfer points. The problem is to provide high-quality collection and distribution service at a reasonable fare and at a low total cost to the transit authority or other public body that may be subsidizing the trip.

In the past few years, many demonstrations and examples of various types of dial-a-ride systems have been designed for the lower density demand patterns that are inefficiently served by conventional transit (1). Most of the implemented systems are in small and medium-size urban areas that either do not have fixed-route bus service or have paratransit services that are not integrated with the existing transit service. Although some examples of feeder service to line-haul bus transit exist, including the systems in the urban areas of Rochester, New York, and Toronto and the smaller cities of Ann Arbor, Michigan, and Regina, Saskatchewan, all are operated by transit authorities and use small bus- or van-size vehicles with seating capacities of 12 to 30 passengers.

This paper discusses using privately operated taxicabs as a cost-effective means of providing feeder service to line-haul bus transit. Three examples of currently operating taxicab feeder systems are described in detail. Questions about feeder service that require empirical investigation are discussed, and a proposal is presented for a demonstration of taxicab feeders in a large urban area.

WHY TAXICAB FEEDERS

The taxicab industry has a number of special characteristics that make it particularly well suited for serving the low-density demand patterns that cannot efficiently be served by fixed-route transit:

1. Taxis now operate in the majority of suburban communities and small towns and generally provide service 24 h/d, 7 d/week.
2. The taxicab industry is experienced in operating exclusive-ride taxi and dial-a-ride transportation systems and has managerial skills for dealing with dispatching, employee utilization, and vehicle maintenance.
3. Vehicle operating costs are usually substantially less for taxis than for conventional transit vehicles, primarily because of lower driver wage rates, flexibility of work rules, and the use of part-time workers (2).
4. Diversifying the types of services provided by taxicabs has potential for increasing overall driver, dispatching, and vehicle productivity so that costs for these additional services can be kept low while profits are increased.

Because scheduled transit service will tend to group feeder users, shared-ride taxi feeder service should allow higher vehicle productivity (average number of passengers per vehicle hour) and lower costs per passenger than the traditional, exclusive-ride taxi service. If taxi drivers were able to provide the feeder service "in between" their regular calls without disrupting this business, then the regular taxi revenue would be the primary source of income and the feeder revenue would be generated at low marginal costs. Establishing the proper balance between service levels and demand for the regular and feeder operations may present some operating problems for the taxi operator, of course. If such problems could be overcome, the feeder service could provide a convenient means of extending public transportation coverage at a relatively low cost per passenger.

Some special difficulties with taxi operations should be recognized. In a number of cities the financial condition of fleet operators is reportedly rather weak, taxicab vehicles are old and poorly maintained, driver turnover is very high, and illegal vehicles with inadequate insurance are on the street. Furthermore, some taxicab operators have been reluctant to work with city officials and transit authorities to develop new services. Improving the quality of taxicab services to these locations, which will require the efforts of both the operators and the regulators, is essential if the taxi operators are to be regarded as sufficiently reliable to provide feeder services to line-haul transit.

EXISTING TAXICAB FEEDER OPERATIONS

As of April 1977, three taxi feeder systems were operating in North America: one in Peterborough, Ontario, one in St. Bernard Parish, Louisiana, and another in Bremerton, Washington.

Peterborough TRANS-CAB

TRANS-CAB, which began in May 1974 as a demonstration project (3), has been operating in two suburban areas of Peterborough, Ontario, a city of 58 000 people. There was fixed-route bus service in one feeder area before the introduction of the taxi feeder service, but patronage was low and the estimated deficit per passenger was between $2.30 and $2.90. TRANS-CAB has proven to be a popular type of transit service that can be operated at a lower deficit per passenger ($0.88 in 1976) than conventional fixed-route service. After the demonstration ended in 1975, the city assumed the feeder service as part of the regular transit operations and now provides the municipal share of the operating subsidy. The taxi operator indicates that, in addition to stimulating bus use, the feeder-service project has helped the taxi business overall by providing advertising and exposure. Thus, the service appears to be successful from the viewpoints of both transit and taxi operators.

The two Peterborough feeder service areas (zones A and B) and the bus routes serving them are shown in Figure 1. The very low feeder use in zone B reflects the short walking distance to the route. Zone A contains a newly developed community of single-family homes (population 2000) that is separated from the main part of the city by a golf course and undeveloped land. The road network and the hilly terrain in this area make extensive bus service impracticable. Zone B on the edge of the city is an area of higher density development with duplexes and row houses (population 1400).

According to household surveys (4), the residents of these zones have substantially different characteristics. Zone A families are older than zone B residents: In zone A more than half of the residents are over 35 years of age and about half of the families have no children. Automobile ownership is quite different in the two zones: Only a quarter of zone B households but about half of zone A households own two or more automobiles.

The feeder service is provided by one of the two private taxicab operators under contract to the city-owned transit company. The taxicab company, which has a fleet of 20 taxis, charges the transit operator its regular meter rate for each feeder trip [$0.70 for the first 0.3 km (0.2 mile) plus $0.10 for each additional 0.3 km]. In 1976 the meter rate increased to $0.80 plus $0.10 for each 0.25 km (0.14 mile). No additional vehicles or drivers were required; the TRANS-CAB service is incorporated into the regular operation. (A new person was hired to answer the additional calls.) When the taxis are providing feeder service, a TRANS-CAB sign is placed on the dashboard at the passenger side.

Figure 1 shows the bus routes and the feeder transfer points. The buses are scheduled to depart at the transfer points for the central downtown terminal every half hour (hourly in the evenings). Bus service operates Monday through Saturday from 6:15 to 12:15 a.m. For inbound (home-to-bus) TRANS-CAB service, a user must call 1 h in advance of the bus departure time, giving address, destination, phone number, and number of passengers in the party. The taxi dispatcher tells the person the time of pickup (no more than 20 min before bus departure) and the bus route. On arrival, the taxi driver waits 30 s, sounds the horn, and leaves after another 30 s. If the person does not "show," the dispatcher will try to contact the passenger to advise him or her that the taxi was there and ask if another pickup is desired at another time.

The users on inbound trips pay the total TRANS-CAB fare to the taxi driver and receive a special transfer for the bus. On outbound (bus-to-home) trips, riders notify the bus driver when they board that they want TRANS-CAB service and pay the fare. The bus driver issues a special transfer for the taxi trips and radios the cab dispatcher the bus route number, the number of passengers, and the expected time the bus will be at the transfer point. Because only four passengers can board each taxi and additional vehicles may be required, the driver must call the dispatcher for every TRANS-CAB rider. Each passenger tells the taxi driver his or her destination in the feeder zone. Regular users are encouraged to reserve rides on a weekly (or longer) basis, which reduces the volume of calls and allows the dispatcher to increase taxi occupancy. The dispatcher also becomes familiar with the usual outbound passenger loads at the transfer points.

The TRANS-CAB fare structure is based on the bus fares with a $0.10 premium for the taxi feeder service. For adults and students the fare is $0.35 cash or $0.10 plus a ticket (5 tickets for $1); children pay $0.10 less. Senior citizens pay $0.25 or use a ticket (8 tickets for $1). Adults can also use a $12 monthly bus pass and pay $0.10 for TRANS-CAB. This fare structure produces an average revenue of about $0.30/user. Tipping drivers is not permitted. The system is audited and controlled: The dispatcher, the taxi driver, and the bus operator each keep complete logs for each day, recording several items including number of passengers and revenue.

Ridership and cost data for the demonstration period (May 6, 1974, to February 8, 1975) through 1976 are given below.

Item	Demonstration Period	1975	1976
Ridership			
Total passengers	35 049	65 754	79 988
Average passengers per week	880	1 260	1 539
Average passengers per weekday	158	215	—
Cost and revenue, $			
Total cost	31 437	61 264	94 970
Revenue	10 286	19 425	24 789
Deficit	21 150	41 839	70 181
Cost per passenger	0.90	0.94	1.19
Deficit per passenger	0.60	0.64	0.88
Taxi productivity			
Trips			
Number	16 445	38 702	44 130
Average per week	410	746	846
Average occupancy per taxi trip	2.13	1.70	1.80

These data show that the average occupancy per taxi trip has declined and the cost per passenger has increased since the initial demonstration period. Most of the higher cost in 1976 is attributable to the change in taxi meter rates. A reason for lower occupancy could be the development of more dispersed demand patterns that make it difficult to group inbound trips, especially with different transfer points for three bus routes. Passengers bound for the central business district are taken to the nearest transfer point, but travelers to other points are taken to the transfer point on the most direct bus route. Although this provides the best service to the user, it makes it more difficult to group passengers.

Perhaps a contributing factor is the manner in which the taxi-service contract is set up. Under the current procedure taxi operators have no direct incentive to increase shared-ride occupancy because they are paid by the distance traveled (through the meter charge). On outbound trips the passengers are grouped on the buses, which tends to keep the taxi occupancy higher. However, on inbound trips the taxi dispatcher and the drivers are not penalized if there are several single trips instead of one or two shared-ride ones. An alternative approach would be to pay the taxi operator on a per-passenger basis and thus encourage him or her to maximize the number of riders per trip. As use increased the operator would attempt to increase productivity to make more money and the transit company would not have to increase the user payment unless the taxi operator could justify it. It should also be less costly to administer payments to the operator based on transfer tickets than to record and audit the various meter fares.

Figure 1. TRANS-CAB service area in Peterborough, Ontario.

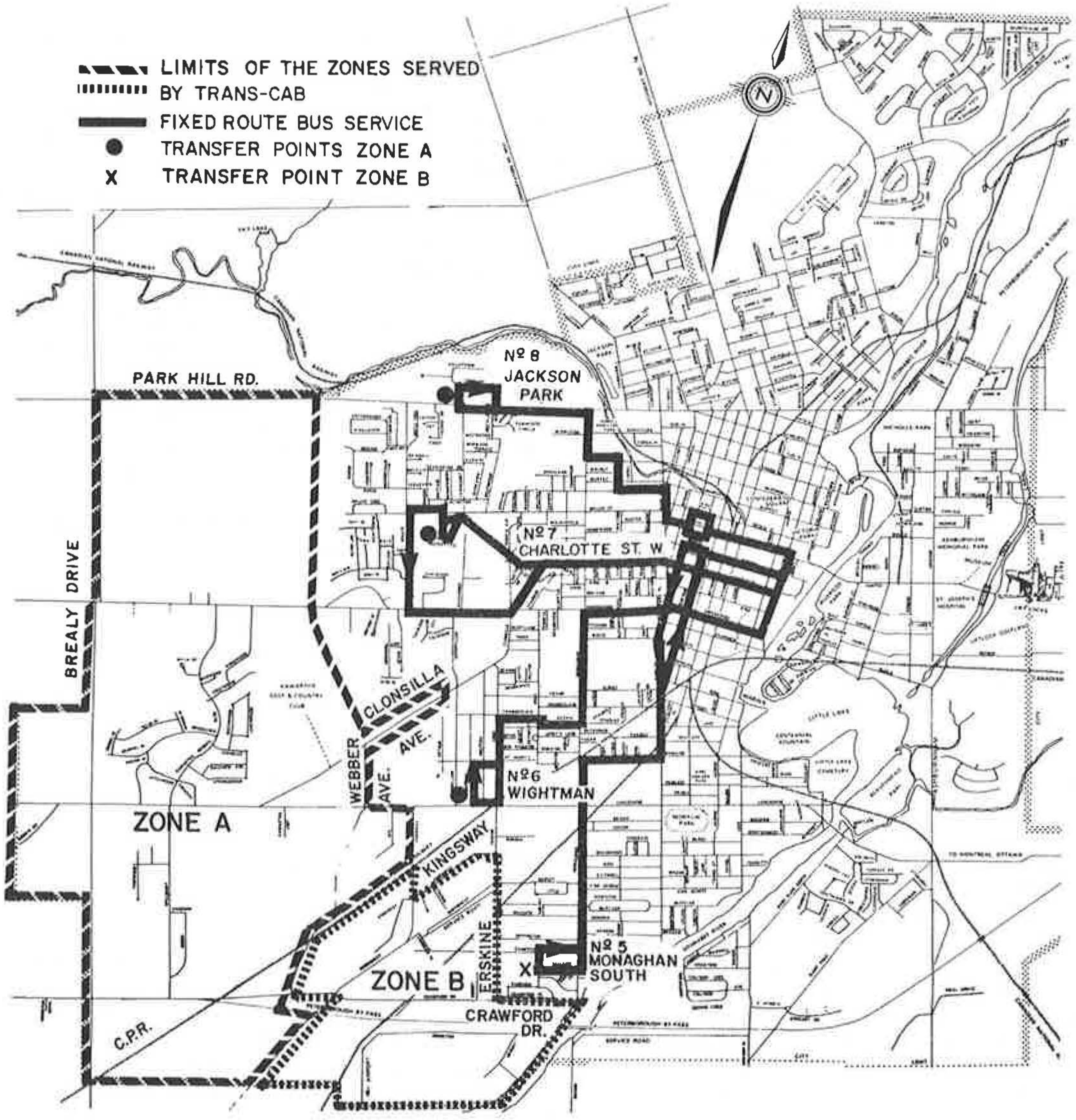
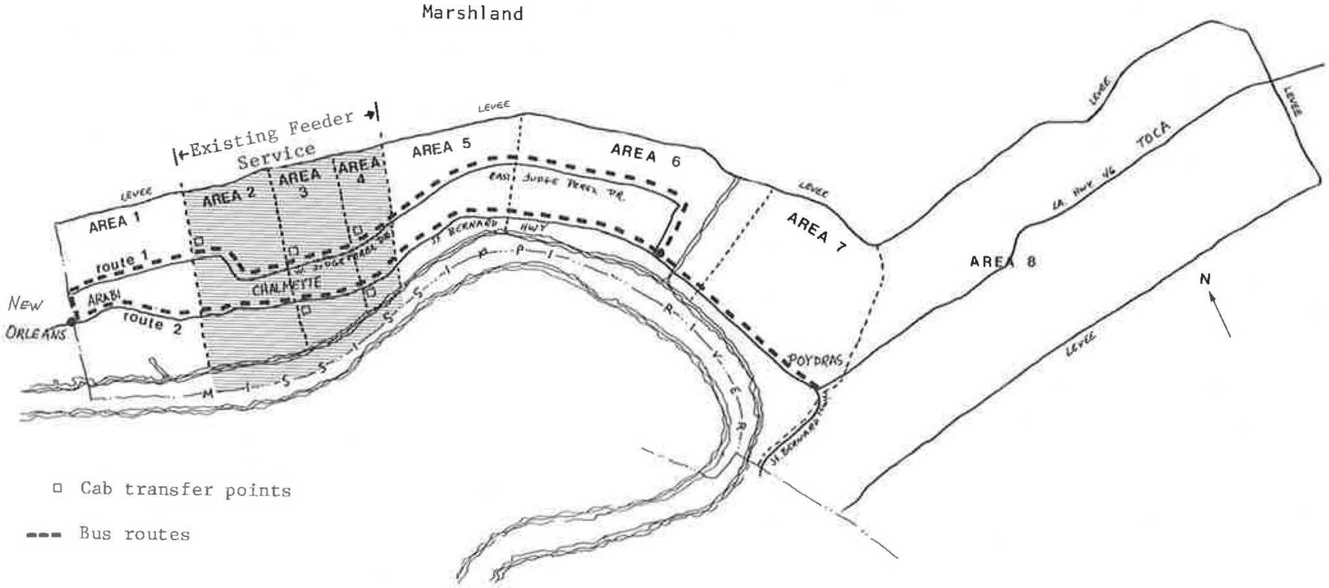


Figure 2. Bus-taxi transfer service area in St. Bernard Parish, Louisiana.



St. Bernard Bus-Taxicab Transfer

Since October 1974, a taxi company has been providing feeder service to two bus routes in St. Bernard Parish, Louisiana. This service is unlike the Peterborough system in that the feeder area was established along the routes and not at the ends. Located on the eastern boundary of New Orleans, St. Bernard Parish (population about 60 000) has developed in a relatively narrow strip, with the Mississippi River on one side and marshes on the other. As shown in Figure 2, the bus routes begin in the rather rural area and run 20 km (12 miles) along the river through suburban development into New Orleans. The feeder area covers 10 km^2 (4 $miles^2$) and contains an estimated 27 000 people, a density of over 2700 persons/km^2 (6700 persons/$mile^2$). Development in the area includes suburban homes, apartments in subdivisions, and scattered shopping and commercial areas.

Before the feeder service was introduced, one of the bus routes wound through the residential streets in the feeder area. Because of low residential density and slow bus speed, the patronage was too low to cover costs and the private bus operator dropped the bus route and substituted taxi transfers to the two direct bus routes. The coordination between the two modes was relatively easy because the private company that operates the three-vehicle bus system (at 40 passengers/vehicle) is controlled by the owners of the 21-vehicle taxi company.

A traveler in the transfer area calls and requests taxi service to one of five bus stops. Bus service on the main route is provided by two buses that shuttle back and forth every half hour from 6 a.m. to 7 p.m. on weekdays and hourly on Saturdays. The other route has only 1 bus/h on weekdays. The dispatcher sends a taxi and also notifies the bus driver that a passenger should be expected at a specified stop. (Passenger wait time is minimized by coordinating the pickup time at the home with the arrival of the bus at the bus stop.) If a bus rider wants to take a taxi home, he or she tells the bus driver, who in turn radios the dispatcher when and where the rider will be discharged. A taxi picks up the passenger, often moments after he or she is discharged by the bus.

Each user pays a joint fare of \$0.50 on the first mode used and is given a transfer slip to be shown to the driver of the connecting mode as evidence of payment. Within the area served by the taxi feeder, the regular bus fare ranges from \$0.35 to \$0.50; the regular taxi fare to the bus stop would be over \$1. Thus, for a payment of a \$0.50 joint fare, the user receives a \$0.35 to \$0.50 bus ride and a \$1 taxi ride. [The transfer service is not available for trips less than 0.4 km (0.25 mile) from the bus stop.]

The feeder system began with about 75 users/month and by August 1976 had grown to over 1000/month or about 10 percent of the bus ridership. The operation of this small-scale system was sufficiently encouraging to interest the Urban Mass Transportation Administration (UMTA) in the establishment of a demonstration project designed to expand the bus and taxi fleets and extend the feeder service throughout the parish. Bus-taxi transfer service will be started in area 1 and areas 5 to 8 (Figure 2). Taxi feeder service to commuter subscription buses will also be introduced. The proposed transfer fare structure is based on the existing distance-related bus fares (ranging from \$0.25 to \$1.30); there is a \$0.25 premium for the off-peak and \$0.35 for the peak taxi ride. The taxi drivers currently receive \$0.50/user, and the bus company does not receive any revenue from the feeder trips. Under the proposed fare structure, a portion of the user charges will go to the bus company.

Bremerton Taxicab Feeder

In November 1976, bus service on a low-ridership route in Bremerton, Washington, was stopped and replaced with taxicab feeder service. Located across the Puget Sound from Seattle, Bremerton (population about 35 000) has a city-owned bus system with five routes serving the downtown area and the naval shipyards. Because only a few persons per day were riding buses on the 4-km (2.5-mile) route segment that served a peninsula of low-density residential development, the city contracted with the major taxi operator to provide feeder service to the nearest bus route. The company was paid \$1.50/feeder user. Taxi feeder use was also very low, about 30 trips/month; the city thus achieved a substantial savings by not operating one bus.

Within the city the joint fare for a taxi-and-bus trip was \$0.50 for all users, which was higher than the regular \$0.35 bus fare. Taxi pickup times inbound were coordinated with the bus schedule; however, because the buses did not have radios, homebound users had to use the taxi phones in the downtown area to notify the taxi company that they wanted a taxi transfer.

In April 1977, a citywide taxi feeder service was started. For a \$0.50 joint fare, any resident can take a taxicab to or from the nearest bus stop along all five routes. For a trial period, the taxi company will receive \$1.50 for each user. Although the service will be convenient for the elderly and people who have difficulty walking to bus stops, the city does not expect many users. At the end of the trial period, the city and the taxi operator will evaluate costs and public acceptance and determine if changes should be made.

UNCERTAINTIES ABOUT FEEDER SERVICE

The two general areas of uncertainty for any new transportation service are supply and demand. On the supply side the major concern is the relation between the cost and the level of service provided. These are influenced by (a) operational and technological requirements, such as speed and capacity of vehicles, nature of the service area, management and control, and labor utilization; and (b) institutional aspects, such as organizational, financial, and regulatory constraints. On the demand side, the major concern is the relation between use and the level and the price of service in different socioeconomic environments.

Before feeder service can be considered for widespread implementation and before its applicability for a particular area can be evaluated, planners, policy makers, and transportation operators need to have a sound understanding of the supply and demand aspects and their interaction. Three sets of general questions regarding feeder service are discussed below. Although some of the questions are specific to taxicab feeder service, most refer to feeder service provided by any operator.

Costs of Providing Feeder Service

The key concerns in implementing this type of service are as follows: How efficiently can coverage be provided by feeders? What are the costs per feeder rider? How do the feeder-to-bus and bus-to-feeder vehicle productivities and average feeder occupancies vary? What are the practical costs per kilometer and costs per vehicle hour for feeder operations? What major factors determine these costs? Can taxi feeder service be provided at a low marginal cost by a taxi company because the regular taxi business covers the fixed costs? What are the costs if the feeder ridership increases beyond the point where it can be handled as a marginal taxi service? How does the size of the service area affect costs? Are costs lower if several taxi companies participate? Are taxi insurance costs affected by the integrated service? Empirical data on the total costs as well as the detailed elements (e.g., wages, vehicle operation, dispatching) for different sizes of operations in various parts of the country would be useful in assessing the costs of implementing this type of system.

Cost savings that result from shortening routes (or not extending them) are a major concern. How are the costs of fixed-route bus service affected by feeders? What are the actual avoidable costs per route? Are there significant new costs associated with the administration of transfer tickets or with the procedures for coordinating buses and feeder vehicles?

Quality of Service

What are the operational and technological procedures for providing high-quality service? If this type of innovation is to be implemented, proven operating techniques will be necessary. Because a key to minimum travel and wait times as well as lower costs per passenger is the dispatcher's ability to develop efficient shared-ride tours, the manual dispatching capacity and any requirements for users to place their call within some set time before the scheduled bus arrival should be determined. What factors improve vehicle utilization and quality of service? How should the boundaries for a feeder area be determined? Are special procedures necessary to ensure that commissioned taxi drivers respond reliably to feeder calls? Is the quality of service affected if several taxi companies are providing the feeder service?

An important question for taxi operators and regulators when they consider feeder service is, Does the shared-ride taxi feeder service affect the level of service provided to regular taxi customers? Regulators would not want the feeder service to adversely affect the dispatching or the availability of taxis for regular service, and taxi drivers would not want to reduce their normal revenue.

Transportation Demand

A basic implementation question for any new service is, What is the ridership response to feeder service? To determine the benefits and costs of a proposed feeder system, planners will need to estimate how many people will use it. Ideally, demand models can be developed that will be useful for forecasting ridership in different socioeconomic areas and for predicting the demand under various fares and service levels. Eventually, as more examples are implemented in different environments, it may be possible to develop planning models. Some of the questions that should be answered as part of the effort to understand travel behavior and to develop useful forecasting models include the following:

1. What are the characteristics of the users? Are they transit dependent or former automobile users? Are they in high- or low-income groups, young or old?
2. How do the characteristics of the service areas (population density, automobile ownership) influence ridership? How does the demand develop over time?
3. Were the trips formerly made by walk-on bus or regular taxi or are they new trips?
4. What is the fare demand elasticity and how do other level-of-service variables (wait time, bus headways) affect ridership?

Does providing feeder service affect regular taxi ridership? Taxi operators will be concerned about the effects on their business. Extensive feeder service might reduce the demand for taxis in the feeder areas; however, if the taxis provide this different type of service the exposure could also stimulate greater use. Taxicab regulatory bodies will be interested if the taxi feeder service increases total revenue and profits because the need for higher regular taxi fares would be reduced. If fares could be kept from rising, this would also influence regular ridership.

Institutional Issues

In addition to an improved understanding of the economic, level-of-service, and demand impacts of feeder services, major legal and institutional issues have to be resolved before private taxi operators can provide the service. A full discussion of these issues, which were addressed at the 1975 Conference on Paratransit (5), is beyond the scope of this paper, but the major areas of concern are as follows:

1. Because local taxicab regulations in most areas prohibit shared-ride services and require the fare to be computed by a meter, ordinances may have to be changed.
2. Bus labor unions may oppose the substitution of taxi service for bus service.
3. Taxi operators may be reluctant to participate with regional transit authorities if too much control and regulation of their companies are required.
4. The additional feeder-service profits could create a competitive advantage for some taxi operators. If this created a monopoly situation, then taxi service in general could be affected.

NEXT STEP IN INVESTIGATING FEEDER SERVICES

Although some useful information is available about costs, level of service, and demand for feeder service in several locations, almost all of the knowledge is based on feeder systems operated by transit authorities. A great amount of information was obtained during the UMTA demonstration project in Haddonfield, New Jersey, and the ongoing UMTA demonstration project in Rochester, New York, is testing the use of a computer-dispatched feeder service in three areas. In addition, there are data on the systems in Toronto; Ann Arbor, Michigan; and Regina, Saskatchewan. Some information is also available about demand response at certain fare and service levels in several environments.

On the other hand, relatively little is known about the supply and demand aspects of taxicab feeders. Although the three existing taxi feeder operations described in this paper demonstrate that it is technically feasible to provide high-quality transfers between buses and taxis, they are small-scale systems with somewhat unique institutional aspects. The next step is to experiment with taxi feeder services in situations with more typical institutional arrangements and with a broader range of demand conditions.

All large urban areas in the United States have publicly subsidized and operated bus systems as well as several private taxi operators; therefore, what are the best institutional arrangements for involving taxi companies with a typical public transit authority? Should the transit agency or another transportation organization plan and manage the service? What should the role of the local taxi regulatory body be regarding the new shared-ride feeder service? Operating arrangements should be developed that allow taxis to receive a subsidy for the feeder operations and to continue to make an overall profit. These arrangements should be perceived as equitable by the taxi operators and must motivate them to continue to provide reliable feeder service at the lowest possible cost. Because a monopolistic situation can be encouraged by exclusive contracts or franchises, efforts should be made to involve more than one taxi company.

Because of the complexities of bus systems in metropolitan areas, many transit authorities may find that it is difficult to estimate how much cost saving is possible when routes are cut back and feeders are introduced. If fewer bus kilometers are operated, some direct costs, such as those for fuel and maintenance, are avoidable. However, labor-related cost savings are not directly related to kilometers of operation. Shortening even one route can affect several other routes because of the ways in which drivers and vehicles are used in large systems. Although it should be possible to make some estimate of the potential cost savings attributable to shorter routes, the actual reductions will depend on how driver and vehicle assignments for the new routes and schedules are made. In some cases, it may be difficult to realize potential labor-related cost savings because under protective labor union agreements the number of drivers cannot be reduced. Actual cost savings under different circumstances need to be demonstrated for typical bus systems in metropolitan areas.

For large bus systems and several taxi operations, the control and coordination procedures for feeder operation may be more complex than those for the three small-scale examples cited here. How can high-quality, reliable service be provided by taxis at low cost in typical urban areas? The usefulness of existing taxi and bus communications equipment and dispatching capabilities should be determined before new technology and expensive computer systems are tried. New technology can be implemented, if necessary, as more is learned about problems with manual decision-making and control procedures for operating integrated service.

Bus service is provided to different types of suburban communities and city neighborhoods in a typical metropolitan area. What will the feeder ridership be in areas with different socioeconomic characteristics? What are the relations between fare or level of service and ridership in different areas? Can the fare surcharge for this new service reflect the actual additional costs and still be considered an acceptable public transit fare? Feeder service in some suburban areas could stimulate increased commuter bus ridership and may be very convenient for the elderly and for persons who find walking difficult. However, in some situations, the same transit dependents who walked to the bus may have to pay more to take the feeder. Information on ridership at different fare and service levels should be developed for taxi feeder service in large urban areas.

The taxi feeder experiments should be part of a broad program of investigation designed to provide comprehensive cost, level-of-service, and demand information for different demand environments and various types of institutional arrangements. Because it is not possible to learn everything in one experiment, each example should focus on specific supply and demand questions. As more results are obtained from various operations, planners will be able to determine more easily the applicability of specific types of feeder services for their particular area.

PROPOSED DEMONSTRATION PROJECT

The hypothetical project discussed here is an initial demonstration project to examine how taxi feeder systems should be set up in a typical metropolitan area. It presents one set of institutional arrangements and operational procedures for involving several taxi operators and would provide ridership information for different types of feeder areas at reasonably high fare levels. Although this is a project for a hypothetical area, it is based on conditions in an actual urban area that is currently under consideration as a demonstration site. It is hoped that this initial demonstration would show conventional transit managers as well as taxi operators that they can work together to provide a new type of low-cost, high-quality service. Other projects should examine bus-system cost savings, level of service, and costs under different institutional arrangements as well as determine the effectiveness of more sophisticated control and coordination procedures. Understanding of ridership response would also be improved with more experience from feeder areas in different environments at higher and lower fares and other service levels.

The demonstration would be conducted by the local government's planning body, which would be responsible for the management of the service. Management skills, labor requirements, and cost-saving motives for conventional transit and taxi service are very different; a third party would thus be required who would be impartial and view each operator as a provider of transportation services that should be effectively integrated. The project would involve all interested taxi operators so as not to encourage a monopoly by one taxi company. This can be accomplished by working out with the taxi operators an acceptable per-person transfer fee for each of the proposed areas. Because the taxi companies receive more revenue per passenger, they should be motivated to provide good service at the lowest cost. It should also be less costly to administer payments to taxi companies based on ridership than to pay them on the basis of kilometers of service or some other performance measure.

Four or five feeder areas might be established throughout the urban area. Factors to be considered in the selection of the proposed areas include (a) cost, ridership, and level of service of the existing bus routes and potential cost savings; (b) the amount of taxi activity in each area; and (c) the availability of convenient transfer points and public concern for personal safety during the walk to and the wait for a bus. The socioeconomic characteristics (such as residential density, automobile ownership, and number of elderly) should be as different as possible in each area. The feeder areas will be opened sequentially during the project so that operational and ridership experience from each area can provide guidance for other areas.

After the operators consider the size and the boundaries of each area and estimate average trip length and occupancy, they propose per-person charges of, say, \$1 for a trial period. These transfer fees could be adjusted periodically based on the actual demand patterns, the level of service provided, and the available subsidy funds. If there are few feeder trips, taxi drivers will receive little revenue and will have an incentive to provide good service and encourage more trips. As the number of riders in an area increases, it should be possible to provide more shared-ride trips with two, three, or four passengers per cab. This increased productivity should keep the total subsidy costs down and could justify a decrease in the transfer fee per rider. On the other hand, if there are so few feeder users in an area that the taxi companies find the service unprofitable, then the transfer fee might be increased to make the feeder trips worthwhile to the drivers.

Although the operators would be free to provide feeder service in any of the transfer areas at the established price per rider, it might be more efficient for them to concentrate on one or two areas. In areas where more than one taxi company provides feeder service, the users select the one that best meets their needs.

Users pay one joint fare when they begin their trip. A premium charge is added to the basic bus fare in each feeder area. The premium would be determined by considering the expected transfer ridership and bus cost savings, the taxi transfer fee, and the available subsidy. In this project the premium charges would be high—say, between $0.25 and $0.50.

A user who pays a joint fare is given a two-part transfer ticket. One part is retained by the operator of the first mode as a record of payment; the user presents the other part when he or she transfers. The tickets are color coded to indicate which operator collects the fare, and codes are punched to show which feeder area or bus route is served. Because the fare is collected by the first driver, the tickets are required in order to ensure proper accounting of the revenue for each company. For example, if a taxi driver collects $0.65 for a transfer, he or she submits the ticket to the transit operator for the remaining $0.35 of the fee. When a user gives the bus driver $0.65 for a transfer, the taxi driver submits the second part of the transfer ticket for the $1 transfer fee. There would be a check on the payments to each company in that every taxi transfer has a corresponding bus ticket.

To coordinate the taxi-bus transfers, all vehicles have radios and the taxi dispatchers are linked directly by radio or telephone to the bus dispatcher. For inbound trips, the taxi dispatcher receives a telephone call and assigns the appropriate vehicle by considering the bus schedule and the location of available taxis. Some users, particularly commuters, would be picked up on a regular basis. On outbound trips, the bus drivers radio the location, the expected time of arrival, the number of transfers, and the requested taxi company to the bus dispatcher who contacts the appropriate taxi dispatcher. The bus dispatcher also informs the appropriate taxi dispatcher if certain buses are not on schedule. As ridership develops for the outbound trips, the taxi dispatchers should be able to anticipate the taxis required for most of the buses. For users, an alternative to calling the taxi companies on inbound trips would be calling the bus dispatcher, who would then contact the different companies under some equitable procedure (e.g., a different company every week).

At reasonably high fare levels, the transfer ridership in each of the areas should be relatively small and manageable by the taxi and bus dispatchers. If ridership in an area increases to the point where the subsidy costs are becoming too great or the level of service is deteriorating, then the premium fare could be raised to discourage use and reduce the costs. If ridership develops so that a good level of bus service could be justified, another option would be to discontinue the feeder service and introduce buses.

A comprehensive data collection and monitoring effort would be undertaken so that the demonstration would be a learning process. Information on economics and level of service would be obtained on a regular basis for each feeder area. Ridership would be monitored and the users and nonusers surveyed to provide information on the demand relations in each area.

CONCLUSIONS AND RECOMMENDATIONS

The description of the three existing taxi feeder operations shows that it is possible to save some operating costs and still provide broad public transportation coverage by substituting feeder service for bus routes. Providing coordinated transfers between buses and taxicabs at low cost per passenger seems to be technically feasible. However, questions remain concerning economics, quality of service, and ridership response to this innovative service. There are also legal and institutional barriers to implementing it.

It is recommended that a set of experiments be developed to address these questions and overcome the institutional obstacles. A proposal for a first demonstration for a typical large urban area is outlined in this paper. As more is learned about the benefits and problems experienced with this type of service in a variety of places, taxicab feeders may become an important element in public transportation.

ACKNOWLEDGMENTS

This paper has been prepared as part of a continuing research effort being conducted by the Urban Institute under a grant from the Service and Methods Demonstration Program of the Urban Mass Transportation Administration, U.S. Department of Transportation. I wish to acknowledge the valuable comments and suggestions provided by Ronald F. Kirby of the Urban Institute. Persons who graciously provided information regarding existing operations include John F. Stephenson, general manager of Border Transit Limited, and Jim Donnelly of Call-a-Cab, Peterborough, Ontario; Peter Rusck of the Arabi Cab Company, St. Bernard Parish, Louisiana; and Robert Steward, commissioner of finance, Bremerton, Washington. The opinions expressed are mine and do not necessarily reflect the views of the Urban Institute or its sponsors.

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Commuter Information System: A New Ride-Sharing Tool

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Robert Redmond and Perry Davison, Federal Highway Administration,
U.S. Department of Transportation

The Commuter Information System is a new package of computer programs, for use by local agencies or organizations, that provides ride-sharing information to commuters on an individual basis. The system includes three functional components: (a) a state-of-the-art car-pool matching program; (b) a bus-pool and van-pool planning program; and (c) a transit information system that informs applicants of transit routes that can serve their commuting needs. Because the system is modular, any component can be used independently, and because it is highly user oriented, it is applicable to a wide range of local situations. All programs were written in COBOL. The development effort was based on a nation-wide survey of major ride-sharing efforts. Before the system was distributed, the city of Dallas tested and evaluated the entire package using live data. The Commuter Information System is being distributed by the Federal Highway Administration. It is intended to be a standardized data-processing tool for ride-sharing agencies as the Urban Transportation Planning System is for transportation planning agencies. It is applicable to transportation system management projects, U.S. Environmental Protection Agency regulations, and energy conservation efforts.

The Commuter Information System (CIS) is a package of computer programs that were developed in 1975 and 1976 as a compatible successor to the Federal Highway Administration (FHWA) car-pool matching program. In designing the new system, the users of the FHWA program as well as the users of other programs were surveyed to determine their needs and capabilities. The CIS design reflects the results of the survey: It satisfies the identified needs of most users without overtaxing their resources. The design also incorporates most of the desirable features of the many car-pool programs that preceded it.

In general, CIS is designed to support local efforts to increase vehicle occupancy rates during peak-period commuting hours. This is done primarily by encouraging ride sharing (car pooling, transit, and van pooling) as an alternative to the 1 person/automobile syndrome that has been predominant in commuter transportation for many years.

The scope of the system is limited to providing information that is helpful to the local ride-sharing project and to the members of the community that it serves. Figure 1 shows the fundamental activities involved in using CIS to supply commuters with ride-sharing information. A commuter who desires such information fills out an application form and forwards it to the local ride-sharing agency. Applications vary somewhat depending on local circumstances; a typical application is shown in Figure 2.

The application data are keypunched onto cards for processing by the CIS computer programs. The result of this processing can be a car-pool match list, a transit trip list, or both. These printouts are returned to the applicant who can use them to join an existing car pool, to form a new car pool, or to ride the transit system to work.

Activities related to the use of CIS, which are shown on the right side of Figure 1, are necessary to a successful ride-sharing effort but they are not sufficient. The crucial items are those that help to motivate commuters to fill out the application and then to use the information that the system provides, but such incentives and disincentives are beyond the scope of CIS.

GRID SYSTEM

The ability of CIS to produce car-pool and transit information for applicants depends on the computer's "knowing" the geographic locations of applicants' trip origins and destinations, usually their homes and places of employment. This is necessary in car-pool matching in order to group people who both live and work near each other. Similarly, to provide transit information CIS must know which transit routes are near the origin and destination points of the applicant's trip. In other words, some sort of meaningful geographic code must be assigned to each applicant's home and work locations and to transit routes. The process of determining the correct location code and assigning it to the applicant and to transit records is known as geocoding.

The geographic coding system used in CIS is a grid system characterized by a uniform numbered grid overlaid on a map of the region served by the ride-sharing project. An example of such a grid map is shown in Figure 3. Every location in the region must fall into one of the squares or cells of the grid. These cells are typically 0.8 to 3.2 km (0.5 to 2 miles) on a side. Each cell is uniquely identified by a number formed from the cell's column (x-axis position) and row (y-axis position) numbers. For example, the cross-hatched square in Figure 3 has the cell number 009-004.

Every applicant record is geocoded before it is entered into the system; that is, the cells containing the home and work locations (called the home cell and the work cell) are determined and made a part of the applicant record. Applicant records can be geocoded manually by using a grid map or automatically by using computer programs such as the ADMATCH program of the U.S. Bureau of the Census. Transit routes must be map-geocoded.

Geocoding applicants and transit routes in this manner allows the CIS computer programs to match applicants who live and work close to each other as well as to pick out transit routes that are near the applicant's home and work locations.

The geocoding system also makes it easy for CIS to produce density matrixes for use in planning bus-pool and van-pool routes. A density matrix (Figure 4) is essentially a schematic map of a region in terms of grid-cell population and shows the distribution of origins for all commuters with a common destination. Areas that show high concentrations may be promising for bus-pool or van-pool routes. The density matrix can also be used for evaluating scheduled bus service.

GENERAL CHARACTERISTICS OF COMMUTER INFORMATION SYSTEM

CIS consists of three major components:

1. A car-pool matching system that contains many (optional) sophisticated features;
2. A bus-pool and van-pool planning system based largely on the density matrix; and

Figure 1. CIS activities.

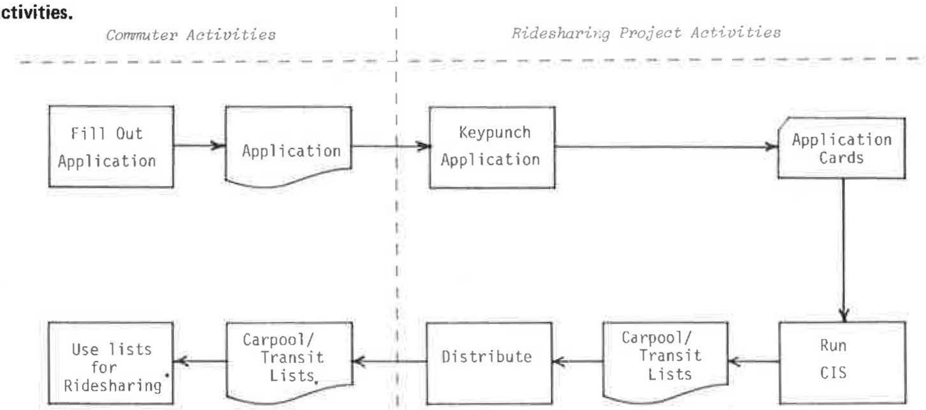
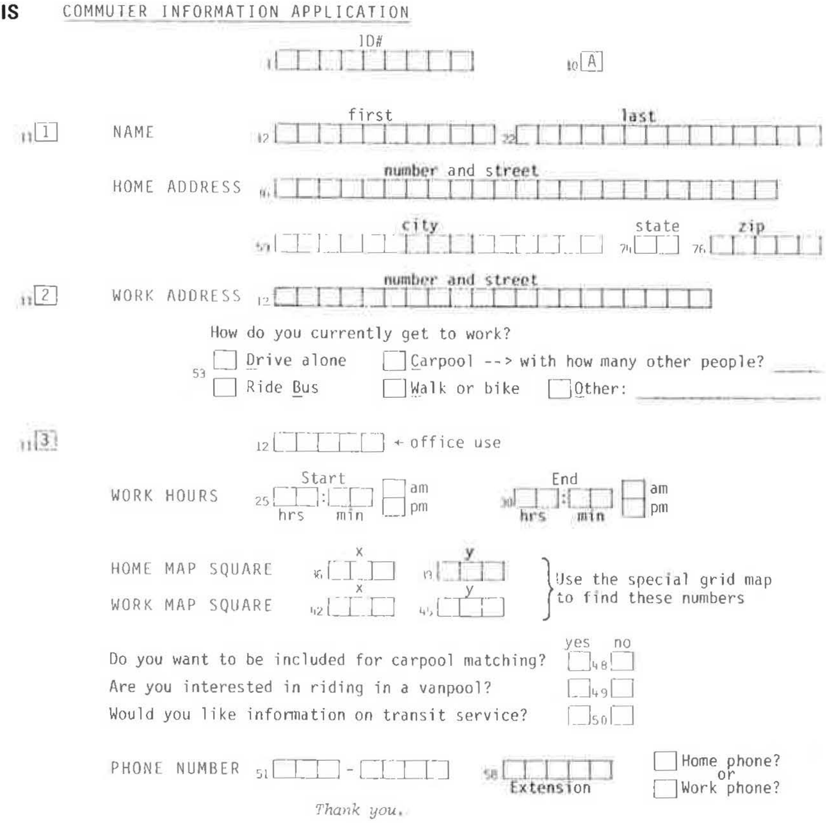


Figure 2. Typical CIS application form.



COMMUTER INFORMATION APPLICATION

ID#
1 ☐☐☐☐☐☐☐☐☐ 10 A

11 1 NAME first 12 ☐☐☐☐☐☐☐☐☐☐ last 22 ☐☐☐☐☐☐☐☐☐☐☐☐☐☐

HOME ADDRESS number and street 46 ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

city 59 ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐ state 74 ☐☐ zip 76 ☐☐☐☐☐

11 2 WORK ADDRESS number and street 12 ☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐☐

How do you currently get to work?
53 ☐ Drive alone ☐ Carpool --> with how many other people? ____
☐ Ride Bus ☐ Walk or bike ☐ Other: ____________

11 3 12 ☐☐☐☐☐ ← office use

WORK HOURS Start 25 ☐☐:☐☐ hrs min ☐ am ☐ pm End 30 ☐☐:☐☐ hrs min ☐ am ☐ pm

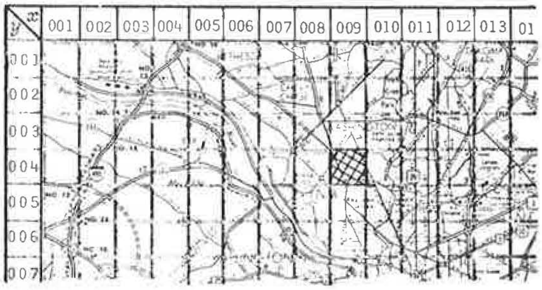
HOME MAP SQUARE x 36 ☐☐☐ y 39 ☐☐☐
WORK MAP SQUARE x 42 ☐☐☐ y 45 ☐☐☐
Use the special grid map to find these numbers

	yes		no
Do you want to be included for carpool matching?	☐	48	☐
Are you interested in riding in a vanpool?	☐	49	☐
Would you like information on transit service?	☐	50	☐

PHONE NUMBER 51 ☐☐☐ - ☐☐☐☐ 58 ☐☐☐☐☐ Extension ☐ Home phone? or ☐ Work phone?

Thank you.

Figure 3. Portion of grid map.



3. A transit information system that informs commuters about the transit routes that serve their commuting needs.

CIS is highly modular. The user can select a basic car-pool matching package with relatively simple operating characteristics or a configuration with more extensive capabilities, depending on local objectives and resources. The transit information system can also be used without the car-pool matching program. CIS is fully compatible with existing data bases that are in the standard geocoding and file format of the FHWA car-pool matching program, the predecessor to CIS.

The package is programmed in COBOL according to the 1974 standard (full implementation) of the American National Standards Institute. It is intended to be operable on most medium-scale computers regardless of manufacture.

DESCRIPTION OF PROGRAMS

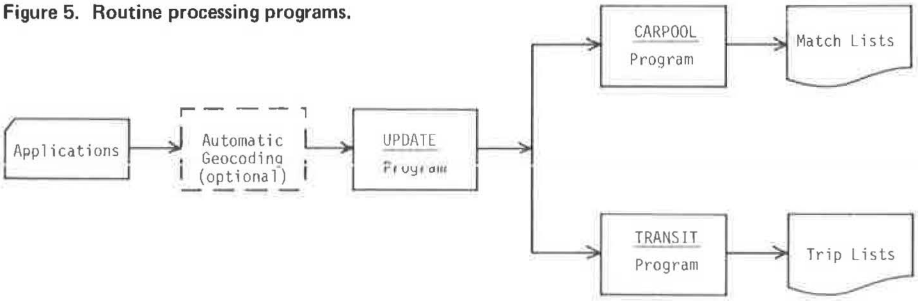
The eight computer programs that make up CIS can be divided into the following two groups:

1. The routine processing programs, which include

Figure 4. Numeric density matrix.

```
                                          COMMUTER INFORMATION SYSTEM
DATE: 12/ 7/76                             NUMERIC DENSITY MATRIX                                    REQUEST # 00

                      NUMBER OF PEOPLE PER HOME GRID CELL, ACCORDING TO THE FOLLOWING CRITERIA:

START TIME RANGE: 12:00AM -11:59PM                         NUMERIC DISPLAY OF DALLAS MASTER FILE
  END TIME RANGE: 12:00AM -11:59PM        ALL WORK CELLS AND ALL TIME RANGES HAVE BEEN COMBINED INTO ONE MATRIX.


                                       1  1  1  1  1  1  1  1  1  1  2  2  2  2  2  2  2  2  2  2  3  3  3  3
       0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5  6  7  8  9  0  1  2  3  4  5  6  7  8  9  0  1  2  3
    |--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+--+
  0 |
    |     1     1                       1                                   5    36324 18  3  1  2     2
  2 |                                                        1        1        1  4 16     1
    |                                             1        1              2     1        1     1  4  6  2  5
  4 |                                                   2                 1                      10 26  2
    |                                                   1                    1  1  7  5     3  2 14 27  1  1
  6 |               2  2           1                    1  1  1  2  3  1  3     2  2     1  2 24 15 34 27  2
    |                                                1              1        2  2     5  9  1  7 69 43 15  1
  8 |                                                1  1     1     2     4  5        3  2     1 48113 15 16
    |                                             1  1              1       32  5  2  1          35 85 52 32
 10 |                                          1     3                    4  8  3  1  3     1    15 52149 93
    |                                                         1                       2  1     1 11 94119 74
 12 |                                                   1  3        4  1  3              7  1  3  5 60106 75
    |                                 3                 1     3  3  1  2              6  4  2  1  ? 39160123
 14 |            1              1  2  1           4  2     2     2  5  2  2 11  1  2 34 52 19  1  1 56 47 35
    |      1                                      2  1  7  3  2 20  7  6 20 49  2  5 92217135 15  1  1 40 27
 16 |      1           1                       1  2  1  7  4 23 26 32 14 28 99  3  8 29 91 86 76 11  4 14 58
    |      1        1  2              1        8 10    12  9 24 33 12 10  1  3     5 24101 78 36 12  7 10 14
 18 |                     2     2  1  1     2  3  3  2  3  1  2     1     1  1  1  5 34158128 81  2  2 14  4
    |                        3  4  4  1  5  1  4  1  1  1  2  1           1  2  3  1  5 36 23 14 58 44 83 37
 20 |      1  2  1     2  8  3           2  3        1     1  3  1     5 29 13  9 14  9  5 43  7 17  9 17 26
    |      1  1  1  1  1  3  3  6  2     1        11  6 10  5  1     3 50 28 55 10 61 73 91 41 36  6 10120116
 22 |         1  4  3  5  1  2  2     2  1  1  3  4  3 12 15 14  2 18 63 90 47 23 58117 35 39 51 17122185196
    |      5  6  1    12  4  8  4  3  4  3  2  4  6  8  4  7  1  2 30 61121141142 26 97 29  2 24 66163159199
 24 |      5  2  5  7  2  2  1  7  3  7     2  1  6  1  2  1  2 11 29 81130 90 62 20155 33  1 13172185144213
    |         1  1  3  2     2  7  4  4  3  3  3  7     3  1  3 15  6 47 39 67  8  4130 29  2 29111187220200
 26 |      3        1     1  6  1  2  5  3     2  2     1  4  6     5 11 33 10  7  6 13  1  2 22 32 20 67283
    |            2  1        4  8  4  1  1  1  3 13  3  1  3  4  2  2  8  2  5  3  5  2  4  9 64 72 20 48108
 28 |         1             19  3  3  2  1  3  1  3  2  1  2  1  3  3  5  1     4  1 12  8 28197136  9 35 76
    |                     4  2  1     4  1  4  2  1  1  1     1     1  3  1        4  3  2  8 50 83  7  6  3
 30 |                        1        1     2  4                 1  1  2  2  3  3  6  1     8 22 15    13 13
    |                                    1  2  1  1              3     1  3  4  5  1     1  6  3  5  2 45 97
 32 |                        1        1  1  1  3     1  1              2  6  1     1     1 17 10  5 12 44 66
    |                              4     1              1              2  3  3  4  3  4  5 29 15  3  4 27 53
 34 |                                    1        1        2        1  4  1  4  3  2  6 36 11  3  1  4  7 11
    |      1                          1 19  1        2  1  4  1  1  2  9  9  1  1  5  4 75  3  5  4 19  3  3
```

Figure 5. Routine processing programs.



those for file update, car-pool matching, and transit information; and

2. The special processing programs, which include those that produce density matrixes, master lists, and miscellaneous lists and also build files.

Routine Processing Programs

Figure 5 shows that the automatic geocoding capability is an optional "front end" that must be locally supplied. This approach permits the use of most of the numerous automatic geocoding systems currently in use. The output of automatic geocoding must include x-y coordinates, which the UPDATE program translates into map squares (grid cells). The design also permits a mixture of automatic and manual geocoding within a local installation.

For those who do not choose to implement automatic geocoding, the map grid-cell numbers are coded on the application forms, which are keypunched and input to the UPDATE program. This program edits all incoming data and makes additions, changes, and deletions to the (indexed) master file, which can be permanently stored on a disk pack if desired. All updates require punching only the field to be changed and not the entire record.

The CARPOOL program, which produces match lists, includes a home-end search, a work-end search, a route-to-work search, and an extended time search. The extent of these searches is controlled by the user, depending on available computer time. The cost per match list is relatively independent of the number of applications processed, which makes feasible frequent, even daily, runs. The user can also define additional matching parameters, to a limited degree, by using control cards. Flexible work hours are supported. Each match is ranked by "quality," and the best matches are printed at the top of the match lists. The user can limit the lists to a specified number of names—the best available matches. For those applicants who receive poor lists, the program can automatically generate a new match list if more matches become available at a later date. This option is also controllable by the user.

The match lists are simpler in appearance and thus more readable than in previous systems (Figure 6). The format of the match lists permits total machine handling and mailing, if that is desired. All match lists destined for employers are grouped by employer number; within each employer group they are ordered in an employer-determined sequence (e.g., department number) to facilitate in-house distribution. All match lists from the general public are sorted by zip code to take advantage of bulk mail rates. The standard format includes a "turnaround" document that can be returned to the ride-sharing agency when applicant data change, simplifying updating. Match lists can be produced on command for specified employers, work cells, or individuals.

The TRANSIT program informs applicants of the transit routes that serve their particular commuting needs. This capability is intended to supplement, not replace, existing information services. The telephone information services and the normal promotional and public-relations activities currently performed by transit agencies will still be needed. Figure 7 shows the TRANSIT printout—the trip list—which includes the transit agency name; the route number, the name, and the frequency of the service; and approximately where to board, where to transfer, and where to alight. A maximum of two transfers is permitted for each direction of the commute trip. The system is multimodal, and special service such as express buses and park-and-ride can be handled in most cases as well. The printout includes up to three routings for each direction of the commute trip. These will generally be the "best" three unless there are a large number of very similar alternatives.

Although TRANSIT is a first-generation system for which there are few precedents, it handles most of the wide range of configurations and circumstances that exist in transit operations today. Certainly, a more comprehensive system is possible, but a high level of transit information is provided for the relatively limited resources required by the user in assembling and maintaining the data base.

CIS allows a maximum of 999 grid cells on each axis. This is primarily intended to permit the use of a "fine" map-grid system with uniform squares in the range of 0.3 to 0.6 km (0.25 to 0.5 mile) on a side. (The extensive search routines eliminate the need for multidensity map grids.) The fine grid provides two major benefits: (a) better distance resolution for improving the quality of car-pool matching and (b) less ambiguity in identifying the closest transit routes for each applicant. On the other hand, the fine grid may have some drawbacks, such as printing of new maps and changeover problems. For these reasons, use of the fine grid is optional, although highly desirable. All regular grid systems used in the FHWA car-pool matching program will work under CIS, but the benefits of the fine grid may not be realized. For those who do wish to change over, all data from the FHWA program are compatible and can be converted automatically by a program included in the CIS package.

Special Processing Programs

The CIS special processing programs provide the capability to purge old records, print two kinds of master lists, print two types of density matrixes, and do file building such as converting the existing data base into the new master file format used by CIS. Except for the conversion program, which is run only once, these programs are typically run on an as-needed basis. Three of these programs are shown in Figure 8.

The SELECT program is a powerful tool that allows the user to extract copies of records from the master file on the basis of a wide range of parameters. The selected records are in a standard format that permits them to be input to almost every other program in CIS for processing. For example, all records for a certain employer can be selected and run into CARPOOL for production of new match lists, or all records from a given geographic (home) area can be selected and processed by TRANSIT to inform residents of a new express bus service. Retrieval can be done on the basis of almost every field within the master file record, in almost any logical combination.

In producing density matrixes, the SELECT program is first used to extract all records with a specified work cell (or cells). These records are then used by the DENSITY program to print density matrixes on the basis of user-specified time intervals (begin time, end time, or both). A major new feature is the optional "shaded" density matrix (Figure 9), which greatly reduces the size of the printout to eliminate "cutting and pasting."

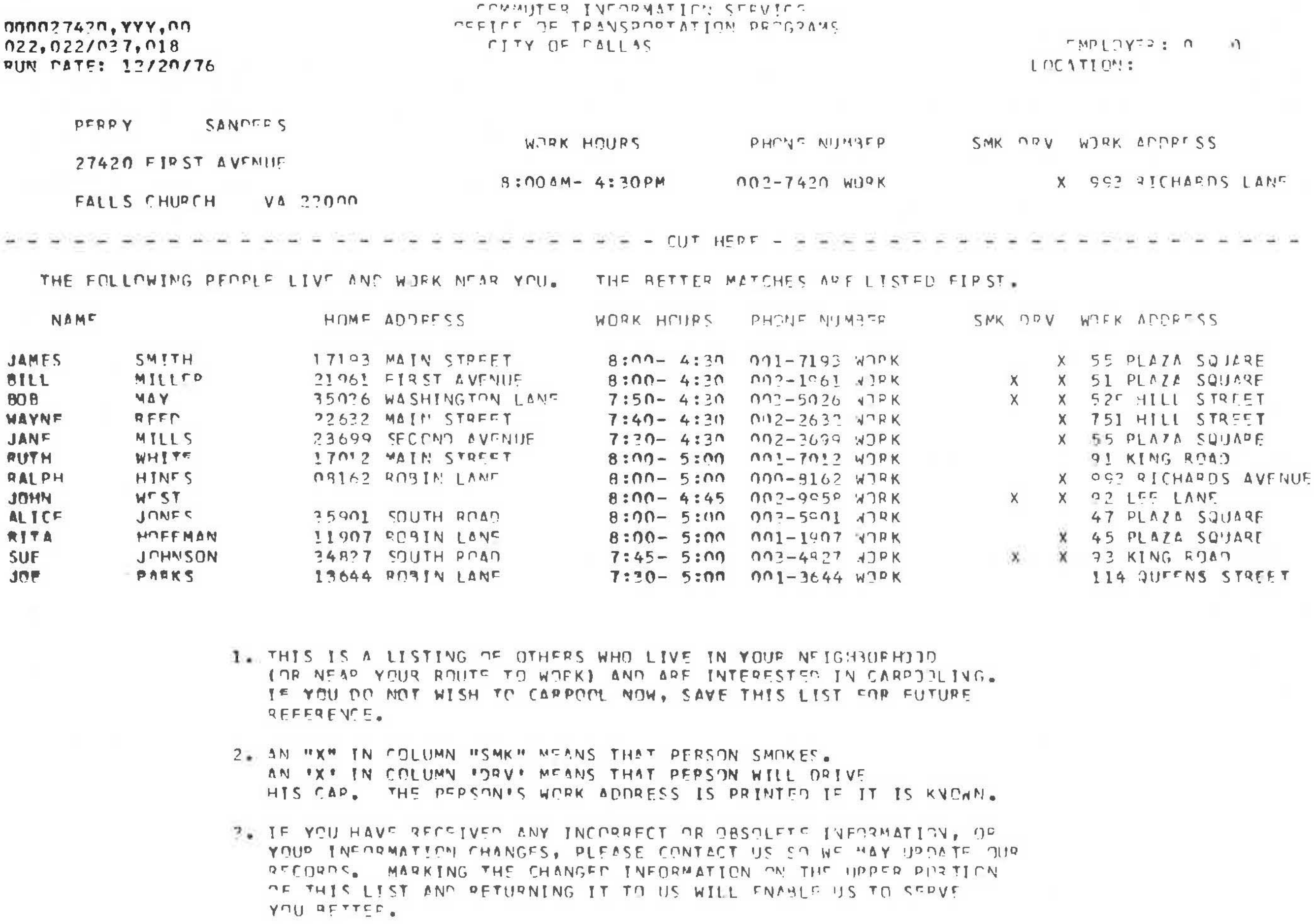
Van-pool planning with CIS is a three-step process: shaded density matrix, numeric density matrix, and letters. The shaded density matrixes are used as a first screening step and are followed by a smaller numeric density matrix to focus in on the promising areas that were found on the shaded matrix. After a tentative van-pool or bus-pool route has been identified from the numeric density matrix, the third step is to notify potential candidates by selecting their records from the master file by work cell(s) and work time(s). These records are then used by the PRINT program to generate personalized letters describing the new service or to produce mail labels for use with form letters.

By using the PRINT program, a listing of the master file in order of work cells can be produced for reference purposes and manual car-pool matching. To expedite manual searching using the master list, the DENSITY program can be used to print a shaded density matrix that corresponds to every work cell in the master list. This can greatly facilitate manual route-to-work searches, for example.

Selective purging of the master file can also be done. Because the last transaction date is automatically kept in the master file, old records can be selected and used by the PRINT program to punch out delete cards, which are read back into the UPDATE program on the next processing cycle. As an additional refinement, the PRINT program can be used to print letters that ask all candidates for deletion if they want to remain on file. Depending on the wishes of the user agency, CIS can then be used to automatically delete all nonrespondents automatically or to delete only those respondents who specifically request it.

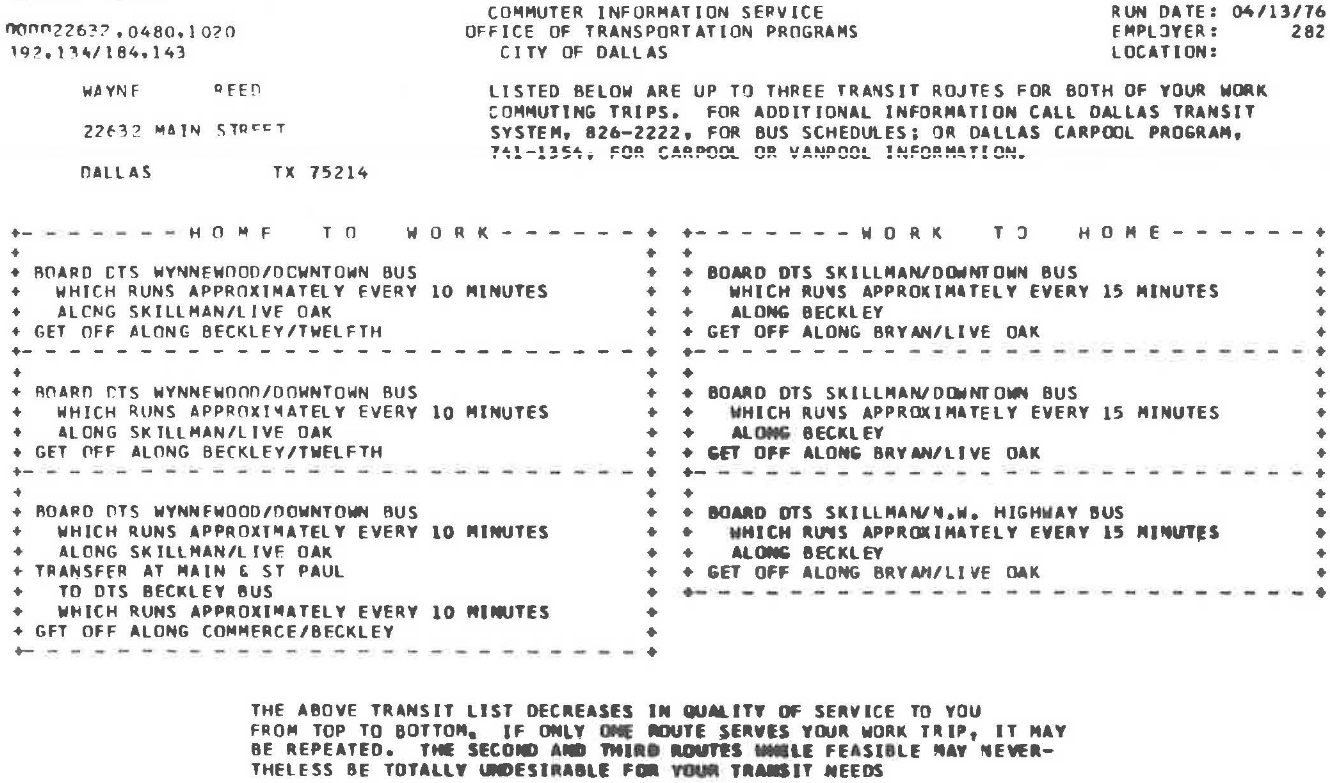
The CONVERT program is provided for automatic conversion of existing files of the FHWA car-pool matching program into the new CIS format. Files that use a nonuniform grid system or are not in the standard FHWA format may require special handling or programming by the user. A special program, TRANLOAD, is also included to build the files that describe the local transit

Figure 6. Match list.



```
                                        COMMUTER INFORMATION SERVICE
000027420,YYY,00                     OFFICE OF TRANSPORTATION PROGRAMS
022,022/037,018                          CITY OF DALLAS                                      EMPLOYER: 0    0
RUN DATE: 12/20/76                                                                           LOCATION:


       PERRY        SANDERS
                                           WORK HOURS          PHONE NUMBER        SMK DRV  WORK ADDRESS
       27420 FIRST AVENUE
                                          8:00AM- 4:30PM       002-7420 WORK              X  992 RICHARDS LANE
       FALLS CHURCH     VA 22000

- - - - - - - - - - - - - - - - - - - - - - - - - - - - - - CUT HERE - - - - - - - - - - - - - - - - - - - - - - - - - - - -

   THE FOLLOWING PEOPLE LIVE AND WORK NEAR YOU.   THE BETTER MATCHES ARE LISTED FIRST.

    NAME                         HOME ADDRESS          WORK HOURS    PHONE NUMBER       SMK DRV  WORK ADDRESS

JAMES       SMITH            17193 MAIN STREET        8:00- 4:30   001-7193 WORK             X  55 PLAZA SQUARE
BILL        MILLER           21961 FIRST AVENUE       8:00- 4:30   002-1961 WORK        X    X  51 PLAZA SQUARE
BOB         MAY              35026 WASHINGTON LANE    7:50- 4:30   002-5026 WORK        X    X  525 HILL STREET
WAYNE       REED             22632 MAIN STREET        7:40- 4:30   002-2632 WORK             X  751 HILL STREET
JANE        MILLS            23699 SECOND AVENUE      7:30- 4:30   002-3699 WORK             X  55 PLAZA SQUARE
RUTH        WHITE            17012 MAIN STREET        8:00- 5:00   001-7012 WORK                91 KING ROAD
RALPH       HINES            08162 ROBIN LANE         8:00- 5:00   000-8162 WORK             X  992 RICHARDS AVENUE
JOHN        WEST                                      8:00- 4:45   002-9958 WORK        X    X  92 LEE LANE
ALICE       JONES            35901 SOUTH ROAD         8:00- 5:00   003-5901 WORK                47 PLAZA SQUARE
RITA        HOFFMAN          11907 ROBIN LANE         8:00- 5:00   001-1907 WORK             X  45 PLAZA SQUARE
SUE         JOHNSON          34827 SOUTH ROAD         7:45- 5:00   003-4827 WORK        X    X  93 KING ROAD
JOE         PARKS            13644 ROBIN LANE         7:30- 5:00   001-3644 WORK                114 QUEENS STREET


                     1. THIS IS A LISTING OF OTHERS WHO LIVE IN YOUR NEIGHBORHOOD
                        (OR NEAR YOUR ROUTE TO WORK) AND ARE INTERESTED IN CARPOOLING.
                        IF YOU DO NOT WISH TO CARPOOL NOW, SAVE THIS LIST FOR FUTURE
                        REFERENCE.

                     2. AN "X" IN COLUMN "SMK" MEANS THAT PERSON SMOKES.
                        AN 'X' IN COLUMN 'DRV' MEANS THAT PERSON WILL DRIVE
                        HIS CAR.  THE PERSON'S WORK ADDRESS IS PRINTED IF IT IS KNOWN.

                     3. IF YOU HAVE RECEIVED ANY INCORRECT OR OBSOLETE INFORMATION, OR
                        YOUR INFORMATION CHANGES, PLEASE CONTACT US SO WE MAY UPDATE OUR
                        RECORDS.  MARKING THE CHANGED INFORMATION ON THE UPPER PORTION
                        OF THIS LIST AND RETURNING IT TO US WILL ENABLE US TO SERVE
                        YOU BETTER.
```

Figure 7. Trip list.



```
                                       COMMUTER INFORMATION SERVICE                         RUN DATE: 04/13/76
000022632,0480,1020                 OFFICE OF TRANSPORTATION PROGRAMS                       EMPLOYER:      282
192,134/184,143                         CITY OF DALLAS                                      LOCATION:

      WAYNE       REED                 LISTED BELOW ARE UP TO THREE TRANSIT ROUTES FOR BOTH OF YOUR WORK
                                       COMMUTING TRIPS.  FOR ADDITIONAL INFORMATION CALL DALLAS TRANSIT
      22632 MAIN STREET                SYSTEM, 826-2222, FOR BUS SCHEDULES; OR DALLAS CARPOOL PROGRAM,
                                       741-1354, FOR CARPOOL OR VANPOOL INFORMATION.
      DALLAS          TX 75214

+- - - - - - - - H O M E   T O   W O R K - - - - - - - +  +- - - - - - - - W O R K   T O   H O M E - - - - - - - +
+                                                      +  +                                                      +
+ BOARD DTS WYNNEWOOD/DOWNTOWN BUS                     +  + BOARD DTS SKILLMAN/DOWNTOWN BUS                      +
+   WHICH RUNS APPROXIMATELY EVERY 10 MINUTES          +  +   WHICH RUNS APPROXIMATELY EVERY 15 MINUTES          +
+   ALONG SKILLMAN/LIVE OAK                            +  +   ALONG BECKLEY                                      +
+ GET OFF ALONG BECKLEY/TWELFTH                        +  + GET OFF ALONG BRYAN/LIVE OAK                         +
+- - - - - - - - - - - - - - - - - - - - - - - - - - - +  +- - - - - - - - - - - - - - - - - - - - - - - - - - - +
+                                                      +  +                                                      +
+ BOARD DTS WYNNEWOOD/DOWNTOWN BUS                     +  + BOARD DTS SKILLMAN/DOWNTOWN BUS                      +
+   WHICH RUNS APPROXIMATELY EVERY 10 MINUTES          +  +   WHICH RUNS APPROXIMATELY EVERY 15 MINUTES          +
+   ALONG SKILLMAN/LIVE OAK                            +  +   ALONG BECKLEY                                      +
+ GET OFF ALONG BECKLEY/TWELFTH                        +  + GET OFF ALONG BRYAN/LIVE OAK                         +
+- - - - - - - - - - - - - - - - - - - - - - - - - - - +  +- - - - - - - - - - - - - - - - - - - - - - - - - - - +
+                                                      +  +                                                      +
+ BOARD DTS WYNNEWOOD/DOWNTOWN BUS                     +  + BOARD DTS SKILLMAN/N.W. HIGHWAY BUS                  +
+   WHICH RUNS APPROXIMATELY EVERY 10 MINUTES          +  +   WHICH RUNS APPROXIMATELY EVERY 15 MINUTES          +
+   ALONG SKILLMAN/LIVE OAK                            +  +   ALONG BECKLEY                                      +
+ TRANSFER AT MAIN & ST PAUL                           +  + GET OFF ALONG BRYAN/LIVE OAK                         +
+   TO DTS BECKLEY BUS                                 +  +- - - - - - - - - - - - - - - - - - - - - - - - - - - +
+   WHICH RUNS APPROXIMATELY EVERY 10 MINUTES          +
+ GET OFF ALONG COMMERCE/BECKLEY                       +
+- - - - - - - - - - - - - - - - - - - - - - - - - - - +


                 THE ABOVE TRANSIT LIST DECREASES IN QUALITY OF SERVICE TO YOU
                 FROM TOP TO BOTTOM.  IF ONLY ONE ROUTE SERVES YOUR WORK TRIP, IT MAY
                 BE REPEATED.  THE SECOND AND THIRD ROUTES WHILE FEASIBLE MAY NEVER-
                 THELESS BE TOTALLY UNDESIRABLE FOR YOUR TRANSIT NEEDS
```

service. CONVERT and TRANLOAD are shown in Figure 10.

OTHER INFORMATION

A highly detailed description of CIS is given in the CIS user's guide, which, in its final form, will eventually be available from the Federal Highway Administration. This document presents highly technical material for the computer staff and, in separate sections, relatively nontechnical material for the ride-sharing staff. It will give the potential user a very clear picture of the costs and

Figure 8. Special processing programs.

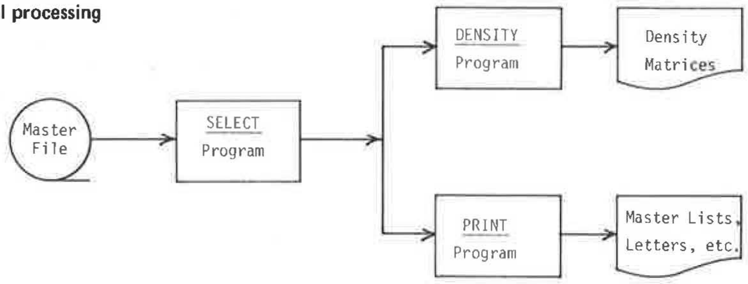
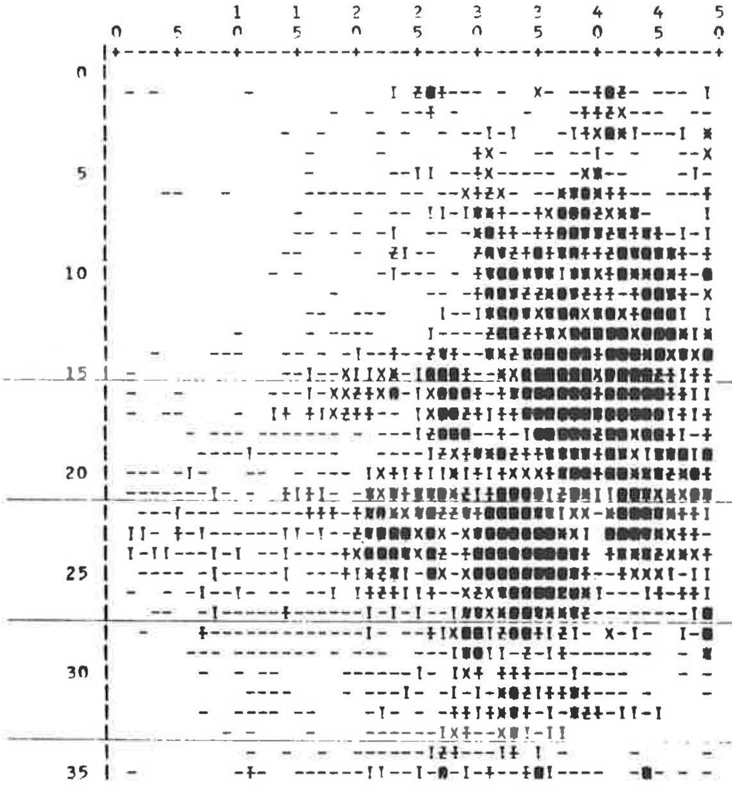


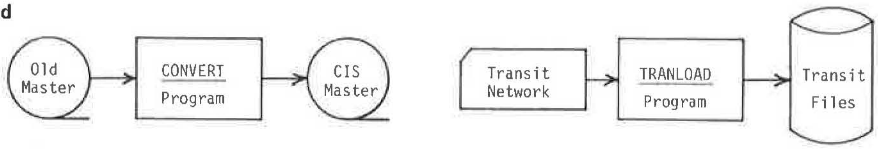
Figure 9. Shaded density matrix.

```
                                COMMUTER INFORMATION SYSTEM
DATE: 12/ 7/76                   SHADED DENSITY MATRIX                                  REQUEST # 00

              NUMBER OF PEOPLE PER HOME GRID CELL, ACCORDING TO THE FOLLOWING CRITERIA:

START TIME RANGE: 12:00AM -11:59PM                   SHADED DISPLAY OF DALLAS MASTER FILE
  END TIME RANGE: 12:00AM -11:59PM       ALL WORK CELLS AND ALL TIME RANGES HAVE BEEN COMBINED INTO ONE MATRIX.
                                         STANDARD SHADING INTERVALS WERE USED.
```



```
 =000-000   -=001-004   I=005-009   ‡=010-019   X=020-029   Ƶ=030-039   ✱=040-049   ▼=050-074   ■=075-099   ■=100-UP
```

Figure 10. CONVERT and TRANLOAD programs.



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:

$$E_k = PD/F \tag{1}$$

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.

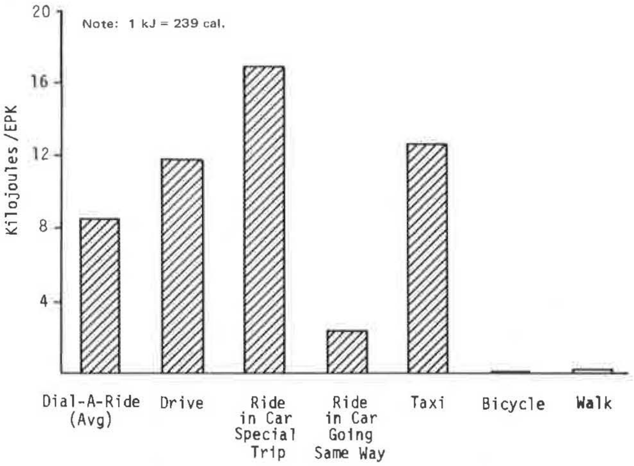
The warm-up factor also differentiates various types of automobile use. Automobile engines operate least efficiently when they are first started, and this poor efficiency would have a noticeable effect on fuel consumption during the relatively short trips in the range considered here [2.9 to 4.0 km (1.8 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_o' 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

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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-

signed to serve access and egress trips bound to and from a regionally oriented line-haul transit system as well as shorter local circulation trips. The model system presented is capable of treating a wide range of modes that can offer such local transit service. In addition to conventional transit and jitney services, which follow fixed routes, point-deviation and checkpoint route-deviation transit can be investigated. More flexible modes, such as checkpoint subscription bus, doorstep subscription bus, and doorstep, many-to-many, dynamically routed transit (dial-a-ride), can also be examined. Comparisons can be made both between alternatives and between operating policies (such as vehicle size and route spacing) within any single alternative. The model system has been designed to predict four important consequences of implementing local transit service: user level of service, operator cost, pollutant emissions, and energy (fuel) consumption. Results from a sample model application are presented. Use of the system would allow a wide range of alternatives to be tested before significant demonstration and experimentation efforts or implementation funds are committed. Such tests can be integrated with corridor and regional analyses on both policy and planning levels of detail.

This paper presents a system of models that is capable of representing the performance of a number of local transit modes, that is, the access modes for a regionally oriented line-haul system as well as neighborhood circulation systems. A comprehensive set of options can be compared relatively quickly and inexpensively by using this methodology. Depending on the level of detail of the required input information, the model system can be applied to planning decisions that involve vehicle size, route and stop spacing, or the resolution of policy issues such as the desirable locations of dial-a-ride and the potential benefits of integrating various components of the public transportation sector. The models were developed as part of a regionwide study of the potential impacts of major diversions to the transit mode (1) and were used to estimate possible economies of scale or service improvements or both without detailed design of bus routes on the local level.

SERVICE ALTERNATIVES

The following local service options were investigated: conventional fixed route, nondeviating jitney, point deviation, checkpoint route deviation, checkpoint subscription, doorstep subscription, and dynamically routed transit.

Nondeviating jitney service resembles conventional fixed-route service except that (a) passengers can board (by hailing) and alight anywhere along the route and (b) a greater number of smaller vehicles provide a frequency that is significantly higher than that offered by typical fixed-route operation. Checkpoint route deviation resembles standard route-deviation operation; however, premium deviations are not made to the doorstep but to a finite number of designated checkpoints on request. Point-deviation service makes scheduled stops at a sequence of checkpoints and is free to take any path between checkpoints; doorstep deviations are accommodated on request. Checkpoint subscription services closely parallel standard (doorstep) subscription operation except that passengers are required to walk short distances to a relatively small number of common checkpoints to meet the bus. Because checkpoints resemble bus stops, checkpoint subscription service resembles conventional fixed-route service. The fact that checkpoints vary in response to prearranged passenger requests distinguishes checkpoint subscription from fixed-route service. Dynamically routed transit, commonly called dial-a-ride, is a many-to-many, areawide service that is also quite responsive with regard to time of request. This service offers less direct routing than subscription service but greater spatial and temporal flexibility in trip making.

Within any of these modes of local transit service, a number of service options can be varied to alter the cost as well as the level of service provided. Such options include (a) route spacing, for those modes with routelike structure; (b) checkpoint or stop spacing where appropriate; (c) vehicle size; (d) design load factor; and (e) fleet size, which affects frequency in routelike modes and all level-of-service components for demand-responsive operations. The model system is capable of considering service guidelines (maximum allowable wait time or walk distance) and of rejecting mode service option combinations that violate these planner-specified constraints.

MODELING

Approach

The method of analysis described in this paper is designed to examine the level of service attainable and the corresponding system cost of local transit at given levels of ridership for various operating policies. The models may be used to examine local options in the context of a particular regional transit-network alternative.

Figure 1 shows the overall model framework. The model is divided into supply, cost, and impact components. Complete model specifications are given by Batchelder and others (1, 2).

Issues of Modeling Process

Equilibrium

The supply model framework represents only half of the real-world process. Later versions of the model will include the demand as well as the supply relations. Significant prior work has been done elsewhere on demand modeling (9); therefore, this effort focuses on the supply side. Load factors have been set as a given condition, and demand has been parametrically varied.

Network

The models, being primarily a policy tool, do not include a specific local network; input data requirements are thus significantly reduced. A number of parameters, e.g., route spacing, stop spacing, vehicle size, and speed, are used to represent design options. The local service area itself is fixed at the outset and is representative of a previously defined catchment area of a line-haul station on a regional transit network. The specification of local services to be offered and the assignment of trips to local services are based on the previous designation of line-haul routes and terminals (transfer points).

Local Circulation Versus Collection-Distribution Service

Local transit services play two roles in a regional transit system:

1. Local transit serves collection and distribution trips associated with the line-haul network. This function is particularly important in peak periods when commuter travel to major activity centers predominates.
2. Local transit serves short-haul circulation trips within individual neighborhoods or suburban towns.

Thus, although small zones (census tracts) may be the finest level of data available, a local service district, or set of related and contiguous zones, was defined as the unit for local transit analyses. Trips between zones within the local service district are assumed to use only the local transit system and are called circulation trips.

Clear differences in local service alternatives also become evident when they are examined with respect to the two trip types. Flexible demand-responsive services provide a more evenly distributed quality of service for many-to-many local circulation trips. Fixed-route service, on the other hand, may offer some portions of these trips shorter travel times and leave other portions without any reasonable level of service. Thus, a fixed-route operation may be serving a different set of trips than the flexible service.

In conducting the comparison of alternative modes for this analysis, data were prepared for fixed, deviating, and flexible bus services where only the flexible alternative consisted of specially tailored service: subscription for many-to-one trips and dynamically routed transit service for many-to-many trips. Fixed-route and deviating alternatives were assumed to provide service for both circulation and collection-distribution service.

Models

Fixed Route

The fixed-route model, which is based on the work of Ward (3), assumes one or more sets of parallel routes operating within a rectangular local service district (Figure 2). Routes within each set converge at zone boundaries to allow for transfers between individual bus routes by intradistrict circulation travelers. In reality, these points would probably be located at line-haul stops to serve the dual purpose of transfer for both local and line-haul trips. The fixed-route program tests a wide range of alternatives by varying vehicle size and route spacing.

The model first computes a design volume based on input travel data disaggregated by trip type (e.g., circulation) and direction. (Input data are based on the assignment of origin-destination transit volumes to regional transit lines.) Other input data include bus-stop spacing, dwell and layover times, base bus speed, zone dimensions, average passenger travel distances, duration of service, and limits for the variable parameters of vehicle size and route spacing. The model determines the frequency of service and the fleet size required to transport the passenger volume, at a given load per vehicle, subject to walk and wait-time constraints. Model output includes supply measures such as fleet size, vehicle hours and kilometers, and level-of-service measures including wait, walk, and travel time.

Nondeviating jitney was analyzed within the context of the fixed-route model; small vehicles were used and fixed bus stops eliminated. The actual number of stops made was assumed to be a function of Poisson arrivals along a route with defined time and distance intervals.

Deviating Bus

The deviating bus model is an extension of the fixed-route model (Figures 3 and 4). For either the point-deviation or the checkpoint route-deviation operation, the model computes the percentages of users who request deviations based on geometry and maximum allowable walk distances specified by the analyst. The expected (probabilistic) number of stops and deviations made by an average bus on a single round trip and the resulting round-trip length are calculated. For the point-deviation service, a "traveling salesman" tour is assumed for the doorstep pickups and drop-offs between fixed checkpoints. Various route and checkpoint spacings can be tested by the model.

Flexible Transit Service

1. Subscription bus model—Subscription service (Figure 5) is provided for peak-period collection and distribution (back-haul) trips as part of the flexible alternative (3). Specific zone to line-haul station (many-to-one) services are specified at the outset of the analysis and tested by the model. A service area is assumed to be divided into small sectors, each served on a continuous basis by a single vehicle. That vehicle's trip may thus be divided into line-haul travel and collection tour portions. Given vehicle size, load factor, trip density (trips per square kilometer per hour), speed, service area, and line-haul station locations, round-trip travel time and fleet size are determined. Both checkpoint and doorstep subscription options for various vehicle sizes can be tested by the model.
2. Dynamically routed transit model—The many-to-many, districtwide, dynamically routed transit model (Figure 6) describing system performance was statistically fit by using ordinary least squares regression on data produced by a simulation model. The simulation itself, originally developed at the Massachusetts Institute of Technology for the Computer-Aided Routing System (CARS) project, has itself been validated by using data collected during the Haddonfield, New Jersey, demonstration (4, 8). Given volume, area, base bus speed, and a target level of service, response and travel times are calculated along with the fleet size necessary to attain that level of service.

Because subscription service would be provided during peak hours by the same basic fleet as that used for dynamically routed transit, a minimum vehicle size required for dynamically routed transit operation is computed based on Poisson multiple-server queuing theory to ensure that smaller vehicle sizes are not tested by the subscription model. Queuing theory also provides a useful productivity measure—the dead-time fraction, or the fraction of time a dynamically routed transit vehicle would be idle.

Measures

Output of the models includes various measures of impedance (level of service) and resource expenditure.

Level of Service

For evaluation purposes, the overall average level of service offered by each service alternative was computed. Level-of-service components such as in-vehicle and out-of-vehicle time (walk, wait, response, or schedule delay) are of varying importance in the overall perception of service quality. Thus, the impedance measure is a weighted sum of the individual components that reflects the differences in wait time at a bus stop, wait time in the home, and the inconvenience of meeting scheduled departures. The relative impedance weights were determined by analyzing data and results of a line-haul access study discussed by Liou and Talvitie (5).

Cost

Service cost per passenger, without consideration of fares or revenues, was used as the major evaluation measure. Annual direct and indirect operating costs, labor costs, and fleet capital costs are calculated by the model based on input unit costs (6). Supply model out-

Figure 1. Model framework.

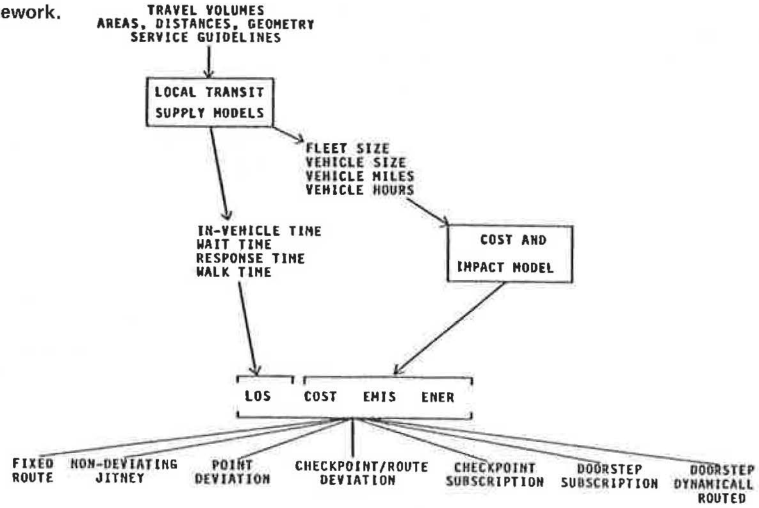


Figure 2. Fixed-route service for a single zone.

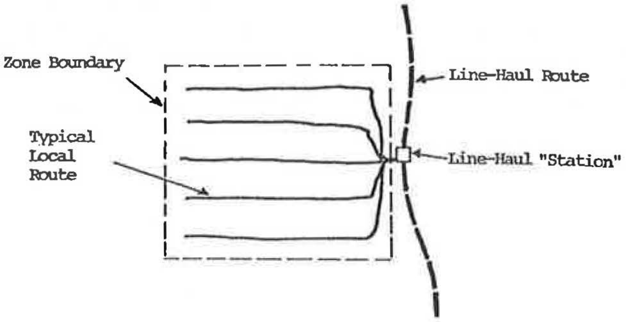
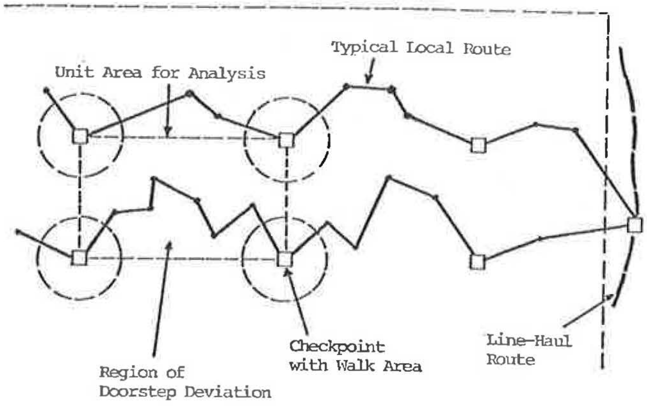


Figure 3. Local point-deviation service.



puts, such as fleet size and vehicle hours of service and kilometers of travel, and peak and off-peak fleet cost-allocation factors are input to the cost models.

Impact Models

Easily quantifiable impacts of interest to transit planners include the energy and environmental effects of transit use. Per-passenger fuel consumption and pollutant emissions were chosen as the appropriate model outputs. Carbon monoxide, hydrocarbons, and oxides of nitrogen were the pollutants viewed as most significant. Both energy and environmental impacts are related to

Figure 4. Local checkpoint route-deviation service.

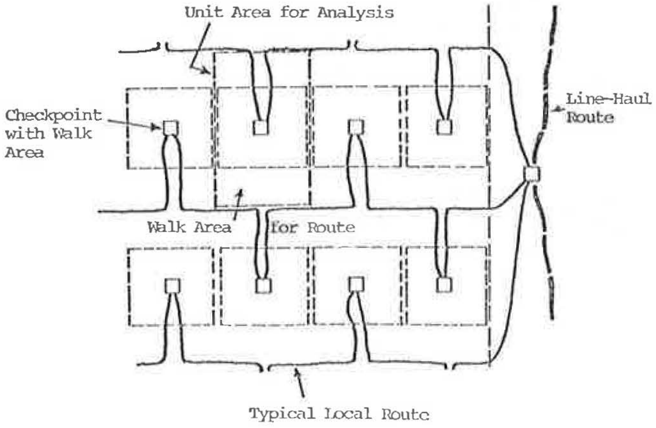
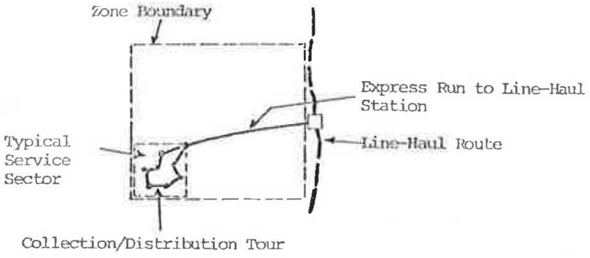


Figure 5. Flexible local service alternative: subscription bus.



vehicle kilometers of travel and are easily computed (6).

Productivity

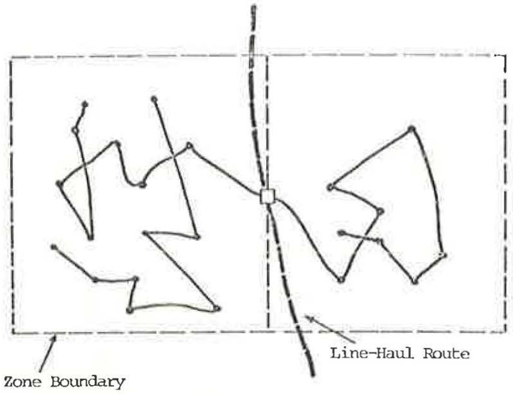
Variables such as passenger trips per vehicle hour, passenger kilometers per seat kilometer, and dead-time fraction for dynamically routed transit are useful for the evaluation of relative operating productivity. Such measures are used in determining system economics and potential economies of scale.

MODEL APPLICATION

The model components (i.e., fixed, flexible, and hybrid service) were applied to an analysis of a high-density suburban district over a wide range of peak-period modal splits. This application of the model was part of a study of the design implications of major diversions to transit (1, 2). Thus, the range of mode splits was considerably greater than that presently experienced with flexible modes.

The models produce data on numerous alternative system designs according to input guidelines. Analysis of these data led to a number of conclusions.

Figure 6. Flexible local service alternative: dynamically routed transit.



Economies of Scale

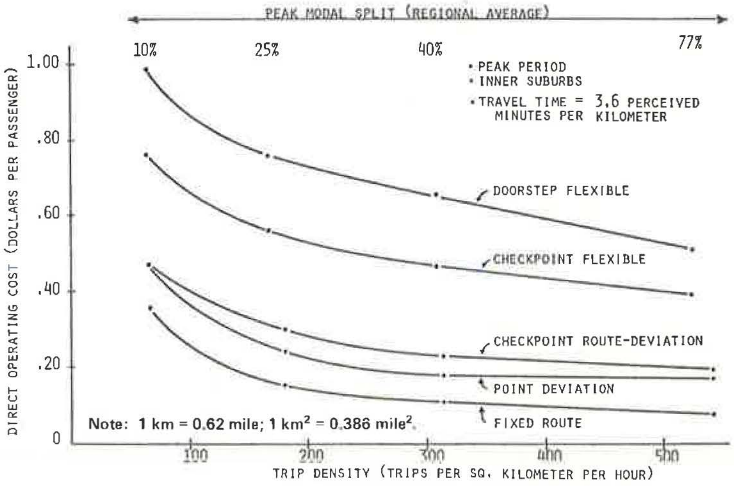
Direct operating costs per passenger for alternative service options were plotted as functions of trip density; level of service (weighted travel time or impedance) was held constant. Figure 7 shows a typical result. Each point in the figure represents the vehicle-size and route-spacing alternative that produces the least cost while meeting the specified service standard [in this case equal to 3.6 (perceived) min/km (5.8 min/mile), including out-of-vehicle time].

All modes tested reveal economies of scale, although at diminishing rates. These economies result primarily from the ability to use larger vehicles and still maintain frequent service, which yields increased driver and vehicle productivity at high modal splits.

Comparison of Modes

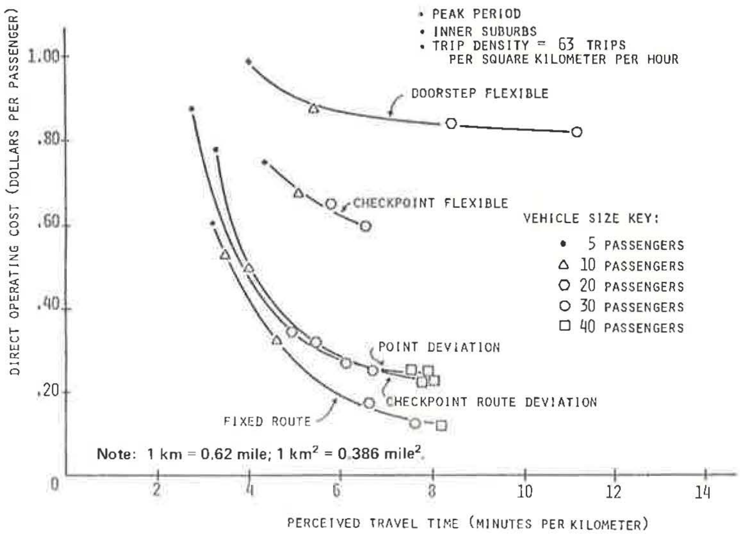
Figure 7 clearly shows fixed route to be the least cost option for providing good peak-period service in an inner suburban district [population density of 2200 to 2500 persons/km^2 (6000 to 7000 persons/mile^2)] over a broad range of trip densities. Figure 8, which plots direct operating costs for a range of service levels at the lowest modal split examined, confirms this dominance: Points closer to the origin are desirable, and thus shorter travel times are provided at lower operating

Figure 7. Direct operating cost versus trip density for various service options and resulting increase in modal split.



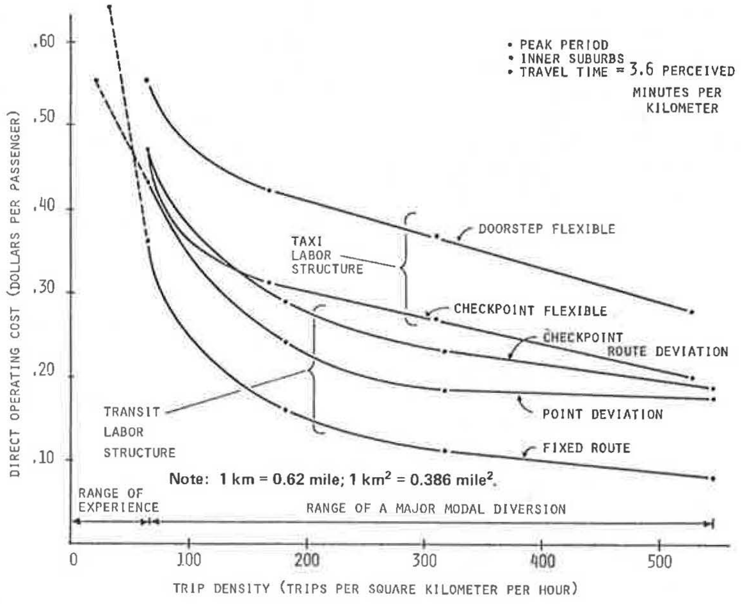
Note: 1 km = 0.62 mile; 1 km^2 = 0.386 mile^2.

Figure 8. Local service performance at 10 percent peak modal split.



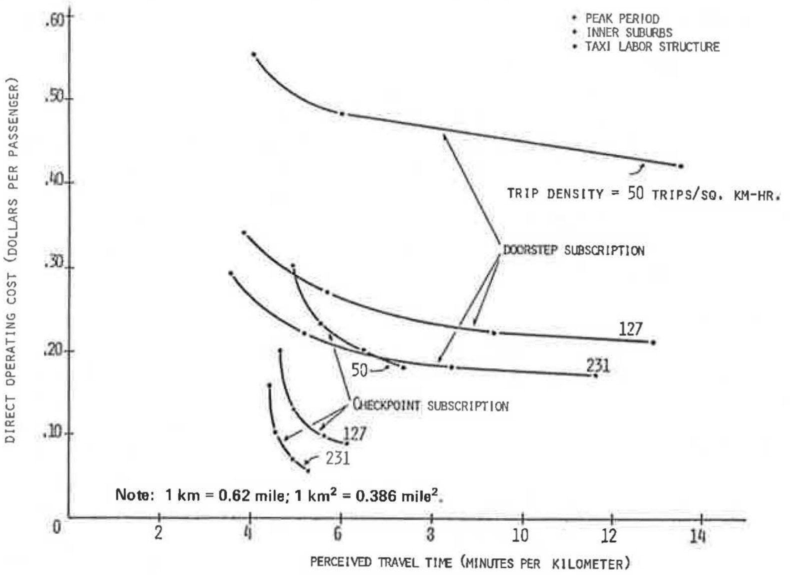
Note: 1 km = 0.62 mile; 1 km^2 = 0.386 mile^2.

Figure 9. Sensitivity of operating cost to labor structure.



Note: 1 km = 0.62 mile; 1 km^2 = 0.386 mile^2.

Figure 10. Subscription service performance.



Note: 1 km = 0.62 mile; 1 km^2 = 0.386 mile^2.

costs. The sensitivity of cost to changes in service varies dramatically by mode, and the route-based modes are the most sensitive, i.e., have the steepest slopes. Increases in vehicle size, which cause increased headways and poorer service, result in large cost savings for these modes because of increased driver productivity. (Fixed-route bus, as analyzed in this study, includes a non-deviation-jitney alternative operated with automobile-size vehicles.) At the other extreme, doorstep flexible operation, an increase in vehicle size increases the length of the collection tour and results in insignificant cost savings.

Two basic questions can be raised at this point:

1. Do the models reflect the real world, where successful flexible operations have been developed to replace failing fixed-route service?
2. If so, do other modes dominate at the lower trip densities that occur in the off-peak and in other parts of the metropolitan area?

Further examination of the model results helps to answer these questions and provides insight into the operation of local transit.

Labor Cost Sensitivity

Most flexible operations do not face the high cost of unionized transit labor but more closely resemble the taxi situation. If taxi labor costs are assumed for flexible transit options, significantly lower wage rates make these services more competitive. Figure 6 should be compared with Figure 9. At the lowest modal split examined, costs for checkpoint subscription with dynamically routed transit circulation are only 20 percent more than those for fixed route and 8 percent cheaper than those for deviating bus. Fixed route, however, still dominates.

Trip Density

The range of trip densities found in existing flexible-route services seldom exceeds more than the 14 to 18 trips/(km^2·h) [40 to 50 trips/(mile^2·h)] served by the Regina, Saskatchewan, and Bay Ridges, Ontario, systems (7). Thus, there is no inconsistency between the results obtained here and the successful operation of existing flexibly routed services. The previous figures do indicate, however, that, if demand density passes certain thresholds, then the types of service provided should change in the direction of less spatial responsiveness.

Flexible Service Operation

In this study, flexible service is provided by a composite of doorstep dynamically routed transit for intradistrict circulation travel and subscription service (either doorstep or checkpoint) for collection-distribution travel to and from line-haul stations. Significant improvements in productivity (accompanied by decreases in per-passenger costs) can be obtained by serving more passengers at each stop with checkpoint subscription and thereby reducing the time of a collection-distribution tour. However, because passengers would no longer be served by door-to-station service, it is expected that these improved productivities would be "bought" with degraded levels of service.

Surprisingly, Figure 10 shows that the checkpoint service provides higher quality service (lower travel time) for all trip densities and for all but the smallest vehicle size, as well as less expensive operation, which was expected. Thus, the required walk distance is more than compensated for by the reduction in the collection-distribution tour that results from multiple pickups at each checkpoint. This effect, therefore, is even more pronounced as vehicle size and trip density increase.

In addition to the above, investigation of various time periods and areas in the metropolitan region tends to show flexible and hybrid (deviating) services in a different light. Whereas fixed route tends to dominate in high-density inner suburbs in the peak, the off-peak and the outer suburbs are more suited to flexible service, probably because of more dispersed trip patterns and street configurations.

SUMMARY AND CONCLUSIONS

Although only a small sample of the results that can be produced by using the models are illustrated in this paper, the models do assess various impacts. They may be useful in revealing the dominance of one particular option over another, pinpointing the thresholds at which alternative policies begin to offer better solutions, and aiding the analyst in other sketch-planning tasks for local transit.

The analysis tool developed in program package form can be extended and refined considerably. Among the areas that call for further work are

1. Automation of the evaluation and selection process;
2. Inclusion of demand models;
3. Refinement of the DRT model so as to increase sensitivity to local transit trip and street patterns;
4. Extension to checkpoint DRT, premium taxi, car pooling, van pooling, and park-and-ride.

The models may be used by a transit analyst to investigate local service alternatives on a macroscale as well as at a finer level of detail. In an overall metropolitan area study, this is useful for indicating which local districts and during which time periods fixed, deviating, or flexible local transit service should be provided. In a long-term study of a dynamic demand situation, the model may help to determine at which point in time it may be advantageous to modify service so as to gain efficiency and reduce subsidies. On the finer level of analysis, preliminary estimates of fleet size and overall cost of service in an area, as well as the comparison of checkpoint and doorstep alternatives and different geometric options (such as route spacing and stop spacing), can be made.

The model has conveniently integrated present understanding of some widely different services and has already proved to be useful in analyzing alternative local transit-service policies.

ACKNOWLEDGMENTS

The work reported here was considerably aided by the helpful guidance of James Batchelder, Nigel Wilson, Daniel Roos, and Martin Flusberg of Multisystems, Inc.; Brian Kullman and Lea Tsai, formerly of Multisystems, Inc.; Jerry Ward, Norman Paulhus, and Katherine O'Leary of the Office of the Secretary, U.S. Department of Transportation; and Donald Ward of the Transportation Systems Center. Although the work was supported by the U.S. Department of Transportation, we accept sole responsibility for any errors in fact or opinion.

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Satellite-City Development Through Improved Passenger Transportation Service

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The lack of adequate transportation services has been a major impediment to the development and growth of satellite communities outside of major metropolitan areas. This paper presents an approach for selecting and organizing transportation services for commuting trips between satellite communities and metropolitan areas. The services of interest are designed as "commuter clubs" in which most of the administrative functions are performed by volunteers. This approach allows inexpensive services to be offered when travel demand is low and supports gradual development of services from a small start. An analytical technique that makes use of the commuter-club approach is presented for formulating, describing, evaluating, and comparing alternative transportation services. Analytical results suggest that van-pooling and subscription bus services are attractive for a wide range of satellite cities. Other services—car pooling, commuter rail, and air—can be attractive in special situations. All require a coordinating function for providing advice, support, and help with problems. This function can best be performed within the satellite-city government.

The urbanization of America has proceeded to an extent that many consider dangerous. Crime, pollution, and poverty are often blamed on the difficulties of living in the concentrated population areas that our major cities have become. For more than a decade, imaginative developers have been creating new towns and expanding rural communities that are separated from major cities by rural land or green belts. These communities offer low-density living and some rural amenities and at the same time retain access to the city. They purport to offer residents the best of two worlds—rural and urban.

What we know as new towns are not a new phenomenon. In the late nineteenth and early twentieth centuries, new towns developed along or adjacent to railroad lines. The whole process of railroad commuting developed around these communities. Automobile-related growth and flexibility have allowed the voids between these towns to be filled with many types of developments. Now, we find that we need the open spaces.

Those who tout new towns as the wave of the future have little evidence to support their view. New towns such as Reston, Virginia; Columbia, Maryland; and Peachtree City, Georgia, have not been outstanding financial successes. Homes, particularly townhouses, have sold slowly, which suggests that the combined rural and urban prospects they offer are somewhat less than utopian. Transportation has been identified as a major problem. Many new-town residents are employed in the city. Long automobile trips prove to be unproductive and slow, especially when they enter the stream of urban rush-hour traffic. Other family members are also dependent on automobiles for their mobility; families are thus required to own two and often three automobiles.

The transportation problems of new towns have not gone unnoticed. Several new towns have launched internal bus services to facilitate circulation within the community; these have largely failed. Other new towns have inaugurated bus services to the city; these too have generally failed. Failures have occurred mainly because new-town residents are automobile oriented and have been unwilling to accommodate to inflexible bus service.

The most promising new developments have been generated by new-town residents themselves. From a modest start, the residents of Reston, Virginia, have developed a subscription bus service that now includes 25 buses carrying 1800 persons/d to and from downtown Washington. A van-pool service recently started in Peachtree City, Georgia, has been warmly received and shows promise of growth and success. Both of these services are characterized by a degree of personal accommodation that is not available in conventional public transit.

Improved transportation is likely to enhance the attractiveness of new towns. It may even facilitate the development of new towns on a scale larger than that now possible, thus relieving urban stresses and supporting a new type of urban development. Sufficient evidence exists to support a careful examination of the transportation alternatives that are available to carry workers between new-town residences and central-city jobs. This paper undertakes such an evaluation for communities that have the following characteristics:

1. Each has a high-speed, limited-access highway link between the new town and the metropolitan area.
2. The new town is small, and offers some attractive features to urban residents such as recreational, educational, and commercial opportunities, and has a potential for population growth.
3. The new town is within 162 km (100 miles) of the central city. This type of new town is called a satellite city because of its location near the outer influences of the central city.

The transportation problem is characterized by collection-distribution in the satellite city, a substantial line-haul, and collection-distribution in the central city. In the satellite community, access to transportation is simplified by the size of the town. However, access in the city is complicated by the wide and growing dispersion of jobs.

The massive literature that is developing on urban transportation has little to say about transportation access to new towns. Some general works, like that of Meyer, Kain, and Wohl (1), include techniques that can be applied to a broad range of problems, but they do not treat the unique new-town setting. Pooling proponents such as Dickerson and Goodson (2) have dealt with new-town-like problems, but their approaches are largely parametric. Paratransit investigations such as that of Kirby and others (3) have produced much useful information, but they have not dealt specifically with the new-town problem.

A few site-specific studies have been done that relate to quasi-new-town environments. Alan M. Voorhees and Associates (4, 5) have investigated high-speed service (intercity travel) links for two urban corridors: San Francisco-Sacramento and Atlanta-Macon. These studies focused on high-speed, line-haul service and largely overlooked access problems. Morris (6) examined the internal transportation needs of new towns. In general, site-specific studies err in attempting to place fully developed transportation systems into environments that are not prepared to receive them. The relations between satellite cities and their companion metropolitan areas have yet to be documented and fully understood.

STUDY APPROACH

This paper uses an approach to transportation development that ensures demand responsiveness to the needs of residents of satellite areas. It presents an analytic procedure that can be used to identify transportation services and to compare potential candidate services. The essence of the method is to develop new services on a vehicle-unit basis; the services do not need to be launched on a massive scale. This concept resembles the successful development at Reston and closely parallels car-pool matching efforts that have been undertaken in many communities.

Another essential feature of the approach is an entrepreneur or broker who is needed to promote, coordinate, and monitor the new service. The broker needs to be a full-time employee of the satellite community who combines considerable personal enthusiasm with a sound knowledge of the analytical procedure. Other participants in the program are users (patrons), volunteers, and part-time employees. These people are associated in "commuter clubs" that organize and administer individual services that may use one vehicle or a small fleet of vehicles.

The approach described here differs from past work in several important respects:

1. All services are designed to commence operation on a small scale and to grow in terms of small increments of demand.
2. All services are based on passenger participation to the maximum feasible extent (they thus become variants of paratransit).
3. All services are designed for new-town commuting and, as such, offer attractive pooling potential.

A broad set of transportation alternatives is initially selected for study. A summary of the characteristics of these alternatives is given in Table 1. Other candidate services can be postulated and evaluated by using the same analytical procedure. A key feature of the analysis is that each service alternative is examined in an environment that favors its development, and thus two unlike alternatives are not subjected to requirements that inherently favor one over the other.

BASIS OF SOLUTION PROCEDURE

The solution procedure is based on key approaches to travel demand and service ownership, which are described below.

Demand

Travel demand between satellite towns and adjacent cities is an unknown quantity. Where good highways are available and the new town offers an attractive life-style, some commuting is known to take place. That commuting is performed almost exclusively by automobile because no other attractive service exists. New-town commuting is limited to persons who are willing and able to invest the time and money required for automobile travel. If a new service were established that significantly reduced travel time or user cost, then it would be reasonable to expect more commuters to appear on the scene. Some residents of satellite areas may decide to seek jobs in the city. Some city residents may elect to move to the new town. Both processes are slow, particularly during the critical early days of the transportation service. Once the initial process begins, there is no adequate way to predict how fast the change will happen or how far it will go.

Existing demand-analysis techniques are anchored in current or observable practices. They cannot adequately predict the impact of entirely new services. Moreover, they do not take into account the impact of quality of service on demand. Thus, the transportation entrepreneur who sets out to justify or establish a fully developed transportation service is doomed to failure unless the service can be operated at a substantial loss for several years.

To avoid excessive capital needs, new services that can survive at low levels of patronage should be introduced. Such services must exhibit (a) low capital requirements, (b) low fixed costs, and (c) variable costs per passenger trip that are reasonably constant for wide changes in demand. The first requirement—low capital requirements—suggests that candidate systems must be able to use existing facilities to a large extent. Thus, the service alternatives given in Table 1 use existing highways, railroads, or airways and airports. The second requirement—low fixed costs—suggests that the administrative organization be minimized. This can be accomplished through the commuter-club concept, which is discussed below. The third requirement—proportional variable costs—suggests that vehicle and operator costs somehow reflect the extent of use. This requirement points to part-time drivers, off-hour uses, or some other scheme that takes the burden of fixed working hours off the commuter service. Pooling accomplishes part of this purpose; brokerage also contributes.

If these requirements can be met, the new services will be relatively insensitive to the level of demand. One of these services could then be introduced at a low ridership level and expanded as demand increases without any great sacrifice in operating economies. If the problem of new-town commuting is seen from this viewpoint, it is not necessary to be concerned with the absolute level of travel demand. Service can be initiated at a level of demand that can reasonably be expected to exist.

Commuter Club

The term commuter club is intended to connote a voluntary association of individuals formed for the purpose of providing commuter transportation to members. A club owns or leases assets (vehicles) and enters into contracts for services. In organizational form it need not differ from community swimming pools, participating nursery schools, and other voluntary civic organizations. The commuter club has a board of directors and elective officers who are empowered to bond the organization. It does not have any full-time employees.

The club designs its own service, including mode, vehicle, route, schedule, fares, and operating practices; executes agreements with its members and collects fares; and contracts for services and pays bills. New members typically pay a membership fee to cover their share of club assets and fares in accordance with their use agreement. Members of a commuter club normally live and work in reasonable proximity to one another so that they can share a common transportation service. As demand grows, a club can expand its area of operation or new clubs can be formed. The use of volunteer labor for administrative chores keeps fixed

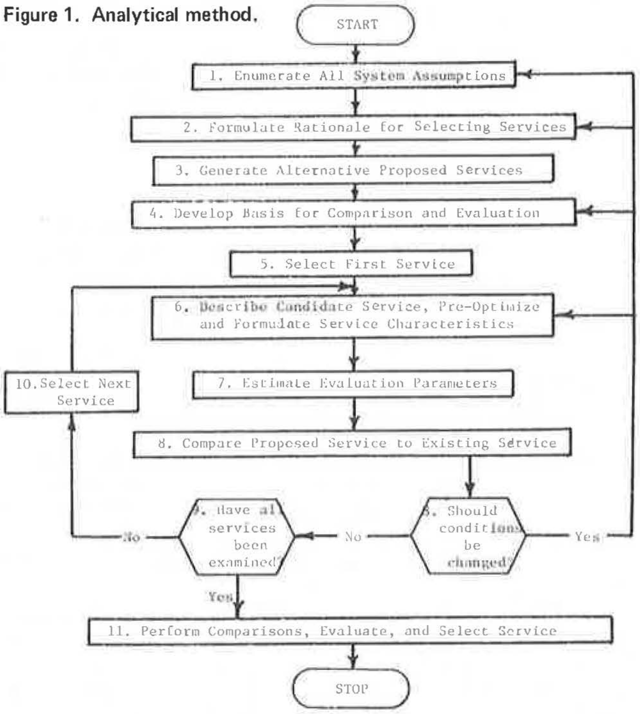
Table 1. Comparative summary of service characteristics.

Characteristic	Service Alternative Automobile	Car Pool	Van Pool	Subscription Bus	Commuter Rail	Commuter Air
Capital cost, $	4100	4100	6500	60 000	1 100 000	2 100 000
Vehicle operating cost,[a] $/km	0.12	0.12	0.18	0.38	1.70	1.24
Maximum operating speed, km/h	88.5	88.5	88.5	88.5	121	322
Practical seating	6	6	15	50	156	60
Mode of access	Residential collection →			Park-and-ride →		
				Kiss-and-ride →		
				Walk or bicycle →		
Distribution subsystem	Same vehicle →			Public transit →		

Notes: 1 km = 0.62 mile.
All costs are expressed in 1975 dollars. Each service alternative is assumed to transport theoretical capacity (100 percent load factor) except for the automobile, which carries 1.5 persons/vehicle (25 percent load factor).

[a] Represents all capitalized costs plus operating costs.

Figure 1. Analytical method.



costs down. Club membership gives each member a stake in the future of the service and a relatively long-term commitment to its success. A club member may also serve as driver at a part-time salary, which further reduces fixed-cost obligations.

Broker

Commuter clubs are not likely to spring up spontaneously in satellite areas around the country. They need to be nurtured, encouraged, stimulated, and guided. These supportive services can best be provided by an employee of the community who is charged with encouraging, forming, and assisting the commuter club, functioning very much like a broker. He or she provides planning support and help with formal club organization, recommendations concerning services and equipment, and financial advice. The broker may also provide analytical support in the form of operating computer matching programs, evaluating services, and advising on insurance and other matters as well as seeking off-hour uses for club vehicles. In general, the broker helps the commuter clubs with their problems and guides and supports them in many other ways.

PROCEDURAL METHODS

The analytical method for formulating and comparing transportation alternatives for commuter service between a new town and a central city is shown in Figure 1. The process is an iterative one, beginning with the enumeration of system conditions and proceeding through the comparison and evaluation of candidate services. Each of the eleven steps in the process is briefly described below.

1. Enumerate systems conditions. The conditions common to all candidate services are described. These include (a) the geographical setting, (b) available guideway facilities, (c) restrictions on routes, (d) available public transit services in the city, (e) admissible interfaces, (f) an interest rate for capital funds, and (g) other factors that constrain all service alternatives.

2. Formulate a rationale for selecting services. A methodology is developed for selecting proposed services. Specific determinants that limit the admissible services include (a) available technologies and equipment, (b) total travel time and total travel cost by the predominant existing mode, (c) available transportation facilities and present travel patterns, (d) the amount of available capital investment, (e) urban-area destinations of satellite-area patrons, (f) distribution capabilities of the proposed service, and (g) ease of implementation.

3. Generate alternative proposed services. A large number of alternative services must be investigated and the more promising possibilities identified. Subject to system conditions and limitations, service alternatives evolve from a screening process that examines the candidate services with respect to (a) guideway, (b) propulsion, (c) equipment (vehicle type), and (d) system control. Guideway is almost always restricted to the facilities that already exist in a serviceable form. Propulsion may consist of any options that are compatible with the guideway. The propulsion system directly influences vehicle type, line-haul travel time, and top speed. The travel-time requirements of the system are determined from the investigation of propulsion and serve to limit acceptable propulsion schemes. Selection of the type of vehicle is thus restricted to candidate vehicles that are compatible with both guideway and propulsion systems. Finally, system control affects travel time and travel cost. The requirements for system control further constrain the service alternatives.

4. Develop a basis for service comparison and evaluation. Evaluation factors are selected for comparing candidate services. A list of possible factors, with suggested units of measure, is given below (1 m = 3.3 ft):

Factor	Unit of Measure
Environmental impact	
Air quality	Grams per passenger kilometer (estimates of vehicle-related levels of hydrocarbons, nitrogen oxides, and carbon monoxide)
Noise	Decibels at 15 m (as result of travel speed, traffic density, and mix of vehicle types)
Energy consumption	Joules per passenger kilometer
Quality of service	
Accessibility	Population or destinations served
Availability	System access time (route geometry)
Comfort	Ride quality, physical comfort, and degree of privacy (vehicle amenities)
Convenience	Number of transfers to destination
Frequency	Departures per unit time
Implementation	Legal and corporate constraints
Safety	Fatality and injury rates per passenger kilometer
Security	Crime rate
Flexibility	Number of potential routes and destinations
Travel time and speed	Door-to-door trip times in minutes
Travel-time variability	Standard deviation of trip time in minutes of delay (service dependability, congestion, system right-of-way)
User cost	Dollars per passenger trip

These factors reflect measures of system use, service quality, transportation costs, and system impacts on nonusers. The analyst is encouraged to tailor these factors to suit local conditions. For example, travel time may be measured as (a) in-vehicle time or (b) door-to-door time if wait time is weighted 2.5 times.

An equitable method for combining such diverse factors as those given in the table above would be impossible to develop. Therefore, for purposes of analysis, candidate systems are ranked in numerical order for each factor. The rankings are then combined in a simple scoring model to give a measure of relative desirability.

5. Select the first candidate service. The first candidate service on the list is selected, and the analysis begins.

6. Describe the candidate service, "preoptimize," and formulate service characteristics. Each service is described in detail from the viewpoints of the travelers and the operator. Service features include (a) the actual route or routes followed, (b) station locations, (c) peak-hour service and service frequency, (d) acceleration rate, (e) deceleration rate, (f) top speed, (g) equipment type, (h) fleet size, (i) load factor, (j) emergency procedures, and (k) maintenance equipment and service and other items. While they are being developed, services are individually preoptimized to ensure that the operation selected is the most suitable for the study conditions. Service alternatives generally have different service characteristics. For example, subscription bus and van pooling would have different station locations, service frequencies and vehicle capacities, and types of operation (such as express, skip-stop, or local running).

7. Estimate evaluation parameters. This step forms the basis for calculating both travel time and user cost plus all remaining evaluation measures. In the computation of service costs, three different options may be pursued: (a) Equipment may be owned by the club; (b) it may be chartered with driver, fuel, maintenance, and insurance provided by others; or (c) it may be leased or rented. Door-to-door travel time is evaluated for each alternative. This factor can be computed by using access time, mode transfer time (including waiting and loading time), distribution time, and walk time. All other evaluation measures are determined for use in the comparative analysis.

8. Compare the proposed service to existing service. Only total travel time and total cost of the candidate service are examined and compared with the predominant existing service—generally automobile commuting. Initially it is hypothesized that each new service can be implemented only if travel time and cost offer favorable improvements over the predominant existing service. This step serves to ensure that that condition is met. If it is not, the proposed service is either deleted from the list of alternatives or revised in a manner that will yield a favorable comparison. Before this step is completed, the following question is asked: Should conditions be changed? A no response transfers control to the next step; a yes response shifts control back to step 1, 2, 4, or 6.

9. Have all services been examined? If one or more services remain to be examined, control shifts to the next step.

10. Select the next service. The process is indexed forward to the next candidate service.

11. Perform comparisons, evaluate, and select a proposed service. The basis for comparing alternatives was established in step 4; now, pairwise comparisons are performed, the results are evaluated, and a service is selected.

SAMPLE COMPARISON

A specific example was developed to demonstrate the analytical method. A satellite area was selected that is 81 km (50 miles) from its companion metropolitan area. The metropolitan area has extensive surface transit service. Five types of commuter service—air, bus, rail, van pooling, and car pooling—were examined and compared with the predominant existing service—the automobile. Table 1 gives the principal characteristics of each service.

Table 2 gives the evaluation summary for the service alternatives. The comparative analysis is based on a comprehensive examination of all system characteristics. The scores indicate only comparative values among the systems studied and do not reflect an overall quantifiable measure of system effectiveness.

Travel cost varied with trip length for each service alternative. Figure 2 compares all six systems for user cost versus trip length. The automobile is without doubt the costliest of all systems but, when fully loaded with passengers, is competitive with other services. Trip lengths more than 100 km (62 miles) from the urban area are least expensive for bus service, and trip distances less than 100 km are most economical for van pool service. The nonlinear relation exhibited by air service results from long takeoff and landing times. For trip lengths well in excess of 162 km (100 miles), bus and air services appear to be competitive with one another.

Figure 3 shows user cost as a function of patronage for an 81-km (50-mile) trip. The steps in the curves reflect the addition of incremental vehicle units as vehicles become fully loaded. The cost of automobile commuting is much higher for all levels of ridership. Although the results presented in Figure 3 apply specifically to an 81-km trip, similar relations exist for other stage lengths. As patronage levels increase, passenger costs are comparable for all systems except the automobile.

Van pools offer travel times comparable to those of buses and, in addition, they offer door-to-door service. However, as passenger collection for van-pooling services approaches 15 persons, convenience is achieved at the expense of longer overall travel time. For very low demand densities (passengers per square kilometer per hour), travel-time differences between systems are negligible.

The automobile and car-pooling and van-pooling sys-

Table 2. Comparative scores of service alternatives.

Evaluation Measure	Automobile	Car Pool	Van Pool	Subscription Bus	Commuter Rail	Commuter Air
Environmental impact						
Air quality	6	4	2	3	1	5
Noise	1	4	2	3	5	6
Energy consumption	6	4	2	1	3	5
Quality of service						
Accessibility	1	1	1	2	3	4
Availability	1	2	3	4	6	5
Comfort	3	5	4	3	2	1
Convenience	1	1	1	2	3	3
Frequency of service	1	2	3	4	6	5
Implementation	1	2	3	4	5	6
Safety	6	4	5	2	1	3
Security	1	1	1	2	3	3
Service flexibility	1	1	1	2	3	4
Travel time and speed	3	4	5	4	2	1
Travel-time variability	3	3	3	3	1	2
User cost	6	4	1	2	3	5
Total	41	42	37	45	47	58

Figure 2. Total travel cost versus trip length for six service alternatives.

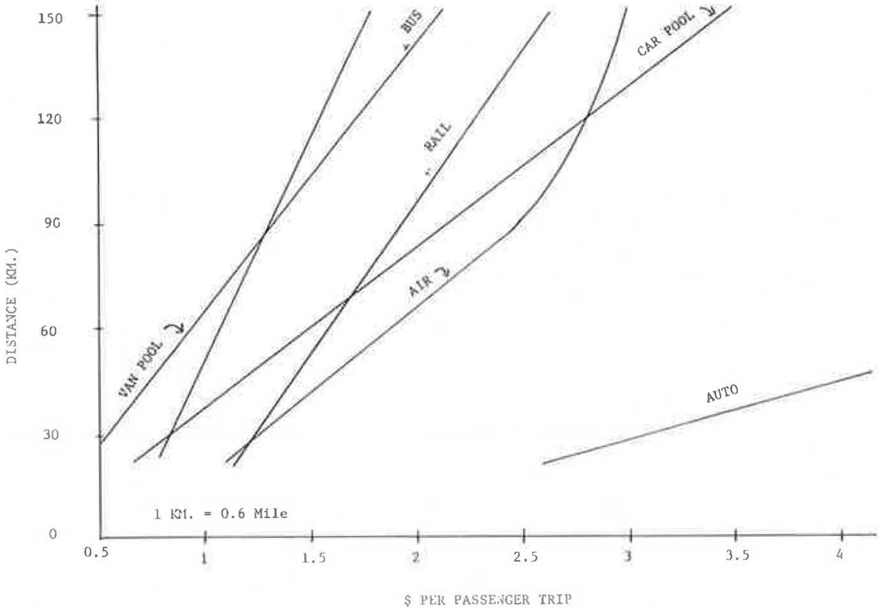
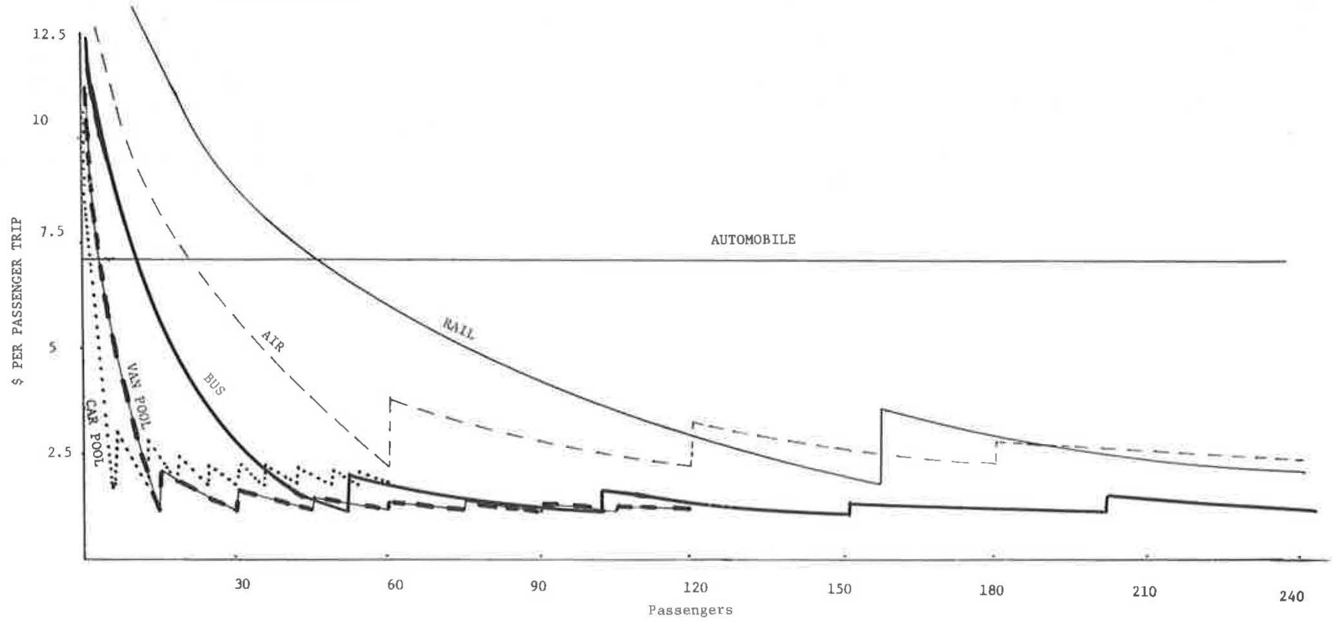


Figure 3. Patronage versus cost of 81-km (50-mile) trip for six service alternatives.



tems provide competitive door-to-door service and are virtually unaffected by rider destination, trip purpose, time period, and trip length, which suggests that subscription, demand-responsive services can effectively compete with automobiles for many commuting trips. Subscription services offer substantially lower travel times and trip costs than conventional transit systems. In terms of travel time alone, trip lengths more than 50 km (30 miles) from the metropolitan area favor air service while shorter trips are faster by rail. Travel speeds by air become constrained as stage lengths decrease. Air and rail services benefit from line-haul speeds and fully controlled right-of-way. For trips longer than 50 km, car pooling, van pooling, and bus services exhibit slightly longer travel times than the automobile. Thus, if public transport services are to be time competitive with automobile travel, they must be given preferential treatment or controlled right-of-way.

Air service is generally inappropriate for medium-length intercity travel and is characterized by relatively high travel costs, low service frequency, and inadequate distribution capabilities. A premium-cost service, air service can be an appropriate alternative under the proper conditions.

CONCLUSIONS

Improved external transportation may well hold the key to the development of satellite areas, but no single transportation alternative is appropriate for all areas. In addition to the example presented here concerning commuting from satellite areas, other site-specific cases (7, 8) have been investigated, and the results of these efforts support the following conclusions:

1. Transportation services for intercity travel to satellite areas develop in much the same way as intracity systems do. Intercity travel can evolve from car-pool or van-pool services. As patronage grows and larger capital-intensive projects become feasible, service can be converted to high-capacity systems such as bus or rail.
2. Difficulties in implementation vary with each service and are of a site-specific nature. Car pools are relatively easy to implement whereas rail and air service may not be achievable. Van pools and buses are typically constrained by regulations. Certificate requirements depend on fare collection and routing.
3. A commuter service can be launched without initial high-volume travel demand. Small units of demand can be accommodated by a successful commuter service.
4. The creation of commuter clubs improves the service that a system can offer by eliminating high organizational and administrative costs. Door-to-door travel time and user cost can be substantially reduced over conventional systems. These benefits are primarily attributed to the demand-responsive, subscription types of services.
5. For stable, low-risk operations, prearranged ride-sharing (subscription) service enables commuters to realize low fares, service longevity, demand-responsive service, and time-competitive travel. Car-pool, van-pool, bus, rail, and air systems offer these benefits. However, for high-risk, nonstable operations, van-pool and car-pool services possess characteristics of low-cost variability.
6. Where a public transportation system exists in the metropolitan area, passenger distribution can be accomplished for each service alternative. Without available public transportation, car pooling, van pooling, and bus service are the only feasible alternatives, particularly for passengers with non-CBD destinations.
7. Subscription services make possible greater use of available seating without sacrifice of service quality or user cost. Ride sharing and risk sharing for intercity travel of this type enable service administrators to capitalize on vehicle efficiencies and to provide low-cost, high-performance service.

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Planning Process for the Design of Integrated Fixed- and Flexible-Route Bus Service in Rochester

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Demand-responsive transportation is an accepted form of transportation in small and medium-size cities. However, as these types of systems are introduced into larger urban areas that already have fixed-route services, the systems and the preceding planning process necessarily become more complex. This paper describes the planning process that was used in the design of an integrated fixed- and flexible-route system in one suburb of Rochester, New York. The system is one component of a federal demonstration project designed to evaluate the feasibility of such systems in major metropolitan areas. A description is given of the planning approach taken and the methodologies and analyses used. The use of a simulation model to determine the extent of the dial-a-bus service area in the suburb and a logit model to predict the expected demand for such service is described. In addition, the methodology developed for the system integration design, i.e., the combination and coordination of existing bus service with flexible-route services, is explained. Provision of opportunities for public involvement during the planning process is also described.

As people, industries, and activities have shifted from the high-density central city to the lower and medium-density suburbs, conventional line-haul public transportation has been unable to serve newly emerging travel demand. Rochester, New York, has experienced this reorientation of metropolitan growth. In 1960, 54 percent of the population of metropolitan Rochester lived within the boundaries of the central city, whereas in 1970 only 36 percent lived in this area. In Rochester, as in other major urban areas, this increased growth in the suburbs has increased the desire for intersuburban transportation. However, the bus network serves only the central-city residents and those in the suburbs who travel directly to the downtown district.

In August 1973, the Rochester-Genesee Regional Transportation Authority (RGRTA) implemented a new type of transit service designed to serve the lower and medium-density suburban areas where little or no service existed. This system, known as PERT (PERsonal Transit) Dial-a-Bus, offered a flexible, demand-responsive, door-to-door service in Greece, a suburb bordering the central city. The main purpose of PERT was to serve intracommunity trips and provide feeder service to regular line-haul transit routes (1).

In April 1975, the PERT system became part of a federal demonstration project sponsored by the Service and Methods Demonstration Program of the Urban Mass Transportation Administration. Specific objectives of the demonstration project were to

1. Increase the level and quality of transit service,
2. Improve transit coverage (through system adjustment),
3. Test the effectiveness of various operating strategies, and
4. Test the use of automated scheduling and dispatching systems.

Three suburban service areas in the Rochester area were chosen as sites for the demonstration.

This paper examines the planning process used for the design and implementation of service in Irondequoit—the second suburb to receive such service—by looking at the techniques used, the alternative system designs evaluated, and the final system design that was implemented. It is not the purpose of this paper to present a detailed description of the techniques used nor to present an in-depth analysis of individual components in the overall system design. Such discussions are presented elsewhere (2). However, one of the most formidable barriers to solving a problem is the process used in its solution. This paper describes only one approach used in planning a demand-responsive transit service, but some of the methods used and system alternatives considered are applicable to future design efforts.

BACKGROUND

Unlike Greece, Irondequoit was served by a larger number of conventional bus routes. Analysis of bus coverage showed that during the peak hours 80 percent of the town's population lived within 0.625 km (0.4 mile) of a bus route. During the off-peak periods, this figure approached 75 percent. An important characteristic of these bus routes, and one that directly affected the final service design, was that they were radial routes serving the north-south travel patterns within Irondequoit and travel to downtown Rochester. The percentages of local trips within Irondequoit for each bus route before the routes were changed as part of the new service design (taken from 1975 ridership counts) are given below:

Route Number	Percentage of Local Trips	
	Midday	Evening
5	10	6
7	11	0
9	2	1.5
10	6	No data
12	0	No service

These data should be contrasted with the following data for Irondequoit taken from a 1974 New York State Department of Transportation travel survey, which found that 52 percent of the trips originating in Irondequoit also had destinations there and thus that the existing transit service was not serving a large portion of the travel demand in Irondequoit (data are for trips by all modes):

Trip	Number	Percentage
Within Irondequoit	105 900	51.9
To Kodak Park	3 850	1.9
To Greece	6 080	3.0
To central business district	14 500	7.1
To the rest of Rochester	47 300	23.1
To the rest of the metropolitan area	26 600	13.0
Total	204 230	100

It was decided that PERT would try to serve this demand better.

Another factor that affected the design of the Irondequoit service was the existence of PERT Dial-a-Bus in Greece. That service had been designed so that a high degree of demand-responsive transportation was provided during the day and subscription services complemented the many-to-many services during the peak hours. When the time came to begin the Irondequoit design process, the Greece system had been in operation for about 2 years. Ridership had reached a somewhat stable level, and daily level-of-service characteristics remained consistent. The use of a computer for customer scheduling was about to begin; when that was successfully implemented, it was to be followed by computer-assisted experimentation with fare and priority variations for different categories of customers. Because of this, it became the objective in Irondequoit to experiment with a more hybrid and possibly less demand-responsive service concept. Even if there had been a desire to emulate the Greece experience, the large number of fixed bus routes in Irondequoit did not permit such a simple solution.

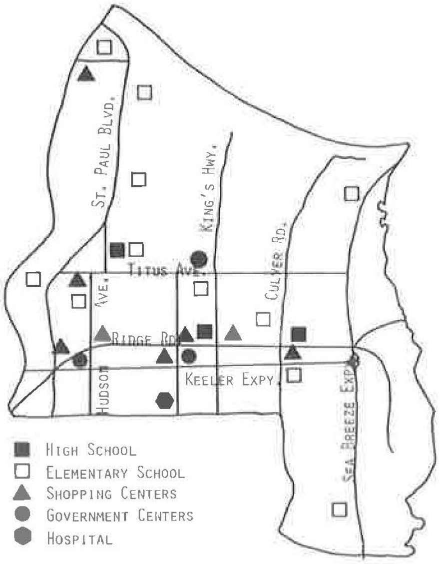
DEMAND ANALYSIS

An integral part of planning the dial-a-bus system for Irondequoit involved being able to predict the service demand that would result from various service designs. Major tasks in this process included identifying the population most affected by the new transport system (demographic data), determining existing travel patterns, identifying major trip generators and attractors, and forecasting travel demand.

Although some demographic changes had occurred since 1970, the 1970 census still provided a good reference for important community statistics. For planning purposes, the base zone system used to aggregate the data was divided into 10 planning areas according to geographical and community considerations. Data such as number of households, total employment, number of automobiles, and population density were collected for each planning area. Information was gathered on the location and trip-making impact of hospitals, schools, apartment complexes, shopping areas, and other major employment centers.

Figure 1 shows the location of some major trip generators and attractors within Irondequoit. A large number of the activity centers are located within two corridors defined by St. Paul Avenue and Ridge Road. Given that the final system design was to service as much of the town as possible and at the same time provide service to major activity centers, these two corridors became the focus of design efforts.

Figure 1. Activity centers in Irondequoit.



Market segments that were identified and analyzed in Irondequoit included the elderly, low-income people, day-care-age children, households with and without automobiles, and current transit users. Analysis of census data for Irondequoit showed a relatively high percentage of elderly—13 percent as compared to a national average of 10 percent. This percentage has increased since the 1970 census as a result of construction of a number of apartment complexes for the elderly in the Irondequoit area. Irondequoit also had more women in the labor force than any other part of metropolitan Rochester—42 percent—which implied a potential transportation need for children of day-care and nursery-school age.

A number of demand models specifically designed for demand-responsive transportation were considered for the analysis of potential demand. Included in this process were a model developed by the Mitre Corporation (3), the market share model developed by Lerman and Wilson (4), and the methodology used in the demand analysis for the PERT system in Greece. None of these models, however, was found to be appropriate as a forecasting tool in the Irondequoit design process. A model was needed that not only predicted the amount of demand but also the spatial distribution of that demand. In addition, the model should be sensitive to service characteristics such as fare, travel time, wait time, and a number of socioeconomic characteristics of the various special markets.

Given these considerations, a disaggregate demand model was designed to estimate travel demand for dial-a-bus service in Irondequoit. The model was of the following form:

$$P(f_o,d_o,m_o) = \exp\left(U_{f_o,m_o,d_o}\right) \Big/ \sum_{\substack{\text{all}\\ f,d,m}} \exp\left(U_{f,d,m}\right) \qquad (1)$$

where

$P(f_o, m_o, d_o)$ = probability of a given frequency of destination and mode choice and
$U_{f,d,m}$ = utility of alternative (f, d, m).

The utility function was assumed to be a linear combination of independent variables that reflects socioeconomic characteristics (household size, income, automobile ownership, and residential location), attractiveness of destination (retail employment), mode-specific variables (automobile bias and availability of transit), and generalized travel cost (money and time).

One problem faced in the model formulation was the value placed on one component of the time variable—out-of-vehicle travel time. Unlike fixed-route bus service, many-to-many service consists of two basic types of demand—requests for immediate pickup and requests for service made some time before desired pickup. In the case of shopping trips, the return portion of the trip will usually be an immediate request whereas the initial request for service will be made ahead of time. Therefore, what should be the value of out-of-vehicle travel time? The value chosen for this variable was 30 min, the time from pickup request to actual pickup as determined from the PERT Dial-a-Bus system in Greece. This figure was subsequently used as the basis for a sensitivity analysis to determine how sensitive the model results were to changes in out-of-vehicle travel time (they were found to be extremely sensitive).

One distinction made for the demand analysis was the separate consideration of shopping trips. This was particularly appropriate because shopping had become one of the major trip purposes served by the PERT system in Greece. According to an on-board survey conducted in Greece, 39 percent of all many-to-many trips were classified as shopping trips. People who currently used the fixed bus routes in Irondequoit were also surveyed in order to estimate the number of passengers who would use a modified service.

The model results were used primarily to verify existing estimates of potential demand, which were based on experiences in the Greece system and in demand-responsive systems elsewhere in the country, and the existing socioeconomic characteristics of Irondequoit. The model was used to provide input for simulation (described later in this paper), but this input also included what common sense said would probably happen. The model results (a predicted 1.1 percent market share) were quite reasonable.

Figure 2. Off-peak bus routes.

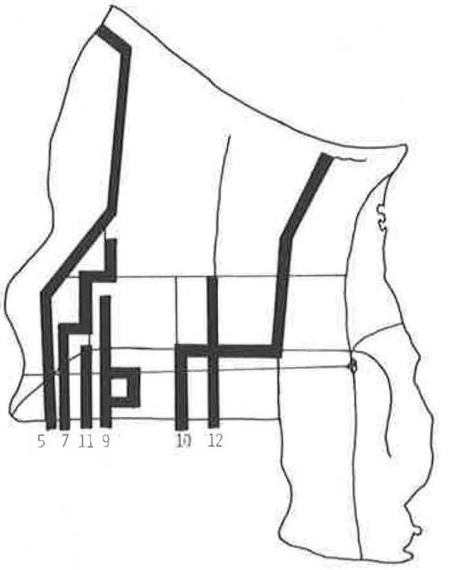
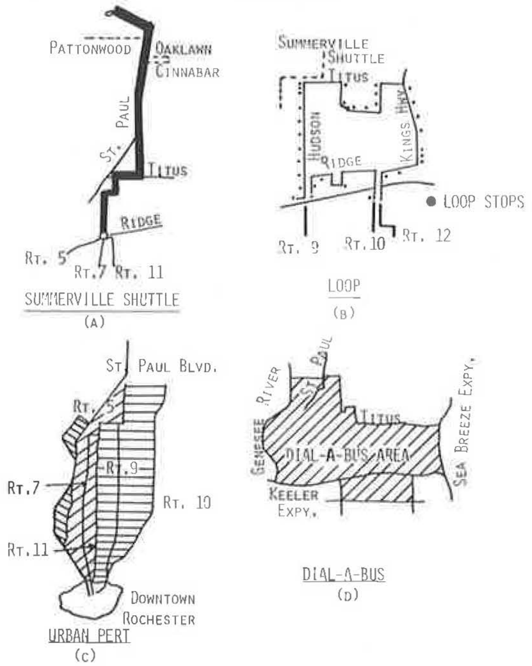


Figure 3. Mix of bus services implemented in Irondequoit.



SUMMERVILLE SHUTTLE (A)

LOOP (B)

URBAN PERT (C)

DIAL-A-BUS (D)

SYSTEM DESIGN

An important aspect of the Rochester demonstration project is the concept of system integration, i.e., the combination and coordination of existing fixed-route with flexible-route service. There are several approaches to the design of an integrated transit system, among them (a) simply superimposing the new flexible-route services on the unchanged fixed routes or (b) performing route rationalization, a procedure in which modifications made to existing fixed routes are then integrated with flexible-route service. The objective of route rationalization is to reduce the cost of transit service in lower density and medium-density areas where fixed-route service is carrying people at a relatively high cost per passenger.

The following considerations motivated the system design process in Irondequoit:

1. A different service plan from that used in Greece should be used so that the two approaches could be compared.
2. Existing fixed routes in Irondequoit should be changed in such a way that people still have a comparable service option at comparable cost.
3. Fixed- and flexible-route service options should be used in addition to many-to-many, flexible-route, dial-a-bus service.

The final design was a hybrid system in which some fixed routes were left, others were modified or eliminated, a new fixed route was added in the Loop to connect principal demand generators and attractors, and dial-a-bus service was introduced in a fairly limited part of central Irondequoit.

The development of a planning methodology for the Irondequoit system integration design (5) was based on a dual approach: an analysis of the adequacy of the existing fixed-route bus system and an evaluation of system economics. Information on the service provided by the fixed-route bus system and corresponding ridership was necessary for deciding which routes should be modified. It also helped in determining an areawide network of transit service that efficiently combined all types of transit, ensured coordinated transfers, and served major origin-destination patterns. Specific tasks in this analysis included the following:

1. Examination of present fixed-route service in potential dial-a-bus service areas,
2. Investigation of the cost characteristics of each route,
3. Separation of unprofitable and profitable-to-marginal routes, and
4. Analysis of actual savings that would accrue by substituting demand-responsive service.

The strategy followed by the demonstration staff was to make no drastic change in a sound peak-period bus network; the dial-a-bus service was thus planned mainly as a feeder service to the fixed-route system. Five bus routes ran during the midday off-peak period (Figure 2). Each of these routes was analyzed by using information such as headways, ridership, and the location at which one bus could be taken off the schedule without adversely affecting the rest of the route. The Irondequoit services that were eventually implemented are shown in Figure 3.

The Summerville Shuttle serves the corridor north of the dial-a-bus service area formerly served by route 5. The advantage of this scheme was that it added one bus (the Summerville Shuttle) and allowed one bus to be eliminated from the route 5 and route 7 schedules, resulting in a net saving of one bus. It also provided a new link between the residential Summerville area (route 5 corridor) and Irondequoit Plaza, a major shopping center. Because the original bus schedule had an exceptionally long layover time, the Summerville Shuttle could also offer some flexible routing and still maintain the original route 5 schedule. On request, the shuttle bus would deviate along specified corridor routes. This concept has been referred to as loop deviation. The Summerville Shuttle meets the route 5 bus at Ridge Road for timed transfers and allows transfers to routes 7 and 11 at the same location. The fare for this service is \$0.40 (\$0.20 for senior citizens), and a loop deviation costs an extra \$0.10.

The Irondequoit Loop runs counterclockwise along Ridge Road, Kings Highway, Titus Avenue, and Hudson Avenue, linking most of Irondequoit's activity centers. Many local trips that were not possible on the radial fixed-route system can now be made. Passengers may board and leave Loop buses at all specially marked stops and may transfer to or from fixed bus routes, shuttle, and dial-a-bus at appropriate stops. Fares for this service are \$0.25/passenger, \$0.20 for senior citizens and the handicapped, and \$0.05 for a transfer to or from a Regional Transit Service (RTS) shuttle route.

One possibility for evening service was the elimination of all service in Irondequoit. This could have been justified by the light ridership in this period and the greater flexibility and doorstop service offered by dial-a-bus. However, after 9:00 p.m. only two buses are used on most routes, the minimum necessary to make the downtown meets. Therefore, cutting routes in Irondequoit would help RTS, the transit operator, only until 9:00 p.m. If such a limited cut were made—from 7:00 to 9:00 p.m., for example—the confusion of the constant changes in service between time periods would not be worth the savings that would result from cutting 2 h of bus service.

Another possibility, and the one that was chosen, was to leave early-evening service substantially intact and to improve late-evening service (after 9:00 p.m.) by providing greater coverage. In this service, named Urban PERT, bus service after 9:00 p.m., not only in Irondequoit but also along the remaining portions of routes 5, 7, 9, and 10 between Irondequoit and downtown Rochester, was taken over by PERT. PERT was to follow the late-night 65-min cycle in order to allow transfers downtown and was to provide some route-deviation service on these routes. This deviation was made possible by the fact that some routes did not need the full cycle time allowed to complete their runs. This deviation service should be particularly appealing during the late-night period when personal safety is a concern of many people. Given the low patronage and the capability of one route-deviation bus to serve fixed-route corridors, another advantage of the PERT takeover of the late-evening service was the possibility of using fewer buses than had previously been used. However, at the beginning of the service, four buses ran these routes, as was the case during the RTS operation.

The fares for Urban PERT are \$0.25 to or from regular RTS stops and \$1.00 to or from special-zone request stops (\$0.25 for each additional passenger making the identical trip); the elderly and the handicapped pay \$0.20 to or from each regular stop and \$0.50 for a special-zone request.

The main issue for the midday routes was the degree to which fixed-route service would be cut back when PERT services began. Eliminating a large portion of this service would tend to increase vehicle productivities on PERT and would save money for RTS. However, given the nonlocal nature of the fixed-route trips, level of service for those using these routes would deteriorate if the routes were cut. This made wholesale cutbacks in fixed-route service unattractive. However, there were cases when fixed routes served very few people (e.g., route 12) or closely paralleled other lines (e.g., routes 5 and 7) and cutbacks became more reasonable.

New fixed-route PERT services that covered the same corridor as current routes but with an improved service pattern were an alternative that fell somewhere between retention and elimination of routes. PERT could provide new fixed-route service linking sections of Irondequoit that had been inaccessible by bus. Another possible PERT service on fixed-route corridors was route deviation, which would allow cutting current routes without eliminating all corridor service.

For any corridor in Irondequoit, the choice was between current fixed-route service (if any), substitution of a PERT fixed-route service, or no corridor service. The major factors in making this choice were current ridership, the resulting cost savings if a route were cut, and the improvements in ridership and connectivity to activity centers and reductions in walking time that would occur with a new PERT corridor service. With these factors in mind, a network of fixed routes and route-deviation services was designed. The interrelations among the various routes were also considered so that routes and schedules would be coordinated as much as possible.

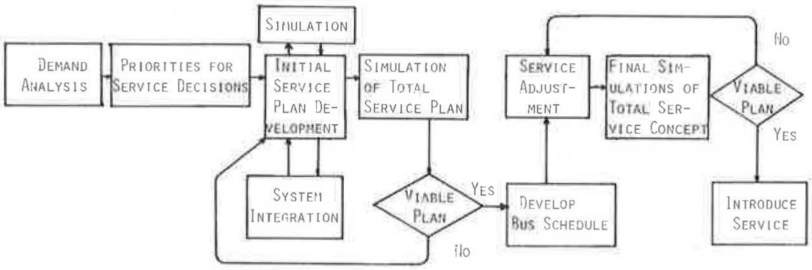
SERVICE-AREA BOUNDARIES

The issue of service-area boundaries was addressed primarily from the standpoint of how much of Irondequoit should be included in the many-to-many dial-a-bus service zone. The extent of dial-a-bus service in Irondequoit became a much debated issue during the months before service implementation. Many groups, and thus many viewpoints, were involved in this debate, but the issue quickly became one of either offering service to the entire town—a position held by some community groups—or designing a reduced service area in which a higher level of service would be provided to a smaller number of people. It was felt, however, that the number of vehicles that could be allocated to the Irondequoit service might be too small to provide adequate service to the entire town. Thus, a simulation model developed at MIT was used to evaluate different service-area configurations with a varying fleet size. The model traced demands for service from their occurrence through assignment and actual pickup and delivery. The critical outputs of the model included level-of-service variables such as average wait and ride times for passengers using the system. The inputs to the model described the vehicle system, the operating environment, and the characteristics of service demand. The simulation model analyzed the impact of different service characteristics (e.g., number of vehicles, demand rate, and service area) on the level of service provided to passengers.

The use of the simulation model in the planning process is shown in Figure 4. Because the model and its use have been described elsewhere (6, 7), a more detailed description will not be given in this paper.

The purpose of this simulation model is primarily to predict system performance for a large number of service-area configurations and vehicle sizes. Unfortunately, the model is expensive to use and is not readily

Figure 4. Role of simulation in the planning process.



available for design work. However, new descriptive supply models are being developed that will predict system level of service and will also be inexpensive and simple to use (8).

The final decision on the boundaries for the many-to-many service reflected a desire by the project staff to follow a cautious strategy in system design. It was much better to start with a small area, an area which could be served reasonably well, and then expand into different sections when the demand built up and the system showed stable performance. The staff did not wish to repeat experiences elsewhere where maximum service on the first day of operation contributed to eventual system failure (9).

CITIZEN INPUT INTO THE PLANNING PROCESS

There were three important participants in the Irondequoit public involvement process: an ad hoc citizens' advisory committee of PERT to specify local transit needs; the demand-responsive demonstration project committee of RGRTA; and the town officials of Irondequoit who wished to see a PERT system that fit in with the town's growth policy and transportation goals.

The citizens' committee was appointed by the Irondequoit Town Board during the summer of 1975 at the request of RGRTA. Its main role was to provide intense local feedback during the planning process and to chair citywide meetings that were to be held before implementation of PERT service.

In its first meeting, the citizens' committee was introduced to the important impacts of PERT, how it functioned, and what the committee's role would be in developing the plan. It was decided in the next meeting that two citywide meetings would be held in September to help Irondequoit residents understand what PERT could mean to their community. An afternoon and an evening session included the following activities: a slide presentation on the PERT Dial-a-Bus experience in Greece, promotion of the special service to downtown Rochester for the handicapped and the elderly (with a vehicle on display), a technical presentation by the project staff, and a question-and-answer period. During the meetings, the people of Irondequoit expressed concern over a reduction in fixed-route service and the impermanence of a demonstration project as well as an interest in a less personal subscription service for a lower fare. After the initial survey of public opinion, the citizens' committee continued to meet regularly with RGRTA and PERT staff and participated in the preparation of the final service plan.

In December, a formal presentation concerning service concepts for Irondequoit was made to the citizens' committee by the technical staff. The reasons for each proposed service design were discussed and, although reservations were expressed about not including the entire town in the service area, the trade-offs involved in an incremental strategy of cautious expansion were clear and the citizens' committee supported the plan.

CONCLUSIONS

The evaluation of the dial-a-bus system implemented in Irondequoit will provide useful information on the role of demand-responsive transportation in a metropolitan transportation network. This paper has addressed another important factor in demand-responsive transportation, i.e., the process used to design such services. Although it is not expected that many such planning efforts will include as many analyses and tasks as did the Irondequoit process, some conclusions have been reached that can be considered generally applicable.

The estimation of demand is a task that can best be accomplished by evaluating prior experience and determining its relevance to the particular situation in question. In Rochester, the existence of PERT Dial-a-Bus in Greece helped in estimating potential demand for dial-a-bus in the neighboring suburb. The formal model developed was used solely to determine the consistency of these estimates.

Much has been written about the value of and the need for public involvement in any planning process. The necessity of such involvement is even more apparent when a demand-responsive system is designed because the service concepts involved are unfamiliar to people used to traditional fixed bus routes. The members of the Irondequoit citizens' committee were very helpful in explaining and promoting the new service, identifying different system options, and participating in system evaluation.

One of the major issues of system design usually debated in the public arena is the size of the service area: Who will get service and who will not? The planner must have available some means of analyzing different service-area configurations, given different vehicle fleet sizes. In Rochester an expensive simulation model was used to provide this analysis, but models are being developed that will be less expensive and easier to use.

In recent years, demand-responsive transportation systems have gained acceptance as a workable means of transportation in medium- and small-size cities. The question that remains unanswered is, What can be the role of such systems in larger metropolitan areas? Just as the systems themselves become more complicated when designed for larger urban areas, so too the planning process necessarily becomes more complex. The eventual success or failure of such systems will thus greatly depend on the ability of the planning process to handle this increased complexity.

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Findings of a Study to Estimate the Effectiveness of Proposed Car-Pool-Incentive Policies

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This paper summarizes the findings of a car-pooling impact study conducted for the Federal Energy Administration. The aim of the study was to estimate the impacts of various proposed car-pool-incentive policies on work travel. A market research methodology was adapted to estimate modal-split impacts under various policy conditions and corresponding estimates of vehicle kilometers of travel and fuel consumption. A trade-off model was used to simulate modal behavior under 14 representative car-pool-incentive policies and nine travel-time sensitivity tests. Paired-comparison responses on work-trip preference collected by a specially designed survey were the primary input to the trade-off model. The study produced two major sets of results: (a) tabulations and cross tabulations of the survey data and (b) estimates of the impact on modal split, vehicle kilometers of travel, and fuel consumption from policy simulations of the trade-off model. Gasoline rationing was found to be the most effective policy for reducing vehicle kilometers of travel and fuel consumption. Substantial surcharges on gasoline sales and parking in the central business district or in facilities of major employers were moderately effective. Purely incentive policies such as tax rebates to car-pool members and car-pool matching programs were not very effective. If practical policies for achieving significant discriminatory travel-time advantages for high-occupancy vehicles could be implemented, they would be moderately effective.

Car pooling has tremendous potential for conserving transportation energy in urban areas. Despite the simplicity of car pooling, Americans have been reluctant to take advantage of its many benefits. Recognizing this problem, the Federal Energy Administration (FEA) sought to determine the incentives and disincentives that will encourage people to alter their basic travel habits.

PURPOSE OF THE STUDY

Significant car pooling already exists in most urban areas but does not approach its full potential. The FEA-sponsored study of car-pooling impacts was specifically designed to select representative policies and assess their potential for reducing vehicle kilometers of travel and energy consumption through their impact on modal choice. The study concentrated on the type of travel that has the greatest car-pooling potential—the work trip in urban areas.

Many policies have been proposed for encouraging the formation of car pools. The following were selected for evaluation in the study:

1. Gasoline rationing,
2. Four types of parking-rate adjustment,
3. Two levels of gasoline surcharge,
4. A toll surcharge,
5. Rebate for car-pool members,
6. Three types of car-pool matching improvement programs,
7. Two programs to improve the availability of midday transportation, and
8. Nine sensitivity tests of travel-time changes.

These policies (with the exception of the sensitivity tests) were applied to specific target groups at levels representative of typical, administratively feasible programs.

METHODOLOGY

Because the decision on whether or not to car pool is highly subjective, a quantitative market research approach was used instead of a traditional modal-split methodology. The study methodology is presented in greater detail in a paper by Rubin, Bruggeman, and Griffiths in this Record.

Market Research Approach

Research techniques used in a marketing context to evaluate products were adopted to predict the modal choice of commuters. Such an approach uses the preferences and attitudes of individuals toward the various attributes of specific products. In this study, the products are the alternative work-trip modes available to respondents. The attributes include the characteristics of both the mode and the specific journey that might influence the modal decision.

A survey was administered that required respondents to choose between alternative levels of the various attributes of the work trip and revealed the weight or the importance of selected attributes in modal decisions. The results of this trade-off task were input to a model that developed a scheme of qualitative preferences, or utilities, for each attribute. The model was applied by defining the levels of each attribute for the specific policy alternative being evaluated and for the mode and the respondent under consideration.

Many attributes with a potential for influencing mode choice were identified. The number of attributes was limited, however, by the ability of the respondent to perform a lengthy trade-off exercise. Therefore, attributes that appeared to be of less importance and those that could not be affected by public policy were eliminated from the study. The attributes selected were mode used, travel cost, parking cost, extra time (i.e., walk and wait time), riding time, the number of people in the vehicle, the ease of finding others to share a ride, the ease of finding transportation during the day for personal business, and the available supply of gasoline. The first, or mode, attribute was used so that specific characteristics of the various modes that were not explicitly included in the other attributes could be included.

Data Base

Data were collected for this study during the summer of 1975 in three major metropolitan areas—Chicago, Pittsburgh, and Sacramento. Interviews were held with 300 selected respondents in each area. Expansion factors were developed for each city so that estimates of impacts could be made at the metropolitan-area level.

A specially designed survey obtained information on the socioeconomic characteristics of the sampled households, the work-trip characteristics of respondents, and the attitudes and opinions of respondents toward various car-pooling issues. Respondents also performed a series of trade-off exercises designed to measure the importance of various modal-choice attributes and to serve as input to the trade-off model.

STUDY FINDINGS

The major findings of the study in relation to the market for car-pooling alternatives and the effectiveness of individual policies are as follows:

1. The effectiveness of policies is tied to the size of the market to which they are applied. Important considerations are the number of persons who pay to park, the proportion of total employment associated with major activity centers and major employers, and the characteristics and the availability of parking facilities.
2. The overall impact of policies that apply to the total population is generally greater than that of policies that apply only to specific groups, but secondary considerations may increase the desirability of the second type of policy.
3. Use of a vehicle (by another member of the household) that is left at home during the day is not substantial.
4. Of the policies tested, gasoline rationing had by far the greatest impact. Energy savings for work travel were less than proportional to the level of rationing, which indicated a greater willingness to reduce nonwork travel.
5. Parking surcharges were highly effective in reducing fuel consumption among the groups to which such policies were applied.
6. Gasoline surcharges achieved a reasonable degree of effectiveness because they applied to all commuters.
7. Travel-time changes that discriminate between the car pool and single-occupant modes have high potential.
8. Purely incentive policies such as rebates, improved matching, reduced parking rates for car pools, and improved midday transportation did not yield substantial energy savings.

SURVEY TABULATIONS

The use of car pooling for work trips can be encouraged by many policies. However, the effectiveness of these policies is influenced by the basic characteristics of the urban work-travel market. Examination of market characteristics is a necessary first step in the detailed assessment of individual policies.

Current Modal Choice

The modal distribution for work travel in each of the three study cities in the summer of 1975 is given in Table 1. The total modal distribution for each region and various group breakdowns are presented.

The proportion of workers driving alone is approximately two-thirds in both Chicago and Pittsburgh; in automobile-oriented Sacramento, it is greater than three-fourths. The proportions for transit use and car pooling are approximately reversed between Chicago and Pittsburgh; Chicago has higher transit use because of the availability of extensive commuter rail and rail rapid transit service.

Examination of the results by the disaggregations presented in the table reveals typical patterns of modal choice. Persons employed in the central areas used transit much more frequently, which reflects the radial nature of most urban transit systems. An interesting aspect is that car-pool participation did not show major variation across most of the socioeconomic classifications examined except for households that do not own an automobile.

These results do not directly reveal any market segments that should be particularly sensitive to car-pooling alternatives, but they do indicate that caution should be used when policies are applied in markets where transit use is high. An overly aggressive car-pooling program could draw participants away from transit and have decidedly undesirable results.

Employer Characteristics

Many car-pooling programs focus on the employment end of the work trip and are more practical for certain specific geographic areas such as the central business district (CBD) of the city and major activity centers throughout the urban area. The number of persons employed in the CBD represented 18 percent of the total in Chicago and 12 and 13 percent in Pittsburgh and Sacramento respectively.

Another important factor in car-pool market potential is the size of the individual employers. It is clear that, in practice, certain policies are only applicable to major employers. The distribution of employees by company size is shown in Figure 1 for the three cities studied. The number of workers at work locations that have 20 or

Table 1. Percentage distribution of work-travel modes by market characteristics.

	Chicago			Pittsburgh			Sacramento		
Characteristic	Drive Alone	Car Pool	Transit	Drive Alone	Car Pool	Transit	Drive Alone	Car Pool	Transit
Work ring									
1	41	13	46	37	8	55	68	18	14
2	72	16	12	60	21	19	79	20	1
3	85	14	1	72	22	6	85	15	0
Income									
<$10 000	48	15	37	65	15	20	67	21	12
$10 000 to $15 000	65	17	18	70	16	14	72	24	4
$15 000 to $20 000	74	15	11	55	35	10	87	10	3
>$20 000	73	11	16	61	21	18	82	16	2
Automobiles owned by household									
0	2	27	71	0	44	56	0	54	46
1	62	16	22	66	13	21	72	20	8
≥2	84	9	7	74	22	4	80	16	4
Sex									
Male	72	15	13	68	21	11	80	75	5
Female	56	12	32	57	18	25	69	23	8
Travel period									
Peak	60	15	25	66	20	14	74	19	7
Off-peak	79	12	9	62	20	18	84	12	4
Car-pooling policy of employer									
Encourage	58	16	26	59	27	14	70	20	10
Not encourage	67	14	19	67	17	16	79	17	4
Distance to work									
<3.2 km	62	24	14	69	18	13	67	24	9
3.2 to 16 km	69	12	19	64	18	18	75	18	7
>16 km	62	16	23	59	28	13	80	16	4
All	66	14	20	64	20	16	76	18	6

Notes: 1 km = 0.62 mile.
All figures are expressed as row percentages and are thus treated as modal splits.

Figure 1. Distribution of employees by size of employing company.

fewer employees is substantial and as a group is hard to reach through most car-pooling programs. Another factor that has considerable impact on the implementation of car-pooling programs is the number of individual employers in the largest categories. Although the number of workers at locations where 200 or more people are employed is only about 35 percent of the total in each area, the number of individual employer markets is quite small.

Many major employers already encourage employees to use car pools as a civic-minded gesture and a way to reduce the demand for costly parking. The percentage of employees in the three cities who work for employers who encourage car pooling is shown in Figure 2. The fact that the actual mode split among employees working for employers who encourage car pooling and those who do not is not very different (Table 1) suggests that simple encouragement by employers is of limited effectiveness as a car-pooling incentive.

Parking Supply

The amount and the type of parking available to employees are among the most important supply characteristics of the urban travel market. Parking characteristics for the three cities are shown in Figures 3 and 4. Parking in company lots dominates in all three cities and accounts for over 75 percent of the total in Sacramento (Figure 3). Parking in commercial lots, which would be a target for a number of car-pooling policies, accounts for a relatively small portion of the total.

The success of car-pooling strategies that affect parking in company lots depends on the identification of benefits to the company and the general feasibility of the proposal at the specific location. The single best measure of these factors is the amount of company parking provided (Figure 4). The primary market for employer-based car-pooling programs is places of employment with a deficiency in existing parking: A direct economic incentive clearly exists for the employer to remedy the condition. Data show that the amount of employment at facilities with deficient parking is relatively small. Thus, the effectiveness of programs aimed at parking in employer lots will not be substantial unless the more drastic policies are implemented.

Parking Cost

The amount of free parking versus the amount of paid parking is another factor that affects certain car-pooling policies (Table 2). A parking cost is clearly easier to implement as a fee added to an existing pay structure than as a completely new collection requirement. In the three cities surveyed, however, approximately 90 percent of all employees do not pay for parking. Only about 2.5 percent in Chicago and Pittsburgh and 0.5 percent in Sacramento paid a daily fee of $1.50 or more to park. This disappointingly small group is the most promising target for the imposition of a meaningful surcharge or a graduated pay structure based on vehicle occupancy (without generating enormous resistance). However, because such workers are employed almost exclusively in the most congested part of the CBD, secondary benefits might be sufficient to warrant such policies even though overall regional impact might be negligible.

Table 2. Weekly parking costs.

	Employee Population					
	Chicago		Pittsburgh		Sacramento	
Cost	Number (000s)	Percent	Number (000s)	Percent	Number (000s)	Percent
None	1861	91.6	490	88.4	225	88.9
$0.01 to $2.49	26	1.3	12	2.1	17	6.6
$2.50 to $7.49	94	4.6	39	7.1	10	4.0
$7.50 to $12.49	20	1.0	12	2.1	1	0.5
$12.50 to $17.49	31	1.5	2	0.4	0	–
≥$17.50	0	–	0	–	0	–
Total	2030	100	555	100	253	100

Note: Mean employee parking costs in the three cities are as follows: Chicago, $0.57; Pittsburgh, $0.64; and Sacramento, $0.33.

Figure 2. Percentage of employees working for employers who encourage car pooling.

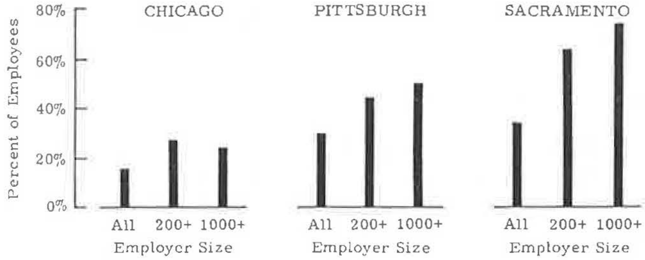


Figure 3. Use of parking facilities.

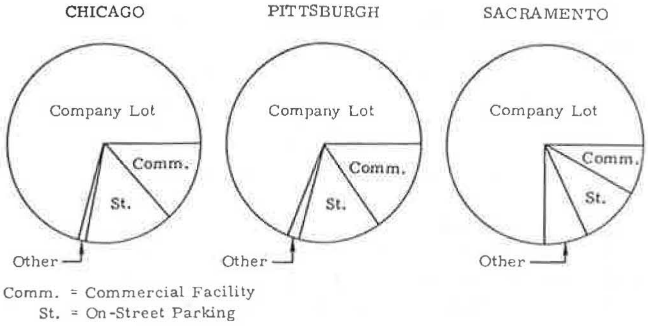
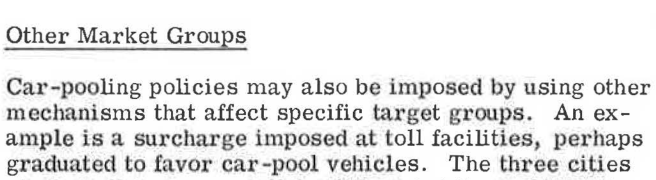


Figure 4. Company-supplied parking.



Other Market Groups

Car-pooling policies may also be imposed by using other mechanisms that affect specific target groups. An example is a surcharge imposed at toll facilities, perhaps graduated to favor car-pool vehicles. The three cities studied all had some toll facilities, but the number of commuters paying tolls amounted to less than 5 percent. In view of this extremely small market, even a massive toll policy would have negligible impact on regional energy-consumption figures.

Another car-pooling policy that has received considerable attention requires the creation of a reserved car-pool lane on an existing freeway. An attempt was made to locate suitable facilities for such an alternative in each of the three cities studied. Two major radial freeways were chosen in Chicago and a radial facility that has been proposed in other studies was chosen in Pittsburgh. No suitable facility could be identified in Sacramento. About 10 percent of Chicago commuters travel in the two selected corridors, and about 7 percent of Pittsburgh commuters use the corridor selected there. Although these levels are not insignificant, the potential of such a policy must be carefully weighed against the difficulties and costs involved in its implementation.

Impediments to Car Pooling

Two major factors have a significant influence on the environment in which car-pooling decisions are made. The first concerns the relative ease of finding someone with whom to share a ride to work. Figure 5 shows that slightly more than 25 percent of the surveyed population in all three cities felt that finding a car-pool match would be easy; this is 40 to 80 percent more than the number of persons who were actually using car pools as their major mode of travel. The percentage of respondents who indicated that finding a match was impossible was much higher. Although many of these persons are merely uninformed about car-pool matching opportunities, the large numbers involved impose a serious limit on the overall car-pool market.

The second major factor is the need for an automobile during the day for personal business (Figure 6). The mode used for 80 to 90 percent of these midday trips is the automobile. Although midday travelers make between 5 and 10 percent of these trips as automobile passengers, many of these trips are probably joint trips to lunch or for some similar purpose rather than a true car-pool activity. Although the availability of midday transportation should not be a major factor for most of the work market, the fact that the overwhelming mode choice of midday travelers is the automobile represents another real limit on the overall car-pool market.

Another factor that is frequently cited as an impediment to car pooling is the additional time required to pick up and drop off passengers. In all three cities, the responses of persons who actually participated in car pools indicated an average pickup time of about 5 min and an average drop-off time of from 1 to 3 min. Although not large in themselves, these values are not insignificant when compared to average reported riding times.

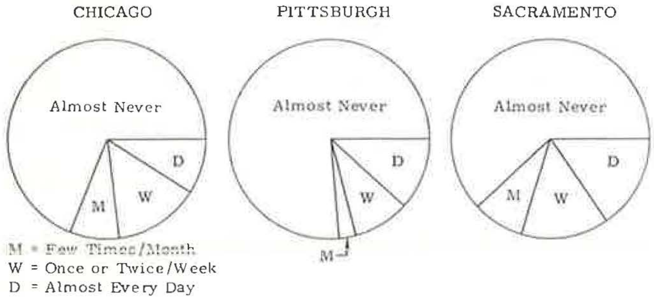
Attitudes That Affect Modal Choice

Each respondent in the survey was asked to rate several attributes of work travel as to their importance in the decision on which mode to select. A total of eleven attributes were assessed; those that were rated highest were reliability, safety from accidents, convenience, and safety from crime. A second set of attitudes that concerned more specific attributes and their importance in the decision to car pool were also assessed. Among these attributes, those chosen as most important were waiting to pick someone up and waiting to be picked up. Also of importance were not having to adjust one's schedule, having to depend on someone else, the ability to drive oneself, and reducing pollution.

These attitudinal responses were not unexpected, but the relative strength of some of the attitudes was not anticipated. Unfortunately, few of the most important attributes of car pools perceived by the respondents can be affected by public policy.

Figure 5. Response of survey population concerning ease of finding a car-pool match.

Figure 6. Response of survey population concerning frequency of midday trips that require transportation.



Car-Pool Characteristics

Reported car-pool occupancies are given in Table 3. By far the greatest number of car pools contain only two occupants. One characteristic of existing car pools that has implications for extrapolating current occupancies to future conditions is the number of family or household car pools. Such pool members have different attitudes and needs than those in a more formal car pool. The number of car poolers who reported members from the same household as members of the car pool represented 9.7 percent, 21.1 percent, and 28.6 percent for Chicago, Pittsburgh, and Sacramento respectively.

Another characteristic of existing car pools that has policy implications is the number of expense sharers in the pool. In all three cities the number of respondents who reported no sharing of expenses is about 50 percent. This may explain some inconsistencies in car-pool forecasting because a cost may not be shared evenly among members, as assumed, but be borne by the primary driver.

POLICY SIMULATION

The trade-off model simulation estimates include the modal-split estimates for each selected incentive policy and the travel-time sensitivity tests as well as related estimates of travel impacts (1).

Overall Modal Impacts

Table 4 gives a brief description of all of the base case and policy simulation runs made with the trade-off model. Table 5 gives a summary of the modal-split estimates for each of the simulated base cases, policies, and travel-time sensitivity tests. Two observations on the modal-split results are particularly relevant:

1. Some policies increase the car-pool share but at the expense of transit ridership. This is especially true of pure car-pool incentives such as the car-pool rebate and policies that call for graduated parking rates.
2. The results for the car-pool-matching and midday-transportation policies in Table 5 correspond to policies that were simulated by using alternate utilities (qualitative preferences) derived from special paired-comparison questions. These results and other indications suggest that the use of paired-comparison questions under alternate assumptions may not be a fully reliable approach for dealing with attributes such as the ease of

Table 3. Car-pool occupancy.

Occupancy	Car Poolers					
	Chicago		Pittsburgh		Sacramento	
	Number (000s)	Percent	Number (000s)	Percent	Number (000s)	Percent
Number						
2	353	60.1	92	52.6	42	65.1
3	164	27.9	37	21.4	16	24.7
4	45	7.6	30	17.3	4	6.0
5	26	4.4	13	7.6	1	1.1
6	0	0.0	2	1.1	2	3.0
Total	588	100	175	100	65	100
Number from same household						
0	531	90.3	138	78.9	46	71.4
1	41	6.9	37	21.1	17	25.5
≥2	16	2.8	0	0.0	2	3.1
Total	588	100	175	100	65	100

Note: Mean car-pool occupancies for the three cities are as follows: Chicago, 2.6; Pittsburgh, 2.8; and Sacramento, 2.5.

finding a car-pool match and the availability of midday transportation.

Impacts on Vehicle Kilometers of Travel and Fuel Consumption

Estimates of vehicle kilometers of travel and fuel consumption under the various policies were made by using the modal-split estimates and the reported work-trip lengths for each survey respondent. Corrections for variations in average speed and type of road were also incorporated into these calculations (2).

Only slight differences appear between the percentage impact of a policy on vehicle kilometers of travel and on fuel consumption; thus, the percentage change in work-trip vehicle kilometers of travel is used as the basis of the following evaluations (Figure 7).

As anticipated, the policy for 25 percent gasoline rationing has by far the greatest impact. The first three parking-tax policies are more modestly successful, pro-

Table 4. Description of policies tested.

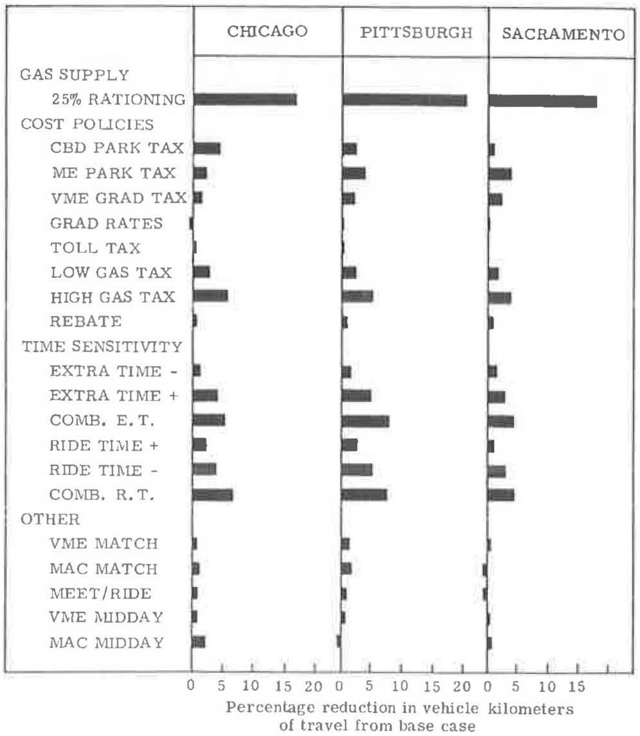
Policy	Description
Base case	All respondents
Gasoline rationing	25 percent reduction in supply
Cost	
CBD parking tax	$2/vehicle/d surcharge
Major employer parking tax	$2/vehicle/d surcharge
Major employer graduated tax	$2.50, $1.50, $0.75, $0.40, and $0.0 for vehicles with one, two, three, four, and five or more occupants respectively
Graduated parking rates	Full, half, or free parking rates for vehicles with one, two, or three or more occupants respectively
Toll	Doubling of existing tolls
Low gasoline tax	$0.05/L
High gasoline tax	$0.10/L
Rebate	$260/year for car-pool members
Time sensitivity	
Decrease extra time	10 min for car-pool members
Increase extra time	10 min for single occupancy
Combination extra time	Both of the above
Decrease urban extra time	For central-city workers
Increase urban extra time	For central-city workers
Combination urban extra time	Both decrease and increase
Decrease riding time	20 percent for car pools and transit
Increase riding time	20 percent for single occupancy
Combination riding time	Both of the above
Other	
Base case match	"Easy matching" respondents
Major employer match	Major employer matching program
Major activity center match	Major activity center matching program
Meet and ride	Meet-and-ride lots in suburban areas
Midday transportation base case	"Easy midday transportation" respondents
Major employer midday transportation	Major employer midday transportation program
Major activity center midday transportation	Major activity center midday transportation program

Note: 1 L = 0.26 gal.

Table 5. Modal split by policy.

	Chicago			Pittsburgh			Sacramento		
Policy	Drive Alone	Car Pool	Transit	Drive Alone	Car Pool	Transit	Drive Alone	Car Pool	Transit
Base case	62.83	16.93	20.24	63.23	19.99	16.77	75.26	17.85	6.87
CBD parking tax	61.27	17.04	21.70	61.85	20.43	17.72	74.34	18.21	7.44
Major employer parking tax	60.11	18.67	21.22	60.39	22.10	17.51	70.69	21.34	7.97
Major employer graduated tax	61.35	18.02	20.62	61.28	21.40	17.32	71.59	20.52	7.88
Graduated parking rates	62.72	17.30	19.98	63.09	20.29	16.63	75.23	17.93	6.84
Toll	62.74	16.93	20.33	63.20	20.01	16.80	75.26	17.87	6.87
Low gasoline tax	61.49	17.52	20.99	62.10	20.70	17.19	73.86	18.99	7.15
High gasoline tax	60.17	18.05	21.78	60.95	21.46	17.58	72.47	20.05	7.48
Rebate	62.24	17.82	19.94	62.77	20.56	16.66	74.49	18.73	6.78
Decrease extra time	60.42	20.07	19.50	61.35	22.22	16.43	73.26	20.07	6.67
Increase extra time	59.17	19.66	21.17	58.36	23.73	17.92	71.13	21.39	7.47
Combination extra time	56.43	23.28	20.30	56.20	26.32	17.48	68.91	23.89	7.20
Decrease urban extra time	60.95	19.50	19.55	62.68	20.68	16.63	73.64	19.67	6.68
Increase urban extra time	59.94	19.02	21.03	61.46	21.14	17.40	72.13	20.55	7.32
Combination urban extra time	57.81	21.97	20.21	60.80	21.97	17.23	70.36	22.56	7.07
Decrease riding time	60.44	18.83	20.73	60.76	20.72	17.52	73.23	19.53	7.23
Increase riding time	59.35	19.59	21.05	59.08	23.35	17.57	71.30	21.26	7.43
Combination riding time	56.88	21.84	21.49	56.43	25.18	18.38	69.17	22.99	7.84
Gasoline rationing	45.78	26.26	27.96	46.37	26.20	27.43	56.16	30.18	13.65
Base case match	65.28	20.88	13.84	65.28	20.32	14.40	73.59	20.12	6.28
Major employer match	65.14	20.86	14.00	65.08	20.81	14.11	73.39	20.08	6.53
Major activity center match	65.23	21.39	13.37	65.21	20.65	14.14	73.57	19.63	6.79
Meet and ride	65.33	20.61	14.05	65.76	19.89	14.36	73.93	19.75	6.32
Midday transportation base case	63.58	16.07	20.35	71.74	17.56	10.70	74.35	17.23	8.41
Major employer midday transportation	62.80	16.27	20.93	71.66	17.74	10.60	74.52	17.01	8.47
Major activity center midday transportation	62.22	16.82	20.96	71.91	17.37	10.73	74.37	17.16	8.47

Figure 7. Summary of the impact of policies on vehicle kilometers of travel.



ME = Major Employer - Over 200
VME = Major Employer - Over 1000
MAC = Major Activity Center

ducing reductions in vehicle kilometers of travel in the range of 2 to 5 percent. The markets for these policies are relatively small, however, ranging from 8 to 21 percent of the total work trips. The CBD parking tax is most potent in Chicago, largely because the market there is nearly twice as large as in the other two cities. Similarly, the very large employer parking tax is least effective in Chicago, which has the smallest relative market of the three cities.

The policy that calls for graduated parking rates, which reduces existing parking rates for car pools, and the toll surcharge policy, which applies only to existing tolls, are both relatively ineffective largely because of the small market size for these policies. The gasoline-tax policies were more effective than many of those involving parking surcharges; as expected, the higher tax, at $0.10/L ($0.40/gal), was nearly twice as effective as the lower rate at $0.05/L ($0.20/gal). The gasoline-tax policies, like rationing, were effective in part because they affected the entire work-travel market.

Because practical policies to test the impact of time changes on modal choice could not be identified, a series of sensitivity tests was run for the entire commuting population. The decrease in time for car-pool modes was not nearly as effective as a similar increase in time for single-occupant automobiles, which again illustrates the problems faced by an incentive policy. The implementation of time changes as actual policies is difficult and would most likely be confined to certain facilities. The market affected by bus and car-pool lanes on major radial freeways may be only 10 percent; thus, the impacts of such facilities would have to be cut by a factor of approximately 10 to simulate a typical policy of this type.

As already mentioned, policies that involve matching opportunities and availability of midday transportation were simulated by using an experimental technique that may have caused some problems for the respondents. The results for these policies may not be valid. In any event, they show very small impacts.

CONCLUSIONS

The results of the study revealed few surprises with respect to policy impacts. The most effective policies were those that had strong, potentially unpopular disincentives and restrictions on single-occupant automobile use. Purely incentive policies had much less impact.

Gasoline Rationing

Of all the policies tested, gasoline rationing (simulated at a level of 25 percent reduction in supply) is the most effective in reducing vehicle kilometers of travel. This is not surprising; a reduction in gasoline supply must result in reduced fuel consumption. The results indicate that work-trip vehicle kilometers of travel would be reduced by approximately 17 to 20 percent in the short run. The impact on nonwork trips would therefore be correspondingly greater than 25 percent.

Gasoline Surcharges

Although they were not nearly as effective as rationing, surcharges achieved significant reductions of approximately 3 to 5 percent. Two such policies were tested: a low surcharge of $0.05/L ($0.20/gal) and a high surcharge of $0.10/L ($0.40/gal). These levels represent rather substantial gasoline price increases. However, they are not much greater than the natural gasoline price increases that motorists have recently been obliged to accept. Such surcharges are likely to be much more palatable to the public than gasoline rationing although equity and ability to pay must be considered. Because the taxation machinery is already in operation, such surcharges are also far less administratively burdensome than rationing would be.

Parking Surcharges

Parking surcharges for facilities of employers of 200 or more people and for CBD parking are also moderately effective. The general rule suggested by the limited results of the study is that the parking surcharge oriented to the major employer will probably have a greater overall impact than a CBD-oriented parking surcharge in all but the biggest metropolitan areas (such as Chicago) because of market size. The important point to be made here is that these policies are defined as affecting all parkers including those who currently pay nothing to park (90 percent of all parkers included in the survey). The imposition of parking charges on those who currently pay none and the imposition of surcharge responsibilities on all employers of 200 or more people are likely to create almost as much opposition as gasoline rationing, if not more.

Travel-Time Changes

The simulation results of the sensitivity tests suggest that a policy that could achieve strong mode-discriminatory travel-time changes for a large fraction of commuters could also prove to be effective. A 20 percent time decrease for car poolers and a 20 percent time increase for solo drivers, applicable to a majority of commuters, would be quite effective. However, the political and administrative feasibility of achieving such substantial and widespread discriminatory time changes by means of a specific policy is questionable.

Less Effective Policies

Toll surcharges, car-pool rebates, and programs to improve opportunities for midday transportation can all be categorized as poor performers. These policies falter because of the small group of commuters affected, their minor behavioral impact, or a combination of both factors. Such policies may still have potential in particular situations, but their effectiveness for most metropolitan areas is questionable.

Car-Pool Matching Programs

The study results with respect to policies to improve car-pool matching opportunities were not conclusive. The results of the trade-off model suggested very modest impacts on vehicle kilometers of travel for the two car-pool matching programs tested. However, for reasons that were previously cited, these results were not treated as completely reliable. Tabulation of attitude and perception responses suggested that the ease of finding someone with whom to share a ride to work was a moderately important factor in the decision on whether to car pool. Although car-pool matching programs are designed to address this problem, it is not clear that a conventional matching program can substantially improve the ease of finding an acceptable match. However, matching programs are incentive rather than disincentive in nature and do not generate much opposition.

General Market Considerations

The potential of any car-pooling policy is limited by the following general considerations:

1. Any policy based on surcharges or adjustments to existing parking rates will affect only about 10 percent of all commuters.
2. Nearly 75 percent of commuter parking is in employer-operated facilities. Only 9 to 17 percent of employees indicated that such parking, if supplied, was deficient. Thus, most employers lack a direct incentive to create some type of preferential parking policy.
3. In most cities, the percentage of commuters who pay tolls is very small. Toll surcharges will be ineffective except perhaps in cases where no alternative routes exist.
4. The perception of more than a third of commuters is that finding someone with whom to share a ride is impossible. This significantly limits the effectiveness of car-pool matching programs.
5. Commuters considered car pooling to be deficient for several reasons, including travel dependence, having to find a ride sharer, and the inability to make side trips on the way to and from work. Only the second deficiency can be significantly affected by public policy.

ACKNOWLEDGMENTS

The research for this paper was performed under contract for the Federal Energy Administration. We would like to thank the FEA project manager, Anne Marie Zerega, for her assistance and guidance in completing this project. We would also like to thank the following persons and their agencies for the data which they so graciously provided: Wade G. Fox of the Southwestern Pennsylvania Regional Planning Commission, Chalabi and Bell of the Chicago Area Transportation Study, and Don MacVicar of the California Department of Transportation.

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Transportation Efficiency and the Feasibility of Dynamic Ride Sharing

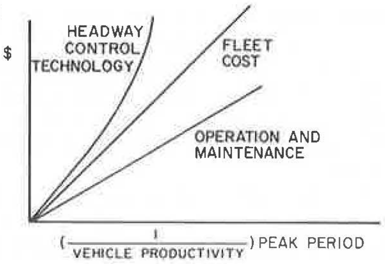
Alain L. Kornhauser, Paul Mottola, and Brian Stephenson, Princeton University

This paper defines the theoretical limits imposed on ride sharing by the spatial and temporal structure of urban travel demand. Differences in market potential between prearranged ride sharing as it is used in car pooling and dynamic ride sharing as it is used in, for example, shared taxi are given. The paper presents the results of the simulation of a hypothetical shared-ride transit system that used various operational policies of dynamic ride sharing and identifies the improvements in transportation efficiency and the economic and technological savings that result from ride sharing. Data on the dynamic ride-sharing taxi system operating at Union Station in Washington, D.C., establish the feasibility of implementing dynamic ride sharing.

As a result of the gasoline crisis of 1973 and the scarcity of federal funds for the construction of new urban transportation facilities, improved efficiency has become a primary focus of urban transportation policy. A recent transportation systems management directive issued jointly by the Urban Mass Transportation Administration and the Federal Highway Administration is aimed toward the efficient use of existing transportation facilities. The most obvious target for efficiency improvement is private transportation—the automobile and the taxi. Van-pooling and car-pooling programs are aimed at trying to increase the people-carrying capacity of street systems during peak demand hours without construction of additional physical facilities. Shared-taxi and jitney enabling legislation is also aimed at the people-carrying productivity and the economic efficiency of the taxicab and its driver.

Even analysts of futuristic automated transit systems

Figure 1. Peak-period vehicle productivity versus cost.



such as personal rapid transit (PRT) have begun to investigate the ramifications of measures that increase vehicle productivity and transportation efficiency. Fleet size, technological requirements of headway control systems, and per-passenger operating and maintenance costs are each inversely proportional to peak-period vehicle occupancy, as shown in Figure 1. Vast economic benefits could be gained by these new systems if they could effect higher peak-period vehicle productivity. The simplest and most effective way of increasing vehicle productivity is ride sharing.

What evidence is there that vehicle productivity can be improved through ride sharing? Some ride sharing does exist in urban areas; it occurs almost exclusively on conventional fixed-route transit systems during peak hours, in automobiles for trips involving families, and among car and van poolers. On a metropolitanwide basis, relatively little ride sharing occurs except for trips involving families. Average automobile occupancy during peak hours is less than 1.5 persons. In most urban areas, the transit share of the peak-hour mode split is less than 25 percent. Even if these transit riders were accommodated by existing automobile trips, automobile occupancy would increase by less than 0.5 persons/automobile. [Several vehicle-productivity measures can be used; each is important for different reasons. For alleviating congestion at a bottleneck (e.g., a freeway or a parking lot), only vehicle occupancy at the bottleneck is important. For energy and pollution, the measures that should be used are (a) the ratio of hypothetical energy consumption (for a vehicle occupancy of 1.0) to actual energy consumption, which penalizes long-distance, single-occupancy trips; (b) the circuity of ride sharing; and (c) the tendency toward larger automobiles for car poolers.]

Although car-pool and van-pool incentive programs have been successful in isolated applications, the impact of these programs on urban-area peak-hour vehicle occupancy has been negligible. Dial-a-ride experiments have experienced a peak-hour vehicle productivity of less than 20 trips/h. Jitneys operate legally only in Atlantic City, New Jersey. Washington, D.C., is the only major urban area in the United States in which shared-ride taxi regulations have been enacted.

To what extent does the fundamental structure of urban travel demand in terms of origin, destination, and time of travel allow for ride sharing? What sacrifices in travel time or changes in operational structure are required to increase the potential for ride sharing? How well do automobile-size vehicles serve extremely high surges in demand?

The simulation results presented in this paper define the ride-sharing potential for one urban area but may be representative of many other urban areas. The study differentiates between the operational aspects of prearranged ride sharing, such as car pooling, and dynamic ride sharing where the matching of demand and supply is accomplished on a demand-responsive, dynamic basis. A discussion of the benefits of dynamic ride sharing is presented here for a simulated automated guideway transit (AGT) system. The feasibility of its implementation from the point of view of passenger acceptance under peak and off-peak demand conditions was investigated by studying the dynamic shared-ride taxi operation at Union Station in Washington, D.C.

POTENTIAL OF RIDE SHARING

Urban travel is many individual trip makers wishing to travel from specific origins to specific destinations at precise times. The degree of specificity of the geographic location of origin and destination and the departure time are very sensitive to an analysis that attempts to find the degree of commonality in trip making. Insisting on too much specificity can lead to zero commonality, and too little can lead to a condition that is unacceptable to trip makers. In this study, the smallest element of geographic specificity is defined by the 0.4-km (0.25-mile) walking radius or approximately 0.5 km^2 (0.2 mile^2), and the departure-time indifference is taken to be on the order of 10 min.

Ride-sharing potential can then be defined as the degree to which there is commonality in trip making. In addition to geographic and time-related commonality, the operational characteristics of the transportation system can either expand or limit the degree of trip commonality. These operational characteristics, which are defined by the number of specific origins and destinations that can be served by a vehicle at any one time, are as follows:

1. One-to-one (O-O)—single origin to single destination (SO-SD), e.g., car pooling, personal rapid transit (PRT), and shared taxi;
2. One-to-many (O-M) or many-to-one (M-O)—single origin to multiple destination (SO-MS or MO-SD), e.g., car pooling, van pooling, PRT, shared taxi, subscription bus, and dial-a-ride; and
3. Many-to-many (M-M)—e.g., jitney, fixed-route transit, PRT, shared taxi, subscription bus, route-deviation bus, and dial-a-ride.

The commonality of trips for the SO-SD mode is constrained by the size of the walking neighborhood and by time. Commonality for the O-M and M-M forms of ride sharing should be further constrained by a circuity measure of order of tens (rather than one or hundreds) of percents for the longest trip being served. Therefore, the potential for ride sharing on an SO-SD system, for example, is simply

$$\text{AVO}_{ijk} = \sum_{n=1}^{\infty} n \cdot P_{n_{ijk}} \tag{1}$$

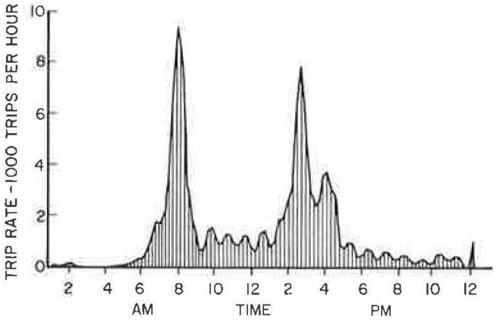
where

AVO = average vehicle occupancy,
i = origin neighborhood,
j = destination neighborhood,
k = time interval, and
P_n = probability that exactly n people request service from i to j within a specified k.

Implicit to the equation is that $\sum_{n=1}^{\infty} P_{n_{ijk}} = 1$.

Relations similar to Equation 1 are appropriate for the other operational conditions of O-M and M-M but include the additional constraints that the feasible sequence of multiple pickup or discharge points lies along a fixed route or results in a travel circuity that does not violate

Figure 2. Total travel-demand rate for Trenton (automobile plus transit) as function of time of day.



some upper bound. From Equation 1 it is obvious that AVO may be increased independently by increasing the specified time interval, the neighborhood area at trip ends, the number of access points, or the circuity limit.

One difficulty with the equation is that its full potential is constrained by the operational limitations of prearranged car pooling and van pooling because (a) prearrangement requires that there be little or no variance in origin, destination, or time of travel from day to day and (b) riders usually share the same vehicle for a round trip rather than a one-way trip. The match of departure times at both ends of the trip effectively restricts car pooling to persons who have proximate destination points. The problem of day-to-day variance in O-D location and departure time has been expressed qualitatively for car pooling. Further study is required to determine the extent to which the round-trip matching requirement restricts the potential for prearranged car pooling.

A much greater ride-sharing potential exists for one-way trips. Dynamic ride sharing removes constraints such as passengers having to share the same vehicle every day; it is simply a grouping of persons with common travel-demand characteristics in terms of origin, destination, and time of travel on a trip-by-trip basis.

Quantitative estimates of the probabilities (P_n) for dynamic ride sharing are difficult to make because the demand data on which to base the estimates must be precise as to O-D locations and times of travel. Moreover, the surveys that would be most useful for this purpose are those that capture all trips at least for some origin. Only then can P_n be estimated for the sampled origin areas and expanded to the entire urban area. No such survey seems to have been made. At some cost in accuracy, spatially and temporally precise total urban travel-demand data can be reconstructed from random samples that contain a large percentage of total trips. This was done in the case of the data base constructed for Trenton, New Jersey, by Princeton University (1). The reconstruction was accomplished by developing temporal and spatial distribution models to expand the survey data (2). The operation of a hypothetical AGT network in Trenton was simulated. The resulting estimates of the potential for dynamic ride sharing are presented below.

QUANTITATIVE ESTIMATES OF DYNAMIC RIDE-SHARING POTENTIAL

In an attempt to estimate the productivity potential of alternative dynamic ride-sharing strategies, a simulation model and a demand data base were developed. The simulation model has the potential of modeling SO-SO, SO-MD, and MD-SO routing strategies (3). The simulation was implemented on a hypothetical automated guideway transit network designed for Trenton, New Jersey. Although the motivation of this simulation was to assess the productivity potential of such systems, its results are transferable to any system that could operate in a dynamic ride-sharing manner in either an SO-SD, SO-MD, or MO-SD operational mode, e.g., a system of taxicabs running between taxicab stands over the routes established for the AGT system.

The travel-demand data that are the "forcing function" to the simulation were developed from a home interview travel-demand survey of 14.7 percent of the residents of Trenton, New Jersey (4). The origins in this data base were coded to specific census blocks and then aggregated to traffic-assignment zones ~ 0.25 km^2 (~ 0.1 mile^2) in area. Recorded departure times were coded to the minute but aggregated to 15-min time increments centered about the quarter hour. Survey data were available for a complete 24-h day with an aggregate trip rate per 15-min interval, as shown in Figure 2.

The travel data were expanded to represent a record of every trip made during a 24-h period by assuming that

1. For each origin the attractiveness of destinations was constant over each of four time blocks—a.m. peak, midday, p.m. peak, and night (sufficient statistics were thus available from the survey data to establish the relative attractiveness of each destination zone for each origin zone); and
2. Continuity in the trip rate existed between 15-min time blocks.

Each trip was reconstructed by using a random selection process from cumulative density functions. Destination was selected from the relative attractiveness functions and departure time from the trip-rate density function; totals were controlled for each origin over each of the four daily time intervals.

In the actual simulation assigning demand to vehicles to determine ride-sharing potential, the demand records were ordered in ascending order of time of departure and a mode-split analysis that eliminated all nontransit trips and assigned transit trips to origin station and destination station on the transit system was performed on the data. Some liberty was exercised in assigning times of travel to the origin data; these times were therefore assumed to be desired departure times at the departure transit station. The simulation dealt with the demand records in sequence. The following procedures were applied for each trip demand:

1. All departure demands were dispatched as soon as the maximum wait time for departure had been exceeded. The occupancy of each dispatched vehicle was recorded.
2. A search for a commonality of demand was made for each vehicle awaiting departure. If commonality was found, the demand was added to the common vehicle. If not, the demand was assigned to an empty vehicle and dispatch was programmed for maximum wait time in the future.

The process was continued for each demand record. For multiple origin or destination service, commonality was defined as applying to stations along the minimum path between assigned vehicles, and a search was made of the minimum-path tree beyond the most distant destination (in the case of multiple destinations) or before the origin (in the case of multiple origins).

Quantitative estimates of ride-sharing potential depend on the topology of the network and the nature of the demand input. Precise details of the spatial and temporal distribution of transit demand as well as the network configuration (station and guideway locations) affect the estimates. The numerical results reported here are for an areawide network serving the 20-km^2 (7.8-mile^2) area of Trenton, New Jersey. The city has a population of 100 000 and is considered to be typical of a large number of older, medium-size industrial cities in the Northeast and the Midwest. The simulated transit network (Figure 3) consisted of 46 stations interconnected by 34 km (21 miles) of one-way guideway. The results of the simulation of dynamic ride-sharing potential are shown in Figures 4 through 10.

Figure 4 shows vehicle productivity in terms of daily average vehicle occupancy over a 14-h operating period (from 6:00 a.m. to 8:00 p.m.) as a function of level of service in terms of maximum wait time for the first occupant. Curves are presented for each of three shared-ride service policies: single origin to single destination (SO-SD), single origin to multiple destination (SO-MD), and multiple origin to single destination (MO-SD). Note that, for the multiple origin or destination service policies, average vehicle occupancy is actually the ratio of passenger kilometers to vehicle kilometers for each trip. The figure shows that, for a maximum wait of 2 min, a 60 percent improvement in daily AVO is possible for SO-SD service and a wait of 5 min improved daily AVO by 120 percent over purely non-shared-ride operation. The addition of more elaborate multiple-stop policies can improve vehicle productivity by 85 to 190 percent depending on the acceptable level of service. These results indicate that significant economies in variable expenses (accompanied by small reductions in level of ser-

Figure 3. Simulated automated guideway transit network.

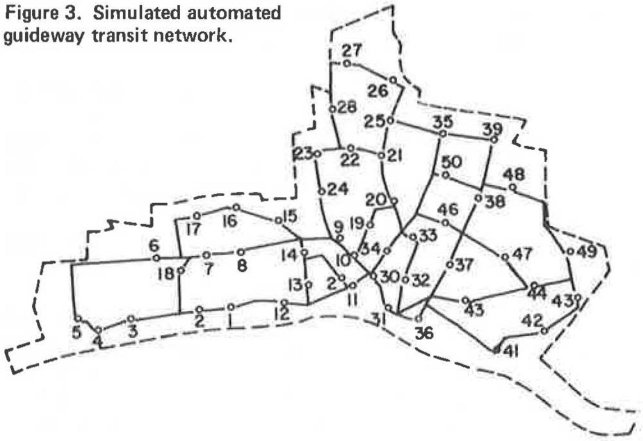


Figure 4. Vehicle occupancy versus wait time.

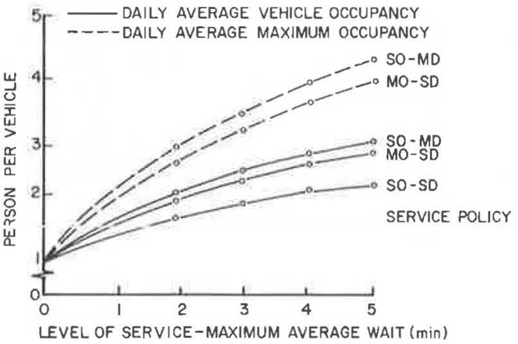


Figure 5. Cumulative distribution of maximum occupancy per vehicle.

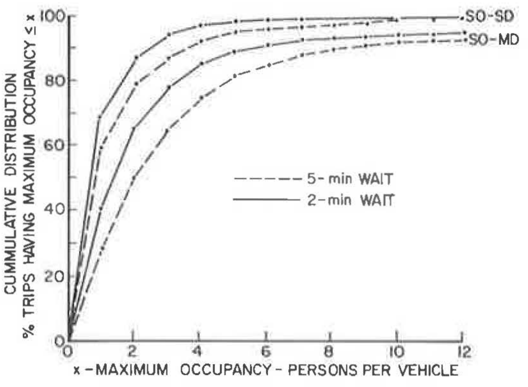


Figure 6. Peak-period vehicle productivity.

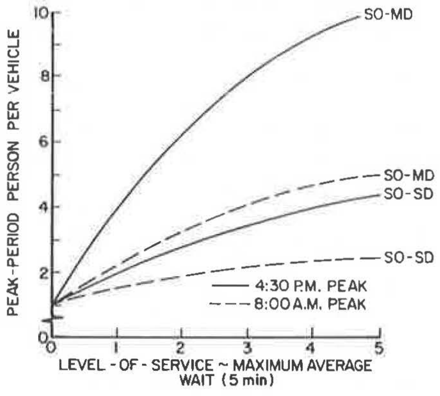


Figure 7. Taxi demand rate at Union Station.

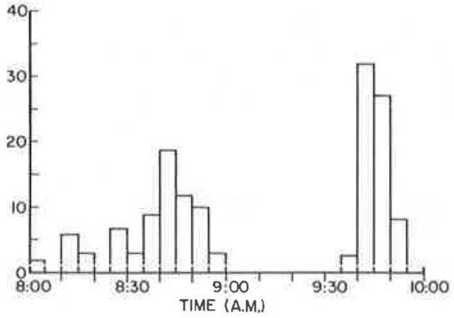


Figure 8. Computer display of passenger destinations for three Union Station taxis.

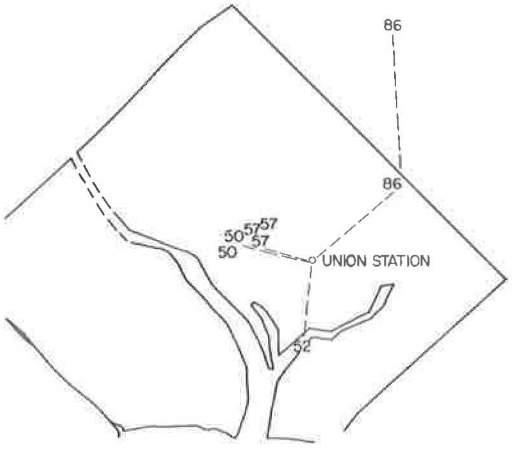


Figure 9. Cumulative distribution of shared-ride taxi passengers served.

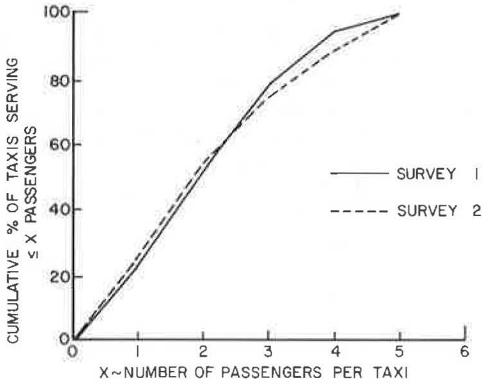
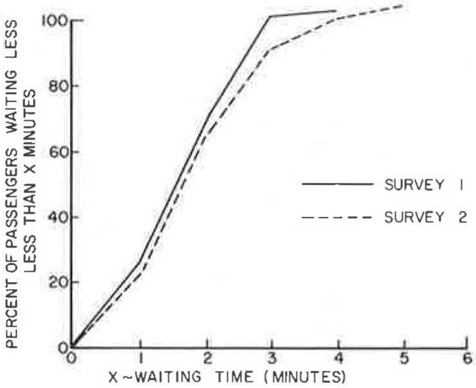


Figure 10. Cumulative distribution of wait time for shared-ride taxi passengers.



vice) are attained if shared ridership is encouraged.

Figure 5 shows the cumulative distribution of vehicle occupancy over the daily period for the two service policies and maximum waits of 2 and 5 min. Note that more than 50 percent of the trips for the SO-SD service policy were private trips and that only for the SO-MD service policy was there a significant need for vehicles of more than 12-passenger capacity. If only 6-passenger vehicles were provided, additional capacity could have been used in only 49 percent of the vehicle departures in the case of the SO-SD mode with a 5-min wait. The appropriate vehicle capacity can be determined from the results shown in Figure 5 once the service policy is established.

The results presented so far have focused on daily vehicle productivity. Peak-hour productivity is probably as important if not more so. Peak-period vehicle occupancy defines the fleet size and the guideway and station vehicle-capacity requirements. Not only is the level of demand higher; it is also more spatially directed so that both the potential and the benefits of dynamic ride sharing are highest. Peak 15-min demand on the Trenton network occurred at 8:00 a.m. and 4:30 p.m. where 2300 and 3500 passengers respectively were served every 15 min. It is interesting that, whereas 4:30 p.m. represented the peak passenger demand period, 8:00 a.m. was the peak vehicle demand period for each of the shared-ride policies. Data for peak-period AVO are shown in Figure 6 for each shared-ride service policy. The figure shows peak-period vehicle dispatches as a function of maximum wait time. The assumption that each vehicle can serve only one dispatch every 15 min during peak periods implies that the fleet size is defined by the maximum of the 8:00 a.m. and 4:30 p.m. curves for each shared-ride policy in Figure 6. Therefore, the SO-DS policy with a 2-min wait results in a 63 percent reduction in the size of the vehicle fleet normally required under a non-shared-ride policy. For the SO-MD policy with a 5-min wait, the reduction in fleet size is 88 percent. These results indicate that dynamic ride sharing does produce significant benefits.

Benefits of equal magnitude, though more difficult to quantify, would accrue from the increase in minimum headway requirements if ride sharing were encouraged in an AGT application. The reduced fleet size implies an inversely proportional reduction in minimum headway; therefore, the 63 percent reduction in fleet size for the SO-SD policy with a 2-min wait implies an increase in minimum headway by a factor of 2.7 (3.1 for a 3-min wait). Therefore, if nonshared vehicles require a 1-s minimum headway, a comparable, nonstop, single-origin to single-destination service could be offered that uses 3-s minimum headway technology (if the maximum wait time in stations is 3 min). This saving goes beyond economic benefits to technological feasibility.

DYNAMIC RIDE-SHARING TAXI SYSTEM

The computer simulations described in the previous section considered a wait-time penalty in the mode-split analysis, which meant that only those persons who would tolerate the maximum wait were considered in the analysis. Questions remain as to whether people would indeed share rides. To answer this, one could propose a demonstration project to determine the feasibility of dynamic ride sharing and examine trade-offs among various ride-sharing policies. Another way is to see if such a demonstration already exists. For most practical purposes, the shared-ride taxi operation at Union Station in Washington, D.C., can serve as an analogous demonstration of a shared-ride transportation system that employs either SO-SD or SO-MD dynamic shared-ride policies.

At Union Station, taxis diverge from Massachusetts Avenue into a passenger boarding area. Passengers approach and are marshalled into waiting taxis. The first passenger establishes the destination of the taxi, and subsequent taxi sharers either have common destinations or destinations en route. After a period of waiting, or as the taxis are filled, the vehicle is dispatched from the boarding area. When demand is low, the taxis provide private service. However, when the demand is high (for example, shortly after the arrival of the 9:34 a.m. Metroliner from New York), rides are shared to increase the productivity of the system.

In an attempt to quantify the productivity gains attributable to dynamic ride sharing, Princeton University's transportation program observed the Union Station shared-ride taxi operation. Surveys were conducted on two mornings during a 2-h period that included the arrival of some local commuter trains and the surge in demand caused by the arrival of a Metroliner. Goals of the survey included (a) recording the magnitude and variation in ride sharing over the 2-h period, (b) obtaining estimates of the distribution of time spent by taxis waiting for additional riders, and (c) obtaining measures of the degree of commonality of destinations among the passengers in each taxi. Data collected for each taxi dispatched during the survey period were (a) time and destination (street corner) of each rider and (b) the time the taxi left the boarding area.

Demand for service was recorded as a function of the time service was requested (Figure 7). Note the extremely sharp peaks in demand over very short periods

Table 1. Results of two surveys of shared-ride taxi operations at Union Station.

Time	AVO Effective	AVO Maximum	Average Passenger-Trip Distance (straight-line km)	Average Wait Time per Passenger (min)
2-h average	2.19	2.53	2.24	1.9
	2.17	2.47	2.15	2.1
Metroliner peak	2.26	2.74	2.17	2.2
	2.31	2.77	2.15	2.4

Note: 1 km = 0.62 mile.

of time. The Metroliner peak represents an hourly demand rate of 800.

Air-line travel distance for each passenger was computed from digitized geographic locations of destinations, and computer graphic maps of trip destinations were produced for each taxi and various groups of taxis. An example is shown in Figure 8. These maps reveal that the apportioning among taxis of patrons with compatible destinations was efficient. Most taxis used an SO-MD type of ride-sharing policy.

Effective average vehicle occupancy for each taxi was computed from the ratio of passenger straight-line distance to maximum straight-line distance (circuity was neglected). Table 1 gives a summary of the performance measures that were assessed in the two surveys at Union Station. Note that the large difference between effective AVO and maximum AVO implies that the ride-sharing policy is serving multiple destinations to a significant extent. Figure 9 shows the distribution of the number of taxis as a function of the maximum number of passengers. Figure 10 shows the cumulative distribution of passenger waiting time. Note that 22 percent of the users received immediate service and 98 percent were served within 5 min.

CONCLUSIONS

The Union Station dynamic ride-sharing taxi operation results in substantial improvements in vehicle productivity. The a.m. peak-period ride sharing results in services being provided by 60 percent fewer taxis that consume 55 percent less energy than if the service were offered by non-ride-sharing taxis. In addition, the cost of the taxi is distributed among the ride sharers, which results in reduced fares per passenger. The reduction in level of service was found to be minimal when it was compared to the additional benefits derived from ride sharing.

The implications of the Union Station demonstration for the operating feasibility of a dynamic shared-ride AGT system are substantial. They may be the determining factor in the economic feasibility of AGT systems. What is certain is that the implications were obtained from a cost-effective demonstration; it cost less than $500 to conduct the study and analyze the results.

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Car-Pooling Programs: Solution to a Problem?

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Information from 26 car-pool programs is reported that suggests that appeals to self-interest made through work organizations are more effective than other means of encouraging car pooling because employees of work organizations form a known population with a common destination and, typically, a similar work schedule. It is proposed that such appeals should focus on the benefits of car pooling for the individual rather than on general values such as patriotism. Interviews of selected long-term car-pool participants (2 or more years) indicated that work organizations provide a setting in which personal information about potential participants can be obtained and that this information facilitates the formation of car pools. These interviews further suggested that the intimacy of the private automobile may limit the size of car pools as well as the willingness of some individuals to participate in them. Ride-sharing programs that present alternative transportation modes may be more effective than car-pool matching programs in changing current patterns of work travel.

In the 1970s, with the advent of the energy crisis, transportation patterns became a national issue. Rising U.S. consumption of petroleum involved increasing energy-related dependence on foreign countries. In late 1973, attention focused on changes in the policies of major oil-producing nations. Automobile gasoline consumption was recognized as inefficient. The U.S. Department of Transportation proposed saving gasoline by increasing the number of car pools. In December 1973, federal legislation was enacted that provided funds for car-pooling programs. Programs were instituted in many places in January 1974, e.g., Austin, Texas; Charlotte, North Carolina; Norfolk, Virginia; and Phoenix. Mass-media campaigns tried to mobilize voluntary energy-conservation behavior, i.e., car pooling to work.

The success of specific programs and general media promotions is difficult to measure because of the lack of local baseline data, unspecified definitions of car pools, and inconsistent measures of car-pooling levels. In this paper, a car pool is considered to exist when any two or more individuals ride together in an automobile on a regular basis. The relative success of car-pooling programs or campaigns should be measured by the percentage increase in the number of pools after program or campaign activities have begun to reach the target population (based on a survey of commuters). Vehicle occupancy counts, in which counters determine the number of occupants in automobiles traveling at specific times on selected days, produce different statistics and thus generate confusion about the relative prevalence of car pooling. Thus, although in 1974 the U.S. Department of Transportation found that 47 percent of commuters shared rides to work with at least one other person (2), others report 83 percent of private vehicles traveling to work are occupied only by the driver (14). Another measure of the effectiveness of car pooling is the calculation of the liters of fuel saved annually or the vehicle kilometers of travel saved (9).

In this paper a variety of data are used to describe problems that occur in the promotion and evaluation of car-pooling programs. Specific concerns are the types of promotional appeals selected, the organization of local car-pooling programs, strategies used to enhance car pooling, and the evaluation of program effectiveness. Recommendations are developed for future car-pooling promotion and evaluation efforts.

TECHNIQUES USED IN PROMOTING CAR POOLING

Before specific problems with car-pooling campaigns are discussed, the general appeals used in the campaigns are reviewed and critiqued. Mass-media appeals for voluntary energy conservation by individuals were ineffective for several reasons. Media promotions appealed to widely shared societal values, particularly patriotism, social responsibility, and savings. These appeals failed to recognize individuals as rational decision-makers concerned about their own self-interest. Other appeals treated individuals as rational decision-makers but failed to recognize the social contacts characteristic of urban life.

Appeals to Patriotism

One set of media appeals focused on general societal values, e.g., patriotism. The nation was described as being confronted with an energy crisis that individuals could help to "cure" by consuming less gasoline and helping to make the nation less energy dependent. Thus, individuals were asked to be altruistic and to modify their existing transportation patterns, as well as other energy-consumption patterns, for the good of society. At the same time, congressional debates over the necessity of rationing gasoline or establishing high gasoline prices suggested that if individuals did not voluntarily behave in the national interest gasoline consumption might be restricted. Restriction of prime parking locations and of vehicle access to central business districts has also been suggested. Coercive measures other than the mandatory 88.5-km/h (55-mph) speed limit generally were not implemented; such measures not only could be difficult to enforce but could also produce undesired effects if the need for them were not perceived as real. For example, rationing lends itself to the development of black markets, which would penalize lower income groups. In addition, the growth and popularization of citizen's band radio use in automobiles suggest the possibility of the emergence of antiregulation behavior.

Two specific sets of problems are involved with socially based appeals. One set of problems involves the perceptions of individuals as to whether or not they should be responsible for meeting the social need. Appeals to patriotism were questioned by many people who felt that others in society were not being asked to alter their behavior or to alter it to an equal or greater degree. For example, some individuals perceived their own gasoline consumption as minuscule compared with that of corporations, and some felt that they did not waste as much gasoline as did other individuals (or family units) with larger automobiles or more than one automobile (8).

Another set of problems resulted from perceptions of the nature, the extent, and the basis of true national crisis (social need). Was there, in fact, enough gasoline or were oil companies withholding it in order to increase their profits or to force independent dealers out of business or both? A weekly study of household units made between January and April 1974 by the National Opinion Research Center showed that from 28 to 43 percent of people interviewed in a given week felt the oil and gas companies were most responsible for the current energy shortage and that from 28 to 45 percent of people interviewed in a given week held the government in Washington most responsible (13). Individual consumers, environmentalists, big business, Arabs, Israelis, and Russians were much less likely to be seen as most responsible (12). Rumors circulated that while the consumer was being told there was a shortage there were vast quantities of gasoline being stored. Some people believed that the energy crisis was proposed to divert the public's attention from other societal problems, e.g., the Watergate scandal.

A general problem with appeals to individual responsibility was that the crisis rhetoric implied that the energy problem was temporary although the apparent goal of policy makers was to alter permanently the level of gasoline consumption by individuals. As Davis (4) notes, "Talk of a crisis connotes that the problems are novel and transitory, when in fact they are the same problems the U.S. has faced many times." Some individuals may have maintained their existing patterns of gasoline consumption assuming that the crisis would end relatively soon if other individuals and units in society voluntarily cooperated and changed their behavior or new technology was developed. The failure of the federal government to establish a national energy policy may have confirmed the perception that the problem was transitory. (The public perception of a crisis was apparently short-lived, for in May 1976 the Federal Energy Administration announced that gasoline consumption had almost risen back to the peak level of August 1973, before the oil-producing countries changed their energy policies.)

Finally, socially based appeals failed to consider the bases of individual behavior. Individuals were asked not to do what might be most rewarding for themselves but instead to invoke some vague conception of the national interest as the basis for their behavior. Rational decision-making models of human behavior (7, 11) as well as the social-psychological literature on such phenomena as bystander intervention (10) suggest that individual action in the public interest is rare. In addition, if some others engage in (or can be expected to engage in) behavior supportive of the national interest, the individual may be less motivated to change his or her own behavior pattern.

Appeals to Self-Interest

Even if individuals support societal values, they may express personal dislike for a specific form of car pooling or for car pooling in any form for themselves. Olson

(15) argues that special incentives such as appeals to self-interest are crucial if coercion is not used in attempts to generate desired behavior. He further states that

> If the members of a large group rationally seek to maximize their personal welfare, they will not act to advance their common group objectives unless there is coercion to force them to do so, or unless some separate incentive distinct from the achievement of the common or group interest is offered to the members of the group.

Some campaigns have attempted to educate (persuade) individuals about the benefits car pooling would offer them. The Pool It and Double Up America campaigns have emphasized how individuals could benefit if they changed their commuting patterns. One frequently emphasized benefit is that the individual could save money by joining a car pool. Various statistics have been used in advertisements to demonstrate to the individual the savings that would result from car pooling, depending on the distance of the work trip and the number of individuals in the pool. The costs avoided and the rewards gained from not having to drive to work every day (e.g., relaxation) and from riding with others (e.g., camaraderie with fellow riders) have been pointed out. The potential disadvantages, such as inflexibility of work hours, earlier departure from and later arrival at home, and lack of freedom to make stops on the work trip, have been deemphasized.

Individuals may come to view car pooling as in their own interest but, unless other facilitative conditions exist, they may not change their behavior patterns. Social scientists recognize the existence of more than one level in the flow of communication. Personal influence modifies the direct effects of mass communication. Although people have individual characteristics that affect their receptiveness to and perception of media communication, they are also affected by the responses of friends and acquaintances (16). Personal acquaintances must reinforce media appeals if an innovation is to be adopted.

Car pooling, particularly when it is organized through computer or other matching programs, is an innovation that requires being accepted by other people. To be matched with others by computer and to receive a printout of names, addresses, and phone numbers is impersonal, and to be expected to establish a relationship with strangers is unusual. Although social units have attempted to increase public acceptance of car pooling, they have failed to use personal contacts in most instances.

Involvement of Social Units

In their efforts to organize car pools, policy makers engaged in "attempts at informal and formal cooperation of specialized elites" (3). On the local level, governmental units and work organizations participated to varying degrees in the promotion of car pools (5). Local governmental units were encouraged to participate because car pooling could reduce local transportation and pollution problems. The media were approached as public service agents responsible for informing the community. Work organizations were asked to serve as markets in which car pooling could be displayed and sold.

One local governmental response to the energy crisis was the establishment of transportation programs, often with the aid of federal energy funds. Programs based in governmental units had limited success. In late 1973 the local government of Cincinnati, Ohio, began using a data processing organization to match citizens interested in car pooling. After 1 year there had been only 100 responses and none of them could be matched. Local departments of transportation and transit authorities approached work organizations and asked them to encourage and support employee car pooling. Another local governmental response was to reward poolers by providing privileged access lanes—for example, an express highway lane in Dade County, Florida—and reduced toll fees.

Local media appealed to individuals to car pool. They did this perhaps to fulfill their public service requirements as well as to appeal to and increase their audiences. National car-pooling campaign messages were carried by local radio stations, and some stations and newspapers conducted independent campaigns.

Media campaigns in various cities promoted computer matching programs that asked individuals to call in to a radio station or to mail in a newspaper form and be matched with other individuals interested in pooling. The city of Columbus, Ohio, for example, offered to match by computer individuals interested in car pooling. The local chamber of commerce and a radio station publicized the service on the radio and in other local media for more than a month. Extensive efforts resulted in only 40 inquiries about the project.

Appeals were made to work organizations to respond to the energy crisis by supporting ride sharing as (a) responsible units of society and particularly of the local community, (b) profit-making organizations, and (c) employers concerned about their employees. Community responsibility could be demonstrated more through alleviating local traffic congestion than decreasing energy consumption. Profit-making organizations were appealed to primarily by suggesting that increased car pooling would reduce the need for employer-provided parking facilities. A stronger appeal suggested that organizations could improve employer-employee relations by facilitating employee car pooling. The appeal for employer support probably has been most effective among companies concerned about their employer-employee relations and their public image and those whose employees have parking and transportation problems. (Some firms are faced with a potential loss of skilled employees if they relocate and do not facilitate employee transportation.)

Supportive employer behavior in Los Angeles, Knoxville, and Omaha included a variety of activities (5). Employers provided company time for completion of questionnaires. The minimal information obtained was the individual's name, home address, work address, time of arrival at work, and time of departure from work. Matching lists were distributed by the employers to those who expressed interest in car pooling. Promotional information on saving money and other benefits was disseminated through company channels, e.g., bulletin boards and employee newsletters.

Both logistical problems and interpersonal considerations suggest that the matching process could be more satisfactory to potential consumers if specific social organizations such as companies or plants are used. Work locations are closer together, work schedules are more similar, and information about potential poolers is more easily accessible within a single organization. In most communities the large variety of residential and work locations, as well as work schedules, necessitate a substantially larger number of individual file entries for successful matching than are necessary in a single company or among geographically proximate companies. In addition, communitywide matching programs generally ask individuals to volunteer to ride with others who share similar work locations and schedules but whose other characteristics are unknown. Given the intimacy of the private automobile, individuals may desire to take more personal characteristics into account. Matching programs should approximate the model of the

Table 1. Car-pooling programs responding to survey (by geographic region).

East	South	Midwest	West
Connecticut Motor Club	Dade County, Florida	Grand Rapids	Los Angeles
Connecticut Department of Transportation	Raleigh, North Carolina	Omaha	Los Angeles Commuter Computer
Dover, Delaware	Houston	St. Paul	Sacramento
Rhode Island	San Antonio	Topeka, Kansas	San Diego
Scranton-Harrisburg	Phoenix	Kansas City, Missouri	San Bernardino
Washington, D.C.	Tucson	St. Louis	San Francisco
			Portland, Oregon
			Seattle

marriage broker more than the computer assignment of students to classes.

Appeals transmitted through work organizations are perhaps more effective because the employee can use existing social networks to obtain information about others, there is a greater homogeneity of work schedules, and other characteristics (6). Common work locations are also essential because they shorten the home-to-work trip by eliminating drop-offs and they ease the establishment or alteration of car-pool arrangements for members of a pool, e.g., by accommodating overtime workers.

SURVEY OF CAR-POOLING PROGRAMS

A limited survey of car-pooling programs revealed support for the desirability of using employers to increase car pooling. In September 1975, car-pooling programs in various parts of the United States were sent questionnaires about the nature and the effectiveness of their programs. The 26 programs that responded are given in Table 1. With the exception of the Dade County, Florida, program, which only involved provision of an express highway lane, all the programs involved computer matching.

Approximately two-thirds of the program directors (17) said that, because their programs were rapidly implemented, they had no measure of how many or what types of people were car pooling when their programs were instituted. Because baseline data were lacking, the impact of these programs on commuting behavior could not be measured. Many of the respondents expressed concern about how effective their programs were. The programs with data on preprogram pooling levels had estimates based on survey questionnaires, telephone surveys, and vehicle occupancy counts.

In response to a question about how programs might be reorganized or modified to make them more successful, respondents advocated working with local employers. On the basis of experience with a program aimed simply at individuals in a geographic area (Connecticut Motor Club), the director concluded that areawide programs have only limited appeal and suggested that greater participation could possibly be obtained if employees of work organizations were the targets. Similarly, a large city's program personnel determined that in their area only employer-based programs could be successful. In Dover, Delaware, something was learned about the importance of employer efforts when employers had to coordinate employee work hours to facilitate car pooling. In the Rhode Island and the Los Angeles programs, staff members found it necessary to go to employers to sell their programs.

The use of work organizations can facilitate both the formation of car pools and the evaluation of car-pooling programs. Data obtained on the work force of an organization are more accurate for establishing the effectiveness of programs because employment records establish a known population. That is, the percentage of an organization's work force that participates in ride-sharing activities at a particular time and the changes in that percentage over time can be computed more exactly than they can for areawide efforts.

Recognizing the crucial function of employers in facilitating car pooling, respondents at the same time affirmed the continuing need to persuade individuals to try car pooling. The Omaha program, for example, which is a part of the metropolitan transportation authority, stresses the need to know how to motivate employees to use the service and to recognize its importance.

FORMING AND MAINTAINING CAR POOLS

Energy conservation is the national goal that car pooling is supposed to help achieve, but the success of car-pooling programs depends on (a) convincing individuals that it is in their self-interest to car pool and (b) bringing individuals together to form pools (assisting them in personal contacts). The basis for matching potential car poolers in most programs is the sharing of a common point or origin, work schedule, and destination. Although these are parameters for establishing pools, certain social characteristics are important to the development of car pools. Thus, another factor involved in the development of successful car-pooling programs is the awareness that these programs create social groups.

The dynamics of car pooling were studied by intensively interviewing 25 long-term car poolers in Knoxville (6). The interviews focused on how the car pools the individuals belonged to were formed, maintained, and changed.

A common pattern of membership selection was indicated by these car poolers: When they were contacted by a person interested in joining their car pool, they would try to obtain some additional information about that person. People at work and in the residential subcommunity were sources of information about potential new members (1). According to one respondent, after you know the new person's work schedule,

> The next thing you want to know before you let someone in a car pool is whether the person is agreeable. You find this out by asking other people who have been in pools with him or by asking people at work if he is dependable or agreeable.

Another respondent stated,

> We've been selective about who is in the pool. Most of us are neighbors, work on this floor, and work the same schedule.

A third respondent said,

> We don't advertise. Someone always knows of someone. Everybody who comes in is a fairly good acquaintance of someone else. In a way the person who brings him in is responsible.

Data from the Los Angeles Commuter Computer and Knoxville follow-up studies indicate lack of interest in riding with strangers. This is illustrated by the fact that only about 6 percent of persons who received a list of potential car poolers (others who lived and worked in similar locations who were interested in car pooling) actually used the list as a means of contact. In Knoxville, a random sample of 150 persons (5 percent of the work force of the Tennessee Valley Authority) were surveyed from May to June of 1974 to determine the effectiveness of various efforts, particularly matching lists. The preference for "known others" as car-pooling members is shown in that, of the 150 people surveyed, 48 percent were car pooling with fellow workers, 15 percent with a relative, and 14 percent with a neighbor.

Matching programs that simply provide a list of people with similar work and home locations fail to deal with the car pool itself as a social unit or with why known others are preferred as members. As people consider the rewards and the costs associated with their current and possible alternative modes of transportation for the work trip, social factors as well as more practical factors (e.g., gasoline and parking costs, vehicle depreciation, convenience) enter into the assessment. One car pooler indicated concern for shared social characteristics by saying, "I try to make sure people are compatible beforehand, compatible by age, locality, similar interests." Another factor, the desire for sociability, is expressed in the statement, "It's more of a get-together than a carpool. It's a friendly thing. It's more a car pool of friends than a car pool of convenience." In fact, a number of car poolers indicated a preference for viewing their car pool as a friendly group that shared rides rather than as an economic convenience.

Poolers deemphasized the economic basis of their relationships by not keeping driving records and having no rules for making up missed driving turns. One pooler who stated that the pool was an amiable group said, "We always swap days but if someone isn't paid back, no one worries about it because they figure they'll be paid back sometime." Another pooler indicated that the pool did not keep records because it all came out even over the long run. Poolers explained that car pools are based on trust and the willingness to believe that no one will take advantage of anyone else.

Unfortunately, the desire for informality and sociability can mean that the full capacity of car-pooling vehicles is not used; some individuals only share rides with their spouse or with one friend or neighbor. One pooler who rode with only one other person indicated, "We wouldn't want it to get above three because I think that's the number where you can remain informal." The limited size of many car pools was shown in a U.S. Department of Transportation national probability survey (2) in which 83 percent of those who shared rides rode in automobiles with three or fewer occupants (58 percent of the automobiles had only two occupants).

RIDE SHARING: A BROADER PERSPECTIVE

A broader approach to increasing vehicle occupancy considers all the modes in which persons can share rides. Ride-sharing modes differ in vehicle characteristics, trip characteristics, and collectivity characteristics. Some modes of ride sharing are car pools, van pools, express buses, and fixed-route public transit, each of which has advantages and disadvantages for potential ride sharers. For example, because the dominant form of financial arrangement in car pooling is trading rides or sharing driving responsibilities, one must usually have an automobile to participate. Van pools (8 to 15 people riding together in a van) are not economical when operated over a one-way trip length of <16 km (<10 miles). Express buses require that approximately 40 persons ride from a given location to another given location at specified times. Express buses are usually less expensive than other modes when enough persons use them. Both the express bus and public transit modes require less personal involvement on the part of the rider than does the van or the car pool. Such factors as maintenance requirements and driver characteristics vary by ride-sharing mode.

The patrons of different modes appear likely to differ in personal characteristics, collective characteristics, and work-related characteristics. Individuals should be more interested in ride sharing if driving alone creates costs in other parts of their lives. For example, early in the family life cycle, heads of households frequently can afford only one automobile. Joining a pool can generate rewards by freeing an automobile for the spouse to do errands and escort children or by providing transportation so that the spouse can work. Individuals who live greater distances from their place of employment and thus encounter greater commuting costs than others might be interested in van pooling as a means to reduce those costs. More generally, individuals whose commuting costs take a greater share of their expendable income should be more interested in ride sharing. Workers who earn lower wages may need to share rides to make a job profitable (17), whereas more affluent workers value the avoidance of heavy traffic. Individuals who have limitations such as no driver's license or no access or irregular access to an automobile may have no choice of mode of transportation.

Ride-sharing programs, unlike car-pooling programs, promote several transportation modes and can potentially assist more commuters. The brokerage demonstration project in the Knoxville area has sought to match the most economical or most preferred modes to commuters willing to try ride sharing. In addition to assisting in the formation of car pools, the program matches available vehicles (vans or express buses) and drivers to commuter routes with concentrations of passengers sufficient to support the service on at least a break-even basis (18). A ride-sharing program is more desirable because it can deal with differences in trip characteristics, vehicle preferences, and social characteristics of commuters.

CONCLUSIONS AND RECOMMENDATIONS

Although car pooling existed in American society for some time before the energy crisis, no one knew its nature and extent. The institution of car-pooling programs was a decision of policy makers for which they had to develop interest and support. Mobilization of individuals into car pools as a result of mass appeals was limited for two reasons: (a) Appeals to patriotism and other social values did not treat the individual as a self-interested decision-maker and (b) the current social situations and preferences of individuals were not recognized in the mass appeals.

Car-pool matching programs reported greater effectiveness when they used large work organizations as a base. A major reason for this greater effectiveness is that people in the same work organization would most likely meet the minimal qualification for pooling (similar work schedules and destinations) and could use existing social contacts to obtain information about other potential poolers.

The following actions are recommended for future car-pooling programs:

1. Collect baseline information. Baseline information provides two important benefits: (a) Estimates of current levels of ride sharing in car pools and other

modes establish the potential market level and (b) the relative effectiveness of various programs can be evaluated.

2. Follow up on list distribution. Car-pooling efforts should recognize that potential poolers want to obtain information about one another before establishing a car pool. Simply distributing lists of names results in little use of the lists. Some opportunity for contact between potential poolers or personal follow-up by a "matchmaker" could increase the number of pools formed.

3. Use work organizations as targets. Work organizations provide known target populations who share common destinations and other characteristics. Informal interaction networks among employees establish a basis of contact among potential poolers. Promotion can be handled through company communication systems. Follow-up and evaluation efforts are easier if there is a well-defined target population.

4. Investigate the preferences of car poolers. The factors people consider when they ask other people to car pool with them should be studied. Most matching programs assemble a list of potential ride sharers based on common origins, destinations, and trip times. Data could be collected on preferences for certain types of people, for passenger and driver etiquette, and for financial or barter arrangements. Use of such preference data in preparing matching lists could increase the number of pools formed and maintained.

5. Recognize social processes. Because car pools involve social activity (interpersonal relationships) as well as economic activity, car-pooling programs involve efforts to form or add to social groups. Groups recruit members and individuals seek to join groups. In addition to marketing a product, car-pooling programs must facilitate human relationships.

6. Emphasize a multimodal approach. Programs that promote multiple ride-sharing modes can increase vehicle occupancy because they satisfy more individual preferences.

ACKNOWLEDGMENTS

This report uses data obtained from a project of the Transportation Center of the University of Tennessee funded by the Urban Mass Transportation Administration, U.S. Department of Transportation. We appreciate the comments of Donald W. Hastings on an earlier draft of this paper and the able work of Thomas Bell on the car-pool questionnaire.

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Use of a Quantitative Marketing Model to Estimate Impacts of Car-Pooling Policies

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This paper discusses a quantitative marketing approach applied in a study designed to estimate the impacts on work travel of various proposed policies for encouraging car pooling. The decision to commute by car pool is influenced by a number of "soft" factors, such as comfort, safety, and midday mobility, that are not easily handled by traditional modal-split techniques. This study provided an opportunity to test the feasibility of adapting and applying quantitative marketing techniques to the projection of modal split under various car-pooling policies. A trade-off model, previously used primarily in traditional product market research, was adapted for modal-split estimation. The model estimates modal split on the basis of quantitative preference (utility) levels calculated for each of the competing modes, which distinguish between car pool and solo driver. The utilities are obtained from responses to paired-comparison questions on work-trip preferences asked of a representative sample of commuters. Modal split and other travel impacts were estimated for each of 14 proposed car-pooling policies. The marketing approach produced useful quantitative results. Additional efforts in the development of this approach are warranted, however, to improve the overall quality of the results and enhance the usefulness of the approach as a tool in transportation research.

This paper describes a quantitative marketing model used in a study of the impacts of car-pooling policies. A specially designed survey and a trade-off model developed to quantify traveler preferences were used instead of a traditional modal-split model to estimate the likely impact of proposed policies for encouraging car pooling. Bruggeman, Rubin, and Griffiths present the specific policy-impact findings of the study in a paper in this Record.

QUANTITATIVE MARKETING METHODOLOGY

Marketing approaches have traditionally been used to evaluate consumer preferences and estimate likely reaction to products. Surveying a sample of the relevant market is usually required. The more sophisticated quantitative marketing methodologies are designed to provide hard numbers, from comparatively "soft" survey response data, on likely market shares for products.

Relatively little use has been made of marketing approaches in transportation for estimation or prediction purposes. Certainly, numerous transportation data are obtained through surveys (such as home interview and screenline surveys). However, these surveys are primarily intended to collect objective data rather than travel-preference data. Applying quantitative marketing tools to a transportation task such as the estimation of modal split is far from straightforward but does offer several advantages:

1. Direct perceptions and preferences of travelers, rather than those inferred from observed behavior, are used to predict behavioral response to changes in policy or environment.
2. Sensitivity to other than traditional predictive factors can be achieved by incorporating in the survey questions on perception and preference that relate to these factors. Because almost all data come from a specially conducted survey, they are recent and internally consistent.
3. Calibration on the level of the individual respondent can be meaningfully achieved for a marketing model. Characteristics and preferences of individual survey respondents can be used directly or can be partially aggregated to impose policies and estimate their impacts on specific target groups.

SELECTION OF METHODOLOGY

The study required the estimation of fuel consumption and related travel impacts of various proposed policies to encourage car pooling. Any such investigation of impacts requires estimates of changes in modal split and vehicle occupancy that are likely to result from implementing the proposed policies. One of the traditional modal-split models would be an obvious choice for this task. However, the fact that the decision to car pool is rather subjective and complex tends to accentuate the inherent limitations of traditional modal-split models. Three considerations significantly reduce the usefulness of traditional modal-split models in dealing with car-pooling tendencies:

1. The almost emotional nature of the decision to car pool strengthens trip-maker perceptions and weakens objective measures of change associated with government policies as reliable predictors of travel response.
2. A number of significant factors other than travel time and cost are prominent in the decision on whether or not to car pool. Gasoline availability and ease of midday transportation for commuters are examples of important factors that could be influenced by policy but are not easily handled by traditional modal-split models.
3. Both the impact of and travel response to policies for encouraging car pooling are likely to be highly individual. If accurate impact estimates are to be achieved, greater disaggregation is needed than that typically available from modal-split models.

These considerations suggested that estimating the impacts of car-pooling-incentive policies would be an excellent opportunity for adapting a quantitative marketing approach to transportation research. A trade-off model was adapted to estimate modal split, vehicle kilometers of travel, and related impacts of proposed policies for encouraging car pooling. The core model generates estimates of relative preference among modal alternatives on a person-by-person basis from responses to paired-comparison survey questions. These estimates, under various policy conditions, are then converted to modal split, vehicle kilometers of travel, and related policy impacts by using travel data also collected by the survey.

TRADE-OFF MODEL THEORY

Trade-off analysis is a variety of conjoint measurement developed to overcome the shortcomings of the conventional attitude research study (1, 2), which probes people's desires when alternatives are not interrelated and without reference to cost. Such studies almost never force the respondent to consider and choose between realistic alternatives. Trade-off analysis is fundamentally a method of solving problems of relative priorities that are not solved by straightforward attitude studies. It deals with preferences among different competing combinations of circumstances.

The trade-off model produces utilities (quantitative preference levels) for various products from responses to questions in matrix or paired-comparison formats. In this study, the products are work trips by a given mode under conditions set by the various government policies to be tested. Each matrix or paired-comparison trade-off question is expressed in terms of two of the several attributes used to characterize the work trip.

EXAMPLE

An example can be constructed by using two of the attributes used to describe the work trip: (a) weekly travel cost and (b) one-way riding time. Since the number of specific trade-offs that can reasonably be asked of a respondent is limited, a small number of discrete levels spanning the typical range of values must be chosen for each attribute. Typical levels might be \$5, \$10, and \$15 for weekly travel cost and 30 percent less, same as now, and 30 percent more for riding time. All other attributes (such as mode and parking cost) are held constant, and the respondent expresses relative preferences among different levels of each of the two attributes of the work trip.

In the matrix format, which is shown in Figure 1, the respondent would be asked to place the integers 1 through 9 in the nine cells in order of his or her preference for the situations defined by the attribute levels corresponding to the cells. The normal respondent would always rank the first and last cells 1 and 9 respectively. The rank order of the other cells depends on the relative importance of the two attributes to the respondent. By ranking these cells in order of preference, the respondent reveals relative preferences among levels of travel cost and riding time.

The respondent is then asked to fill out analogous trade-off matrixes corresponding to other pairs from among the total set of attributes used to describe the work trip. If the number of attributes is small (three or four), the respondent may be requested to express preferences for all possible pairs of attributes. But when the number of attributes is larger, such a task becomes overwhelming. Under such conditions, the respondent is asked to fill out only a selection of all possible matrixes. The pairs of attributes are chosen so that each attribute appears in at least two or three matrixes, and a tight linkage is maintained among the attributes so that relative preferences among attributes not directly compared can be inferred from those that are. The model is then used to convert the trade-off responses to quantitative utility estimates for each specified level of each attribute by means of an algorithm that searches for those sets of utility numbers that best preserve the rank orderings of the respondent.

Figure 2 shows a typical response. Each cell has been split diagonally. The rank-order preferences of the respondent are in the upper left corner. The trade-off model produces utility values for each level of the two attributes; these values appear in parentheses with the corresponding row and column headings. They are normalized to sum to one for each attribute and thus best preserve the respondent's expressed rankings across all matrixes. The match for the matrix shown in Figure 2 is excellent. The products of the row (riding time) and column (travel cost) utility levels (shown in parentheses in the lower right portion of each cell) are in the same rank order as the respondent's expressed preferences.

USING THE MODEL TO ESTIMATE MODAL SPLIT

Once the utility values have been generated for each level of each attribute, a respondent's utility for any work-trip situation (expressed as the collection of levels for each attribute) can be estimated as the product of the corresponding component utility values. For this study, modal-split estimates were made by using an assumption of proportionality. Under any given policy condition, a respondent's utility for each mode was estimated. Because each respondent in a sample represents many similar people in the general population and because this study was concerned with average trends, the probability of choosing a mode was assumed to be proportional to the utility for that mode. Thus, the estimated utilities were normalized to sum to one (100 percent) over all modes. The resulting values were modal-split estimates for the population group represented by the sample respondent.

Because respondents filling out a matrix tend to simplify their task by placing the integers 1 through 9 across the rows or down the columns, it is sometimes desirable to replace the matrix with a number of simple paired comparisons. Each paired comparison essentially asks the respondent to choose between two cells of the matrix. There is usually an assumed order of preference along each row and down each column (low cost is always better than high cost, if travel time remains constant); thus, it is possible to obtain virtually all of the preference information of a matrix from a limited number of diagonal cell-comparison questions and a transitivity assumption. This format does not have the patterning bias of the matrix format. Otherwise, the trade-off methodology is identical to that used with the matrix format.

APPLICATION OF THE MODEL

The analytical framework of the study was built around a detailed survey for measuring attitudes on and perceptions of work-trip mode choice in general and car pooling in particular. Model requirements and the characteristics of the analytical marketing approach provided a framework for the design of the survey. Representative cities were selected, and the survey was administered in each. After model calibration and validation, the selected car-pooling policies were simulated to produce estimates of effects on modal split. Finally, vehicle kilometers of travel, fuel consumption, and related impacts were estimated for each policy.

Presurvey Selections

The survey was the primary input to the trade-off model and the estimation of policy impacts. Specific capabilities had to be incorporated, and it was necessary to decide well in advance on (a) the specific policies to be tested and (b) the specific attributes to be used in defining the modal alternatives.

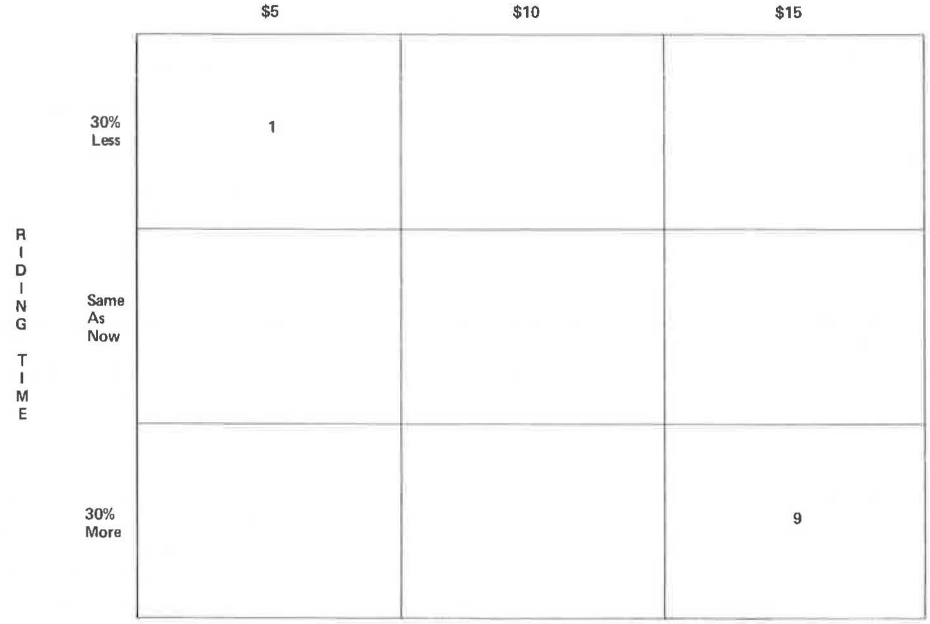
Test Policies

Nine generic travel-time sensitivity tests and 14 specific policies were chosen for simulation. The sensitivity tests were included to permit evaluation of the impact of discriminatory travel-time changes, which was difficult to measure with the specific realistic policies being considered. The policies that were to be tested included (a) gasoline rationing, (b) four different adjustments to parking rates, (c) two levels of gasoline surcharge, (d) a surcharge on tolls, (e) a tax rebate for car-pool members, (f) three kinds of car-pool matching programs, and (g) two kinds of improvement in midday transportation for commuters. These policies applied to specific target groups and were defined at levels representative of administratively feasible programs.

Simulation Attributes

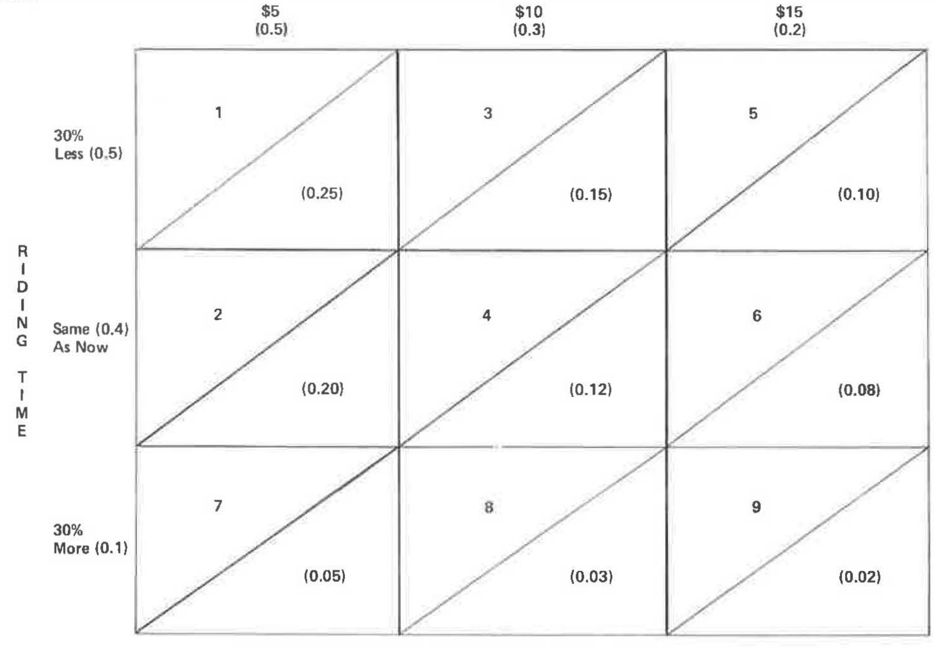
The trade-off model approach requires that a work trip by a given mode under a test policy be defined in terms of a set of selected trip attributes. The attributes must adequately discriminate among modes under a given policy and among policies for a given mode, and the set of attributes must span the major dimensions of commuter trip preferences but not be so large as to impose an unreasonable burden on the typical respondent in the form of trade-off questions. The following attributes

Figure 1. Trade-off problem in the matrix format.



RIDING TIME	$5	$10	$15
30% Less	1		
Same As Now			
30% More			9

Figure 2. Possible trade-off responses and utility levels estimated by the model.



RIDING TIME	$5 (0.5)	$10 (0.3)	$15 (0.2)
30% Less (0.5)	1 (0.25)	3 (0.15)	5 (0.10)
Same (0.4) As Now	2 (0.20)	4 (0.12)	6 (0.08)
30% More (0.1)	7 (0.05)	8 (0.03)	9 (0.02)

were chosen for use with the model:

1. Mode used (drive alone in an automobile, drive with passengers in an automobile, be driven by another in an automobile, ride public transportation);
2. Travel cost (including gasoline and tolls or transit fare as appropriate);
3. Parking cost;
4. Extra time (time spent walking, waiting for others or for public transportation, and picking up or dropping off others);
5. Riding time (line-haul time or total elapsed door-to-door time minus extra time);
6. Number of people in the vehicle;
7. Ease of finding others to share a ride;
8. Ease of finding transportation during the day for personal business; and
9. Supply of gasoline available for consumption.

The mode attribute was included to reflect unique modal characteristics not reflected in the remaining attributes.

The Survey

The survey that was central to the marketing approach adopted for the study was specially designed to provide (a) basic preference data for the trade-off model, (b) the parameters and base condition values necessary to simulate the various car-pooling policies, and (c) trip characteristics and socioeconomic and attitudinal data useful in evaluating the various policies.

Limitations on time and funds dictated the selection of three representative metropolitan areas for survey sampling: Chicago, Pittsburgh, and Sacramento. No three cities could possibly span all combinations of conditions that might influence modal choice and car-pooling potential but, for study purposes, these three cities were reasonably representative. The actual survey was conducted during the period from July 18 through August 3, 1975. Respondents were commuters selected from sampled households. In each of three approximately concentric "rings" in each region, 100 interviews were conducted for a total of 300 interviews in each city. The employed population of each ring, based on 1970 census data, was used to factor the sample results to total area figures.

Calibrating and Validating the Model

The model was calibrated by establishing the numerical utility values for each level of each attribute for the individual respondent. A computational algorithm, based on the model theory discussed previously, was applied to the respondents' trade-off answers to obtain these utility values. The model was validated by using the trade-off model to simulate the base case (conditions prevailing during the survey period) and comparing the estimated modal split with the modal split calculated from the actual responses for "mode currently used." Survey responses were used to define for each respondent the value of each attribute that best characterized his or her work trip by each competing mode for the base case.

Mode-specific adjustment factors were calculated as the ratios of the actual reported mode shares to the values estimated by the model. These factors were applied to all subsequent model estimates to ensure the best fit of the model to reality. They represent mode-specific adjustments that should not vary significantly with the policy being tested. Thus, modal-split estimates for various policies, relative to base-case values, should not be affected by these adjustments.

Policy Simulations

The trade-off model was used directly to simulate all cost-related policies and the various time-related sensitivity tests. Modifications to attribute levels were computed separately for each individual based on his or her work-trip situation. In some cases, only a portion of the total population was affected by the policy and the adjustments were made only for this group. The remaining respondents kept their base-case attribute levels.

Simulation of a gasoline rationing policy required special treatment because it involved a basic change in the modal choice faced by the respondent rather than a simple change in attribute levels. A procedure was developed by which the responses to a series of special survey questions were used to adjust the base-case modal splits. These questions asked respondents to indicate the percentage of time they would continue to use their current travel mode and the percentage of time they would switch to the other modes for the work trip when they were faced with a specified decrease in gasoline supply for total travel. The individual base-case modal splits were adjusted on the basis of these mode-change percentages to obtain modal-split estimates under rationing conditions.

Policies that affect the ease of finding a car-pool match and the availability of midday transportation also change the basic car-pool environment. To simulate policies in these areas, several special trade-off questions were asked of each respondent to determine his or her utility values under an assumed change in the car-pool environment. A revised set of utility values was computed for each respondent under the altered conditions. The various car-pool-matching and midday-transportation policies were then simulated by using the appropriate set of modified utility values in the same way as they are used for the other policies.

Impact Estimates

The trade-off model runs produced estimates of modal split for the simulated case or policy. Three other types of policy impacts were estimated from the modal-split results (3):

1. Vehicle kilometers of travel—Vehicle kilometers of travel associated with work trips were estimated by applying respondents' specific work-trip frequency and trip-length factors and average mode-specific vehicle occupancy factors to each respondent's estimated mode-split distribution. These estimates of vehicle kilometers of travel were then expanded by using the appropriate sampling rate factors to permit aggregation of the estimates by group and for the metropolitan area as a whole.
2. Fuel consumption—By using available transportation planning data from the region and responses to survey questions, a matrix was developed for converting vehicle kilometers of travel by origin and destination in the sampled ring to vehicle kilometers of travel by average speed and road type. This made it possible to apply speed-specific and facility-type-specific average fuel-consumption rates to estimated vehicle kilometers of travel to obtain fuel-consumption estimates.
3. Air Pollution—Estimates of three types of automotive air-pollutant emissions (carbon monoxide, hydrocarbons, and nitrogen oxides) were made. The procedure was analogous to that used for the fuel-consumption estimates. Speed-specific emission rates were applied to the estimates of vehicle kilometers of travel by average speed.

OBSERVATIONS ON USE OF THE TRADE-OFF METHODOLOGY

Adapting the trade-off methodology to modal-split estimation and applying it to estimating the impact of car-pooling policies revealed both major strong points and problem areas.

Survey

Work-Trip Map Tracings

One of the more unusual aspects of the survey was the map tracing each respondent was asked to make of the actual route to work. Minor logistical problems arose in supplying the appropriate maps for all respondents to use, but the results were generally good. Although map tracings are not generally appropriate as a data-collection method, their use in this survey proved to be a reasonably accurate and effective procedure for obtaining data on length of the work trip, home and workplace location, and similar work-trip parameters.

Cross Tabulations

The survey was conducted primarily to provide the raw preference data for the trade-off model. However, tabulations and cross tabulations of the survey responses were also generated, and these proved to be valuable adjuncts to the results obtained by the trade-off model in adjusting model estimates and evaluating policy potential. The special tabulation on the alternate use of a vehicle left at home, an example of the first type of side benefit, provided data for adjusting the estimates of first-order savings in vehicle kilometers of travel. This adjustment is necessary to account for other household members' use of a vehicle left at home by a commuter who is projected as switching to car pool or transit.

Ambiguity of Questions

Despite careful design and pretesting of questions, survey results indicated a number of areas in which ambiguity remained or respondents otherwise experienced difficulty in giving accurate answers. For example, the analysis of survey answers indicated that, despite instructions to the contrary, respondents were including non-work-trip as well as work-trip fuel consumption in their estimates. Probable causes were a lack of emphasis in the question or the inability of the respondent to make such an estimate. Such sources of survey errors can be identified and largely remedied or circumvented in subsequent applications. More intensive interviewer training would also help to reduce this problem.

Trade-Off Model

Use of Soft Variables

One of the major advantages of a marketing technique such as the trade-off model is the ability to deal with so-called soft variables. Car pooling is clearly an area of transportation in which less easily quantified trip attributes such as comfort, dependability, and midday mobility are important considerations. The more traditional modal-split techniques can only indirectly and inadequately deal with such attributes.

Adaptation of the trade-off model was proposed as an approach that could handle these soft variables. Perceptions, opinions, and preferences with respect to any possibly significant attribute could be asked of a respondent in a survey. But for an attribute to be incorporated into application of a trade-off model, the various levels of the attribute must be presented unambiguously and consistently to all respondents. The attribute and its levels must also be such that any policy that is to be simulated can be associated with a specific change in the level of the attribute for a given individual and mode. In designing the survey instrument and the specifications for policy simulation, it was found that these requirements are difficult to satisfy for some attributes.

For example, if comfort were chosen as a work-trip attribute, the levels chosen to express that attribute in the trade-off questions might be very comfortable, somewhat comfortable, and not comfortable. Does any given respondent know how much comfort is meant by very comfortable? Just as important are questions on the use of such an attribute in policy simulation. For example, a respondent reports a certain comfort level in using public transportation. A policy is implemented that calls for installing more comfortable seats in all public transportation. Even if it can be assumed that the respondent experiences an increase in comfort, how is the new comfort level estimated for purposes of policy simulation?

These problems do not mean that the trade-off model cannot address the attribute of comfort. They do suggest that treatment of such soft attributes will be more complex than that of easily quantifiable attributes. Most likely, comfort would have to be disaggregated into more specific attributes such as level of temperature control, the exclusion of smokers, and legroom, which do meet the above requirements. However, the resulting increase in the respondent's burden in the trade-off task must be carefully balanced against the desirability of explicitly treating such a soft attribute.

Environmental Factors

In the application of the trade-off model to the problem of estimating the impacts of car-pooling policies, some factors important in the mode-choice decision turned out not to be true trade-off attributes. For example, factors such as gasoline availability, the ease of finding a car-pool match, and the ease of obtaining midday transportation were more environmental in nature than characteristic of a specific work trip. These background factors could influence the modal decision but could not really be treated as attributes of the work trip itself and thus could not be directly traded off. Special procedures were used for incorporating these characteristics into the simulations, as discussed earlier. However, the procedure used for the car-pool-matching and midday-transportation factors did not deal satisfactorily with the problem. Further work is necessary on incorporating such factors into the trade-off model approach.

Disaggregate Nature of the Model

One of the greatest strengths of the trade-off model was found to be its ability to deal with the preferences, characteristics, and circumstances of respondents on an entirely individual basis. This capability was used extensively in the study application. Two examples are (a) the use of the respondent's reported transit availability in policy simulations and (b) the use of the reported home-to-work distance for the work trip in the estimation of vehicle kilometers of travel.

Model Application

The original unadjusted base-case modal-split estimates of the model did not match average reported modal split. A set of regional adjustment factors for mode preference were applied to model utility values across the four modes to replicate reported modal split at the metropolitan-area level. The need for such adjustment factors is probably attributable to three problems:

1. Analysis of the summary utility results of the model suggests that respondents did not impart to the mode attribute all of their mode preferences not captured by the other attributes that were explicitly traded off. Some of the variations in mode preferences, based on comfort and other attributes not explicitly included in the trade-off questions, were evidently not expressed in utility scores for the four modes. Respondents' confusion as to what was being held constant and what was to be included as implied by a given mode was most likely responsible.
2. The expense-sharing assumptions used to simulate the base case may have been misleading. Dividing total vehicle expenses by the average number of occupants for the two car-pool modes probably overstates the degree to which cost sharing is perceived by commuters. Simulation assumptions used in future work should reflect this.
3. Car-pool modes were broken down into two submodes: driver and passenger. Because an assumption of proportionality was used to convert mode utilities to estimates of modal split, splitting a mode into two submodes tends, if everything else is equal, to give the resulting pair a greater total normalized utility proportion. This probably does not affect the model's accuracy in making relative impact estimates for different policies, but it does contribute to the need for base-case modal adjustments.

CONCLUSIONS

The trade-off model approach has been shown to be quite successful in its application to a rather complex problem of impact estimation. The strengths and the potential of the approach as an effective alternative to conventional modal-split techniques warrant further developmental work. Two major areas that would merit investigation in future research are (a) the possibility of expanding the size of a workable trade-off problem by splitting the answering task among several respondents who represent a single socioeconomic or travel group and (b) the feasibility of incorporating a soft factor in the trade-offs by using several more tangible component variables.

ACKNOWLEDGMENTS

The research for this paper was performed under contract for the Federal Energy Administration. We would like to thank the FEA project manager, Anne Marie Zerega, for her assistance and guidance in completing this project. We would also like to thank the following persons and their agencies for the data that they so graciously provided: Wade G. Fox of the Southwestern Pennsylvania Regional Planning Commission, Chalabi and Bell of the Chicago Area Transportation Study, and Don MacVicar of the California Department of Transportation.

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Reductions in Automobile Use in Four Major Cities as a Result of Car Pooling and Improved Transit

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Voluntary car-pool matching programs and improvements in transit services are two transportation control policies that have received wide support from environmentalists, energy-conservation groups, and the public. This paper presents estimates of how these two policies would affect vehicle kilometers of travel and automobile emissions in Boston, Los Angeles, Chicago, and Washington, D.C. Because the four cities differ widely in terms of their spatial structure and their transportation systems, the estimates should cover the range of impacts expected in many large cities. The results indicate that car pooling will reduce vehicle kilometers of travel and automobile emissions by roughly 0.1 percent if pessimistic responses to employer-based car-pool matching programs are used and by as much as 1.5 percent if optimistic levels of participation are used. Improvement in transit performance, represented as a 20 percent reduction in travel time, is projected to reduce vehicle kilometers of travel by 0.5 to 1 percent and automobile emissions somewhat less. Crude cost-effectiveness analyses suggest that voluntary employer-based car-pool matching programs are attractive even if they only reduce vehicle kilometers of travel by 0.1 or 0.2 percent. The costs of improved transit service are difficult to estimate, but some bus-lane proposals are likely to be cost effective. However, savings that result from reductions in vehicle kilometers of travel attributable to improved transit performance are unlikely to justify investments in fixed-rail systems.

Much can be learned about the effects of various transportation control programs by analyzing their impacts in several large cities that have widely varying characteristics. The four cities included in this analysis—Boston, Chicago, Los Angeles, and Washington, D.C.—cover a wide range of employment and population densities, spatial organizations, transit use rates, and development paths. At one extreme is Boston—an old, high-density northeastern city with an extensive transit system. At the other is Los Angeles—a new, low-density southwestern city with an automobile-oriented development pattern.

Data given in Table 1 (8, 10) reveal pairwise similarities between Boston and Washington and Chicago and Los Angeles in terms of population, central-city share of the population of the standard metropolitan statistical area (SMSA), and central-city area. Population trends indicate that only the Los Angeles central city is still growing; the other three central cities peaked in 1950 and have since declined. Table 1 also gives the year when each city reached half its maximum population, a common way of measuring a city's age (4). By this definition Boston is the oldest and Los Angeles the youngest of the four cities. Measuring the age of a city is useful because it indicates when the city was laid out and provides information about the age of the housing stock and the type of transportation available. The two older cities, for example, have extensive transit systems whereas Los Angeles residents rely largely on automobiles.

The spatial distribution of activities within urban areas can be an important determinant of how effective transportation control programs are. Table 2 gives summary information about population and employment distributions within the four cities (8). Data are shown for the central business district (CBD), the central city other than the CBD, and the metropolitan area other than the central city. These areas roughly comprise the center and two concentric rings. Population distributions given in Table 2 mirror the numbers in Table 1: In all four areas more than half the population lives outside the central city and very small proportions live in the CBD. Employment is nearly as suburbanized as population; only in Chicago does the suburban ring contain less than half of SMSA employment. These distributions suggest that urban workers are likely both to live and to work in the suburbs.

The CBDs in the four cities contain a large number of jobs in absolute terms, but only in Washington does the share of metropolitan-area employment exceed 10 percent. The popular misconception that most jobs are in the CBDs undoubtedly stems from observation of high CBD employment densities, which, as shown by data given in Table 2, are always an order of magnitude larger than for the rest of the central city. Employment and population densities in Washington and Boston are very similar for the CBD and the central city; Chicago has very high CBD employment densities whereas the Los Angeles CBD has the lowest employment density of the four cities.

Table 1. Population and area of four urban areas studied.

Item	Boston	Los Angeles	Chicago	Washington
SMSA population in 1970	2 754 000	7 041 000	6 978 000	2 862 000
Central-city population in 1970	641 000	3 169 000	3 367 000	757 000
City's percentage of SMSA population	22.1	45.1	48.2	26.0
City's percentage of SMSA area	3.6	11.2	6.0	2.2
Area, km^2				
SMSA	3 578	11 302	10 330	7 811
City	128	1 264	617	169
Date central city reached half of maximum population	1885	1936	1903	1918

Note: 1 km^2 = 0.386 $mile^2$.

Table 2. Employment and population distributions.

	Employment			Population		
Location	Percentage	Jobs	Jobs/km^2	Percentage	Persons	Persons/km^2
Boston						
CBD	7.6	91 000	253 000	0.1	3 700	10 300
Rest of central city	29.3	351 000	22 000	23.1	637 000	39 320
SMSA other than central city	63.1	757 000	1 690	76.7	2 113 000	4 725
Total	100	1 199 000		100	2 754 000	
Los Angeles						
CBD	4.3	143 000	144 000	0.3	22 150	22 290
Rest of central city	43.9	1 446 000	8 900	44.7	3 147 000	19 330
SMSA other than central city	51.8	1 707 000	1 300	55.0	3 872 000	2 975
Total	100	3 296 000		100	7 041 000	
Chicago						
CBD	8.3	252 000	453 000	0.1	4 826	8 650
Rest of central city	46.4	1 413 000	17 800	48.2	3 364 000	42 380
SMSA other than central city	45.3	1 379 000	1 095	51.7	3 609 000	2 870
Total	100	3 044 000		100	6 978 000	
Washington						
CBD	11.7	147 000	296 000	0.2	5 105	10 280
Rest of central city	33.8	424 000	19 750	26.3	752 000	35 045
SMSA other than central city	54.5	683 000	690	73.5	2 105 000	2 125
Total	100	1 254 000		100	2 862 000	

Note: 1 km^2 = 0.386 $mile^2$.

Table 3 gives the interactions between residential locations and workplaces in terms of a trip table (8). Ring-to-ring trips comprise the largest share of work trips in all four cities although only in Boston does this category represent a majority of work trips. The trip tables for Boston and Washington are similar, as are the tables for Los Angeles and Chicago, reflecting the data given in Table 1 on the size of their central cities.

The importance of the trip table becomes apparent when the journey-to-work mode choice, which varies significantly by workplace as well as by the residence-workplace combination, is examined. In most metropolitan areas, the transit system has a strong radial orientation to the CBD; this often makes transit service between points outside the central city nonexistent or circuitous and time-consuming. The poor service caused by such circuitous routing often means that very few trips originating at and destined for the suburban ring will be made by transit. Moreover, it is often difficult to use transit to make work trips from the city center to outlying areas because of scheduling problems or poor transit service to suburban workplaces.

Table 3. Percentage of total work trips from residence to workplace.

	Percentage of SMSA Work Trips			
	Workplace			
Residence Location	CBD	Non-CBD Central City	Ring	Total
Boston				
Central city	3.0	13.5	4.5	21.0
Ring	4.3	13.3	50.1	67.7
Outside SMSA	0.3	2.5	8.5	11.3
Total	7.6	29.3	63.1	100
Los Angeles				
Central city	2.4	28.2	12.2	42.8
Ring	1.8	15.3	37.8	54.9
Outside SMSA	0.2	0.5	1.8	2.5
Total	4.4	44.0	51.8	100
Chicago				
Central city	5.3	35.0	7.4	47.7
Ring	3.0	11.0	36.7	50.7
Outside SMSA	0.1	0.5	1.2	1.8
Total	8.4	46.5	45.3	100
Washington				
Central city	4.7	16.8	4.7	26.2
Ring	6.7	15.6	46.4	68.7
Outside SMSA	0.3	1.4	3.3	5.0
Total	11.7	33.8	54.4	100

Work trip mode choices by workplace, taken from data in the 1970 Census, are given in Table 4. Data for persons per automobile have been calculated by dividing the sum of automobile drivers and passengers by the number of automobile drivers. Across the four cities studied, transit's share uniformly declines and the share of automobile-driver trips increases with workplace distance from the CBD. Walking is one mode often overlooked by transport planners, and Table 4 reveals its importance: In Los Angeles, walking is only slightly less popular than transit as a mode to work.

In all four cities the automobile occupancy rate for work trips declines with increasing workplace distance from the CBD. High automobile occupancy rates in the Washington CBD undoubtedly reflect the impact of the federal employee car-pooling program that has been encouraged there for many years. An interesting contrast is the workplace-related change in automobile occupancy rates and share of work trips made by automobile passengers. The automobile passenger share, a measure of car-pooling activity, increases with distance from the CBD in Boston and Chicago but decreases in Los Angeles and Washington. The low share of automobile passenger trips made to the Boston and Chicago CBDs is probably attributable to the presence of extensive transit systems, which suggests that car-pooling and transit are competing modes.

VOLUNTARY CAR-POOL MATCHING PROGRAMS

Car pooling and other high-vehicle-occupancy policies have aroused great enthusiasm as techniques for reducing vehicle kilometers of travel in urban areas. These policies have many strengths: (a) They use existing fa-

Table 4. Work-trip mode split and automobile occupancy by workplace.

	Mode Split (%)						
Workplace Location	Automobile Driver	Automobile Passenger	Transit	Walk	Taxi	Other	Persons per Automobile
Boston							
CBD	29.0	7.6	57.4	4.8	0.6	0.6	1.26
Rest of central city	49.2	11.3	25.6	10.7	1.5	1.8	1.23
SMSA other than central city	65.6	13.1	7.4	9.4	0.7	3.9	1.20
All	58.0	11.6	17.0	9.5	1.0	2.9	1.21
Los Angeles							
CBD	62.2	13.1	22.2	1.2	0.0	1.3	1.21
Rest of central city	76.8	8.4	6.4	4.4	0.0	3.9	1.11
SMSA other than central city	80.5	8.9	2.5	4.2	0.1	3.8	1.11
All	78.2	8.6	5.2	4.1	0.1	3.8	1.11
Chicago							
CBD	18.8	3.7	75.6	1.1	0.5	0.4	1.20
Rest of central city	49.8	9.5	30.3	8.3	0.3	1.9	1.19
SMSA other than central city	70.6	13.4	5.8	5.7	0.3	4.1	1.19
All	57.0	10.8	22.6	6.5	0.3	2.8	1.19
Washington							
CBD	39.0	18.0	35.4	4.0	1.9	1.3	1.46
Rest of central city	54.2	14.1	22.6	5.0	1.4	2.7	1.26
SMSA other than central city	72.0	11.5	5.8	5.2	0.8	4.6	1.16
All	62.2	13.1	14.9	5.0	1.2	3.6	1.21

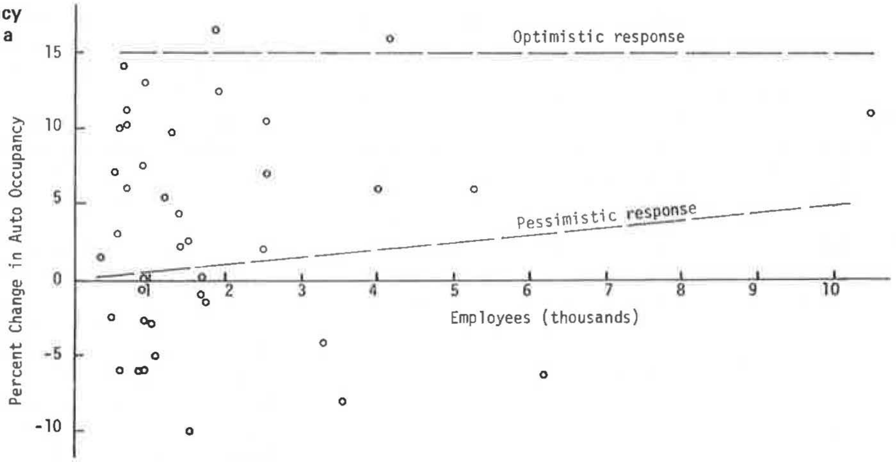

Figure 1. Change in automobile occupancy for New Jersey firms that participated in a car-pool matching program.

cilities and do not call for massive public or private investments, (b) they can be as efficient as some higher occupancy modes such as buses, (c) they involve few public employees, and (d) they can serve almost any location presently accessible by automobile. The major difficulty with high-vehicle-occupancy policies is their service characteristics. Car and van pools have particularly inflexible schedules: The service is offered once a day to a member, and changes in trip times generally require the consensus of all members.

The difficulty of finding potential car poolers has been significantly reduced in many metropolitan areas by publicly supported, voluntary car-pool matching programs that solicit information from commuters and match groups by origin, destination, and time of travel (2, 3). Perhaps the major service of such programs is their lowering of car-pool "transaction costs." The number of successful car pools formed by areawide voluntary programs has been very small, however. Car pooling has been much more successful when it involves employees from a single firm; these individuals are less likely to be strangers and typically share workplace and work hours, and so residential location is the major dimension requiring commonality. As a result, most metropolitan car-pooling programs are now employer based.

Theoretical work suggests that the proportion of successfully matched applicants in a car-pool program will increase with the number of applicants (3). This observation has led designers of employer-based programs to solicit potential car poolers only from large firms. The Massachusetts Mass Pool program, for example, deals only with firms that have 250 or more employees.

Estimating the impacts that a voluntary employer-based car-pool matching program would have in the four selected cities requires three major steps:

1. Presentation of data on the "dose-response" relation between car-pooling programs and increases in car pooling,
2. Definition of the pool of potential candidates in terms of employment distribution by firm size (number of employees), and
3. Application of the dose-response relation to the pool of potential candidates to determine how a voluntary matching program affects vehicle kilometers of travel in each of the four metropolitan areas.

Automobile Occupancy Rates

Because relatively few of the early matching programs were employer based, data that link changes in car-pooling rates to the application of voluntary, employer-based car-pool matching programs are relatively rare. Data from 42 New Jersey firms that participated in a car-pool matching program begun in the winter of 1973-1974 measure changes in car-pooling activity in terms of the percentage change in each firm's automobile occupancy rate over 18 months.

Figure 1 relates the change in automobile occupancy rates to firm size and reveals that firm size has no strong effect. The decline in automobile occupancy rates for many firms is attributable to employment reductions that disrupted car pools and to the high level of voluntary car pooling during the 1973-1974 energy crisis. Given the wide distribution of data in Figure 1, two extreme responses to an employer-based car-pool matching program are hypothesized. An optimistic response, defined by the upper bound of points, is approximately a 15 percent increase in automobile occupancy rates independent of firm size. A pessimistic response, defined by the lower bound of positive changes, increases linearly from zero at a firm size of zero to 5 percent at a firm size of 10 000. These responses serve to bound the experience of firms in other areas.

Distribution of Employment by Size of Firm

Many analysts believe that increases in car pooling vary with firm size. Although the data in Figure 1 do not support such a relation, they are certainly not the final word on this matter. Furthermore, the smallest firm shown in Figure 1 has 350 employees. Because some employer-based programs have a minimum firm-size requirement, the distribution of employment by size of firm will show what proportion of workers will be eligible as the minimum size is varied.

Table 5 gives the cumulative distribution of employment by firm size based on 1973 county business patterns and the 1970 Census. There are obvious differences among the four metropolitan areas: Chicago has many large firms and Washington many small companies. In the suburbs of Washington only 30 percent of private employment is in firms with 250 or more employees, whereas in Chicago roughly 44 percent of suburban employment is in such firms. In all four cities about 15 percent of employment is in firms with 100 to 249 employees; thus, from 45 percent (Washington suburbs) to 60 percent (Chicago) of private employment is in establishments with more than 100 employees. Obviously, therefore, the minimum required firm size for employer-based car-pooling programs must be carefully selected because moving that minimum point from 250 down to 100 can have such a large impact on the percentage of

Table 5. Cumulative percentage distribution of employment by firm size.

Number of Employees in Firm	Employment Distribution (%)							
	Boston		Los Angeles		Chicago		Washington	
	Central City	Ring	Central City	Ring	Central City	Ring	Central City	Ring
1 to 49	31.36	36.60	36.28	37.66	29.43	31.34	34.66	42.77
50 to 99	42.87	48.07	47.40	49.05	39.89	41.71	45.99	55.23
100 to 249	58.54	61.83	61.71	63.46	54.74	55.99	60.12	70.11
250 to 499	69.53	71.87	70.97	73.15	65.82	67.79	71.22	79.01
500 to 999	78.37	80.54	79.10	81.00	74.99	76.71	77.60	85.42
1000 to 1499	83.67	85.65	83.28	84.96	80.51	81.98	82.98	90.78
1500 to 2499	88.76	90.34	86.62	87.89	85.66	86.63	88.82	93.48
2500 to 4999	93.32	94.52	91.22	91.96	91.54	91.99	96.81	97.49
5000	100	100	100	100	100	100	100	100

Note: Excludes workers in the public administration category.

Table 6. Percentage change in automobile occupancy for various responses to car-pool matching program.

Item	Boston	Los Angeles	Chicago	Washington
Persons per automobile				
Average	1.40	1.39	1.4	1.4
Work trip	1.21	1.11	1.19	1.21
Elasticity of total with respect to work trip	0.368	0.339	0.388	0.368
Work-trip share of vehicle kilometers of travel, %	0.38	0.35	0.40	0.38
Increase in automobile occupancy for various car-pool responses, %				
Work-trip estimates				
Pessimistic	0.363	0.583	0.599	0.358
Optimistic				
≥250 employees	6.03	5.72	6.74	5.32
≥100 employees	8.10	7.98	8.92	7.97
Overall estimates				
Pessimistic	0.138	0.203	0.239	0.136
Optimistic				
250 employees	2.21	1.93	2.59	1.96
100 employees	2.93	2.66	3.39	2.89

eligible workers. Accordingly, estimates of car-pool response have been calculated for minimum required firm sizes of 100 and 250 employees.

The firm-size distributions exclude public administration workers, a group that comprises from 6 to 8 percent of the work force in Boston, Los Angeles, and Chicago but 36 percent of central-city workers and 26 percent of suburban workers in Washington. Because of a lack of comparable data for the four cities on firm size for public administration workers, the distribution of public administration employment by firm size is assumed to be similar to that in the private sector. If this proves to be a poor assumption, it will clearly produce the largest biases in Washington.

Reductions in Vehicle Kilometers of Travel

Given the dose-response relations derived from Figure 1 and the distribution of employment by firm size, a range of car-pool-induced changes in automobile occupancy rates can be calculated for each city (Table 6). The basic data on overall automobile occupancy rates for Boston and Los Angeles were obtained from 1963 and 1968 home interview surveys; rates for Chicago and Washington are estimates based on the Boston and Los Angeles figures. The work-trip automobile occupancy figures for the four cities are 1970 Census-based rates reported previously in Table 4. The work-trip shares of vehicle kilometers of travel for Boston and Los Angeles are based on Boston and Los Angeles survey data, and the Washington figure is from a paper by Horowitz and Pernela (5). The work-trip share of vehicle kilometers of travel for Chicago is an estimate based on the work-trip share of total trips.

The elasticity of the overall automobile occupancy rate, derived elsewhere (7), equals the proportion of vehicle kilometers of travel times the proportional change in the work-trip automobile occupancy rate. Because the elasticity varies with the change in work-trip automobile occupancy rates, Table 6 reports the elasticity for a 5 percent proportional increase in the work-trip automobile occupancy rate. This elasticity and the following calculations assume that increases in work-trip automobile occupancy rates result only from redistributing automobile travelers among vehicles and that no travelers on other modes are diverted to car pools. Because a matching program is, in fact, likely to divert some CBD or central-city workers from transit to car pools, the calculations presented may overstate the reduction in vehicle kilometers of travel.

Table 6 also gives the increase in work-trip automobile occupancy rates for the hypothesized responses to a car-pool matching program. The pessimistic estimate assumes that work-trip automobile occupancy rates will increase by 0.0005 percent times the number of employees in a firm. This calculation is done for firms with 250 or more employees and provides a lower bound for the impact of a matching program. The optimistic estimates for firms having ≥250 or ≥100 employees assume that work-trip automobile occupancy rates will increase by 15 percent for these firms. Differences in the estimated change in work-trip automobile occupancy rates among the four cities are caused by differences in employment distribution by firm size. For example, the optimistic estimate for Boston for firms with ≥250 employees is 6.03 percent because only about 40 percent of Boston employment is in firms of that size.

The overall increase in automobile occupancy rates given in Table 6 is obtained by multiplying the change in

Table 7. Percentage reductions in areawide vehicle kilometers of travel and mobile-source HC emissions for various responses to car pooling.

Estimate	Reduction (%)			
	Work-Trip Travel		Induced Nonwork Travel[a]	
	Vehicle Kilometers	HC Emissions	Vehicle Kilometers	HC Emissions
Boston				
Pessimistic	0.124	0.121	0.074	0.073
Optimistic				
250 employees	1.99	1.95	1.19	1.17
100 employees	2.64	2.59	1.58	1.55
Los Angeles				
Pessimistic	0.185	0.183	0.111	0.110
Optimistic				
250 employees	1.76	1.74	1.06	1.05
100 employees	1.43	2.40	1.46	1.44
Chicago				
Pessimistic	0.22	0.22	0.13	0.13
Optimistic				
250 employees	2.4	2.4	1.4	1.4
100 employees	3.1	3.1	1.9	1.9
Washington				
Pessimistic	0.12	0.12	0.07	0.07
Optimistic				
250 employees	1.8	1.8	1.1	1.1
100 employees	2.6	2.6	1.6	1.6

Note: 1 km = 0.62 mile.

[a] Net reductions.

work-trip automobile occupancy rates by the elasticity of the overall occupancy rate with respect to work-trip occupancy rates. Changes in overall automobile occupancy rates vary from nearly zero to 3 percent, a range that seems fairly small. Clearly, however, this is the right order of magnitude because 40 percent of travel is for work trips, 40 percent of the workers are affected, the change is 15 percent, and 0.4 x 0.4 x 0.15 = 0.024.

The next step in the analysis is to translate the increase in automobile occupancy rates into a reduction in vehicle kilometers of travel and automobile emissions. This was done by using a transportation and air shed simulation model (TASSIM) (6) calibrated to Boston and Los Angeles; for this analysis the results were extrapolated to Chicago and Washington. Reductions produced by the various hypothetical car-pooling responses are given in Table 7. Data for vehicle travel and hydrocarbon (HC) emissions for each city show the direct impact on travel, assuming that a reduction in work trips is not accompanied by an increase in nonwork trips. It is likely, however, that the increased availability of automobiles to household members may induce more nonwork travel. Estimates using TASSIM suggest that about 40 percent of the reduced work-trip travel may be replaced by nonwork travel, and this estimate has been supported by others (1). Work-trip car-pool programs might reduce areawide vehicle kilometers of travel by up to 2 percent, although a reduction between 0.1 and 1 percent seems more likely. The adjusted figures for induced nonwork travel may still overstate the reduction in vehicle kilometers of travel because the calculations assume that no transit riders are diverted to car pools.

Diversion of transit riders to car pools interferes with the simple relation assumed so far between automobile occupancy rates and vehicle kilometers of travel. For example, if car-pooling programs only turn transit passengers into car-pool passengers, automobile occupancy rates (and the mode share of automobile passengers) would increase but vehicle kilometers of travel would be unaffected. Furthermore, the data in Table 4 suggested that car pools and transit may be viewed as substitutes, and so some adjustment in projected vehicle kilometers of travel may be called for.

Preliminary estimates have been made of the relation between car pooling and transit ridership for a sample of 159 firms participating in the Massachusetts Mass Pool program. The sample was compiled by Alan M. Voorhees and Associates, Inc. The regression analysis for the entire sample is as follows [numbers in parentheses are t-ratios, and locations of firms are identified by a system of 2.6-km^2 (1-mile^2) grids]:

$$\mathrm{PUBTR} = \underset{(1.8)}{0.198} - \underset{(2.8)}{0.30\mathrm{CP}} - \underset{(9.7)}{0.012\mathrm{LFS}} + \underset{(5.9)}{0.04\mathrm{STN1}} + \underset{(4.2)}{0.013\mathrm{STN2}} - \underset{(0.3)}{0.016\mathrm{SUB}} \qquad R^2 = 0.66 \qquad N = 159 \tag{1}$$

where

PUBTR = proportion of the work force that commute by transit,
CP = proportion of the work force that commute in multioccupancy vehicles,
LFS = log of firm size (number of employees),
STN1 – number of subway stations located in the same 2.6-km^2 grid as the firm,
STN2 = number of subway stations in the eight grid squares that surround the grid square in which the firm is located, and
SUB = dummy variable (1 for suburban location and 0 for central city).

The regression for the stratified sample is as follows:

$$\mathrm{PUBTRC} = \underset{(1.1)}{0.207} - \underset{(2.9)}{0.66\mathrm{CPC}} - \underset{(0.3)}{0.009\mathrm{LFS}} + \underset{(3.7)}{0.034\mathrm{STN1}} + \underset{(3.2)}{0.016\mathrm{STN2}} \qquad R^2 = 0.44 \qquad N = 76 \tag{2}$$

$$\mathrm{PUBTRS} = \underset{(1.9)}{0.204} - \underset{(0.6)}{0.047\mathrm{CPS}} - \underset{(1.4)}{0.023\mathrm{LFS}} + \underset{(3.8)}{0.150\mathrm{STN1}} + \underset{(0.6)}{0.002\mathrm{STN2}} \qquad R^2 = 0.36 \qquad N = 83 \tag{3}$$

where

PUBTRC = PUBTR for central-city firms,
PUBTRS = PUBTR for suburban firms,
CPC = CP for central-city firms, and
CPS = CP for suburban firms.

The table below gives the means for the work-force variables used in the analyses:

Variable	Mean
CP	0.217
CPC	0.181
CPS	0.251
PUBTR	0.240
PUBTRC	0.428
PUBTRS	0.069

The regression for the entire sample indicates that 30 percent of new car-pool riders will be drawn from transit. Stratification of the sample by employment location reveals that the extent of this diversion from transit differs dramatically: In the central city, 66 percent of new car poolers may be drawn from transit but, in the suburbs, 5 percent. Other studies have also found that transit and car pools are substitutes. Atherton, Suhrbier, and Jessiman (1) estimate that in Washington approximately 25 percent of new car-pool riders attracted

Table 8. Reductions in areawide vehicle kilometers of travel and related savings as result of car pooling and transit improvement.

Item	Boston	Los Angeles	Chicago	Washington
Approximate daily vehicle kilometers of travel, 000 000s	32[a]	210[a]	85[b]	35[c]
Daily vehicle kilometers of travel × 365, 000 000 000s	11.8	76.6	31.1	12.9
1.0 percent of annual vehicle kilometers of travel, 000 000s	118	766	311	129
Value of 1 percent reduction at $0.04/km, $	4 380 000	28 500 000	11 500 000	4 800 000
Value of 0.1 percent reduction at $0.04/km, $	438 000	2 850 000	1 158 000	480 000
Approximate cost of present car-pooling program, $	600 000	1 000 000	270 000[d]	150 000

Note: 1 km = 0.62 mile.

[a] Scaled to the metropolitan area from TASSIM estimates for the air quality control region.
[b] Scaled from Washington vehicle kilometers of travel by population.
[c] From Wickstrom (9).
[d] Costs for a program operated by a radio station.

by an employer-based program would be diverted from transit. If a diversion rate of one-quarter to one-third is applied to the other three cities in Table 7, the maximum reduction in vehicle kilometers of travel from the most optimistic program would be less than 1.5 percent.

From the point of view of designing car-pool-incentive programs, the diversion of commuters from transit can be reduced significantly by not offering a computer matching program to firms if a large proportion of their work forces commute by transit. The mode-split figures in Table 4 suggest, for example, that employees of firms located in the Chicago and Boston CBDs are heavy users of transit and that relatively little would be gained by offering them car-pool matching services.

IMPROVED TRANSIT PERFORMANCE

Improved transit performance has also been suggested as a policy to reduce vehicle kilometers of travel and automobile emissions, but improvements in the form of new transit systems are very costly. Of course, other low-cost alternatives are also available, such as transferring existing highway lanes from automobile to bus use. But such a policy improves performance only where highways are presently congested and is thus likely to benefit high-density central cities more than suburban areas.

The evaluation of improved transit performance as a technique for reducing vehicle kilometers of travel and automobile emissions was carried out for Boston and Los Angeles by using the TASSIM model. In both cities the model was used to simulate the impacts of a hypothetical (and extremely optimistic) 20 percent decrease in transit travel times; vehicle kilometers of travel are reduced because improved transit service induces more travelers to use transit for all or part of their trips. The results of the TASSIM simulations are given in the table below:

	Reduction (%)			
Item	Boston	Los Angeles	Chicago	Washington
Vehicle kilometers of travel	0.50	0.62	0.4	1.1
HC emissions	0.39	0.46	0.3	0.9

Overall vehicle kilometers of travel are reduced by about 0.5 percent in Boston and Los Angeles. The reduction in HC emissions is less because many commuters drive to the transit station and cold-start emissions constitute a large share of total emissions from urban automobile trips.

Because transit serves CBD-destined trips especially well, the TASSIM extrapolations to Chicago and Washington were based on the current share of all CBD-bound automobile trips for the four cities. The results are given below:

	Automobile Work Trips by Workplace Location (%)			
City	CBD	Rest of Central City	Rest of SMSA	Total
Boston	4.0	25.5	70.8	100
Los Angeles	3.7	43.0	53.3	100
Chicago	2.8	41.8	56.4	100
Washington	8.9	30.7	60.5	100

In Boston and Los Angeles, roughly 4 percent of all automobile work trips are made to the CBD; in Chicago the proportion is lower, and in Washington it is higher. Reductions in vehicle kilometers of travel in the table above are based on the importance of automobile use for CBD-bound trips; improved transit is thus expected to have the largest impact in Washington and the smallest impact in Chicago. In both cities the forecast reduction in HC emissions is again less than the reduction in vehicle kilometers of travel because of cold-start emissions.

DISCUSSION OF RESULTS

It is easy to be disappointed by the relatively small reductions in vehicle kilometers of travel projected here for car-pooling and transit improvement policies: from 0.1 to 1 percent of daily areawide vehicle kilometers of travel, depending on the assumptions used. In absolute terms, however, the impact of these reductions is significant. Table 8 gives order-of-magnitude estimates of daily and annual vehicle kilometers of travel for the four case cities as well as the value of 1 percent of annual vehicle kilometers of travel calculated at $0.04/km ($0.06/mile) to approximate out-of-pocket operating costs for automobiles. This rather conservative valuation implies that a 1 percent reduction in annual vehicle kilometers of travel would produce annual savings of from $4 million in Boston to $28 million in Los Angeles. Moreover, the approximate costs of car-pool matching programs suggest that these programs will be cost effective even if they reduce vehicle kilometers of travel by as little as 0.1 percent.

Calculating costs for a transit improvement program that would reduce transit travel time by 20 percent in each of the four cities is difficult. Reserved bus lanes may have relatively low costs and be cost effective, but more detailed analysis on a corridor-by-corridor basis in each city is necessary to produce adequate estimates of improvement costs. The values of a 1 percent reduction in vehicle kilometers of travel suggest, however, that investments in extensive fixed-rail transit systems would probably not be justified in terms of reductions in vehicle kilometers of travel.

A final point worth emphasizing is that transit and car pools appear to be highly substitutable modes for many commuters. This finding suggests that car-pooling programs should not be vigorously promoted in areas where a large proportion of the work force uses transit. The data suggest that extremely high transit use occurs mainly in CBDs but that CBDs typically contain less than 10 percent of a metropolitan area's employment. Even so, car-pool matching programs appear to have a wide potential market.

ACKNOWLEDGMENTS

Research for this paper was supported through an interagency agreement between the Council on Environmental Quality and the U.S. Environmental Protection Agency. The contents do not necessarily reflect the views and policies of the funding agencies. I would like to thank Eugene Kroch and Donald Walls for assistance; William Crowell, Arnold Bloch, and Granville Sewell for related data preparation; and John Attanucci for information and data concerning the Massachusetts Mass Pool program.

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Abridgment

Integrating Transit and Paratransit

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The declining fit of radially oriented transit to today's more dispersed travel, the recognition of the role of taxis, and the growth of paratransit have led to strong interest in integrating conventional transit and paratransit. This interest has been based on the expectation that, by and large, these services complement each other—particularly that paratransit can serve markets for which conventional service is either unequipped or overly expensive. Policy statements by the Urban Mass Transportation Administration (UMTA), the American Public Transit Association, and the International Taxicab Association support service integration.

However, the emergence of paratransit has raised more options and issues than can be dealt with by using current information. For example, there are a bewildering variety of service options—choices between public and private operators, labor questions, regulatory changes, insurance issues, high costs, and requirements for special services, to name just a few. Moreover, although UMTA activities for specific modes, primarily dial-a-ride and its variations, have been in progress for over 5 years, research and demonstrations addressing the integration of paratransit and transit only began within the past 3 years. The Rochester, New York, demonstration began in April 1975; the UMTA areawide demand-responsive transportation projects are just now being started.

Definitive results are not yet available, but the lessons from previous experience and research point toward several general conclusions. This paper highlights such tentative results.

PARATRANSIT IMPACTS

The major impacts of expanded paratransit services appear to be the following:

1. Improved mobility for people permanently or temporarily without access to private automobiles or high-quality transit service;
2. Reduced total cost of transportation for commuters, taxi users, and other individuals; and
3. Reduced congestion or parking requirements at individual employment or activity centers.

Improved mobility might well be the single largest impact of paratransit service. The low demand densities, scattered trip patterns, and special service needs that characterize the travel of people who are currently without adequate transportation are often more appropriate for demand-responsive or local minibus service than for conventional transit. Almost invariably, these people are unable to drive or they find the cost of private automobiles too high; the availability of a private automobile would remove the limitation on their mobility.

Notably missing from the list of impacts are the major national concerns of energy and environmental protection. Improvements in vehicle technology would probably have a larger impact on reducing energy use and pollutant emissions than would any foreseeable effect of paratransit. The percentage of trips by public transportation, about 5 percent nationwide, is so small that the impact of changes such as paratransit on total fuel consumption and emissions is small relative to the total problem. Paratransit by itself is not seen as a solution to energy and environmental problems, but paratransit as an element of the overall transportation system fills some roles—e.g., van pool, subscription bus, or line-haul feeder—better than any other mode.

In addition, the impacts of paratransit are likely to be more noticeable to individual people and at individual employment or activity centers than in national aggregate transportation statistics. As long as the private automobile is the overwhelmingly favored mode of travel, changes in one of the other modes will have only limited effect on the aggregate statistics for total transportation energy, total vehicle kilometers of travel, or total cost of transportation. However, paratransit can have significant impacts on the mobility of the nondriver and on the cost of transportation for commuters, for young families, for the elderly, and for others to whom the cost of one or more private automobiles is too large. Commuter paratransit can affect employer parking costs and the amount of space for parking, and it can affect highway construction by increasing the people-carrying capacity of existing roads.

PARATRANSIT COSTS

A major concern for localities considering paratransit is the cost of service; costs per ride of $1 to $3 have been common. Pooling and volunteer labor reduce costs, but these measures are often not available or not appropriate.

Not long ago, aggregate statistics for conventional bus transit showed average costs of about $0.40/ride. But costs have risen and fixed-route operating costs are approaching $1/ride. A recent UMTA report on the impacts of section 5 of the Urban Mass Transportation Act of 1964 showed that in 1975 one-quarter of the largest U.S. urban areas had bus operating costs of over $0.70/ride. Conventional, fixed-route buses are considerably less efficient for serving the low demand densities and dispersed travel patterns of paratransit markets than they are systemwide. For example, a low-density, suburban Washington, D.C., bus line showed an average operating cost of $2/ride on weekdays and over $12/ride on Sundays; the average cost on the Washington system was $0.78/ride.

In fact, costs of $1 to $3/ride appear to be realistic expectations for low-density service. Low densities limit the amount of possible trip aggregation and thus productivity. Common trip densities range from <2.5 to 12.5 passenger trips/km^2•h (<1 to 5 passenger trips/mile^2•h). At these densities productivity will range from <2 to about 8 trips/vehicle•h. Even at the higher productivity of 8 trips/vehicle•h, the operating cost must be below $8/vehicle•h, among the lowest seen in practice, for the cost per ride to be held to $1. If productivity is lower or operating costs are higher, the cost per ride will exceed $1. When operating costs exceed $20/h, as in the case of the larger transit authorities, low-density productivities lead to costs of $3/ride or more.

Whereas cost per ride is an important measure of efficiency, it is the annual subsidy that measures the impact on the local budget. Commuter paratransit (car pool, van pool, or subscription bus) operates with little or no subsidy. Moreover, any subsidy is visibly associated with an employment center and can be funded in part or in whole by the employers. Local community paratransit, in contrast, is often more highly subsidized by the community and there can be strong competition for tax funds and pressure to resist additional expenditures. The notable exceptions are private shared-ride taxis, such as those in Little Rock, Arkansas, which operate without subsidy.

Faced with competition for local funds, community transportation is being asked to justify its subsidy. The major justifications used are the provision of (a) equitable public transportation service and (b) mobility for people without access to private automobiles. Equity refers to providing public service opportunity in low-density areas in return for tax funds for regional bus or rail service. Providing mobility for the transportation disadvantaged is a well-known problem.

Several approaches to controlling cost and subsidy for community transportation are available. Briefly, these include limiting the coverage and headways of local fixed-route service, limiting those eligible to use demand-responsive service, providing service on limited days, requiring advanced reservations, and using taxis. Other promising approaches include user rather than service subsidies and marginal-cost fare policies to limit the subsidy without restricting the system to selected users.

CONTROLLING SUBSIDIES FOR DEMAND-RESPONSIVE SERVICES

One of the major problems of dial-a-ride has been controlling the total cost of the service. Attempts to hold down costs by deploying a small number of vehicles have failed because the generated demand has overwhelmed the capacity of the system; the resulting poor service has led to strong complaints and, in some cases (e.g., Santa Clara County), to the demise of the service. The conflict is that a dial-a-ride system large enough to satisfy the demand it generates can cost more than a locality can afford, and a system that can be afforded might not satisfy the demand. The limitation of service to special markets (e.g., the elderly and the handicapped), the development of computer scheduling, and the use of taxis address the conflict either by limiting demand, improving productivity, or reducing costs. Recent results suggest marginal-cost fare policies as a method of controlling subsidies.

Providing mobility for people who do not have private automobiles is a common objective of community-level transportation service. In fact, the near-term growth in public transportation is likely to be justified by the need for mobility of those market groups. But transportation services limited to such selected market segments are inherently inequitable; other people with limited mobility are faced with using conventional taxis, depending on relatives, or not traveling. People often not served by special transportation include young families and middle-income families for whom the cost of automobile ownership is becoming too great.

Demand-responsive services oriented toward special markets can be opened to others in the same service area, without increasing the subsidy and at reasonable fares, as long as operating costs are kept in line. The fares for additional passengers can be around $0.80 to $1.50/ride and operating costs about $8 to $15/h.

Table 1 gives a hypothetical example based on the El Cajon, California, shared-ride taxi system. The service in El Cajon is open to anyone in the service area, but 67 percent of the riders are elderly or handicapped. The average fare is $0.38, the subsidy $0.90/ride, and the operating cost $8.16/vehicle•h. The system subsidy is about $21 400/month.

Limiting service to the elderly and handicapped would reduce the operating subsidy to about $17 900/month; as productivity decreased the cost per ride would

Table 1. Estimated results of marginal-cost fare policy for El Cajon shared-ride taxi system.

		Marginal-Cost Fare Policy		
Item	Current System	Limited Service for Elderly and Handicapped	Service to Other Users	Result
Average fare, $	0.38	0.38	0.82	
Monthly passengers	23 700	15 800[a]	4500[b]	20 300
Productivity, passengers/vehicle·h[c]	6.4	5.4		6.0
Cost per ride, $	1.28	1.50	0.82	1.35
Subsidy per ride, $	0.90	1.15	—	0.90
Monthly cost, $	30 400	23 900	3700	27 600
Monthly revenue, $	9000	6000	3700	9700
Monthly subsidy, $	21 400	17 900	—	17 900

[a] Two-thirds of current system passengers.
[b] Estimated from fare-elasticity relations developed in the Haddonfield, New Jersey, demonstration project.
[c] Estimated from a supply model based on the Haddonfield and Rochester dial-a-ride systems.

increase to $1.50. The marginal cost of carrying additional passengers is about $0.82/ride; thus, with fares of $0.38 for the elderly and the handicapped and $0.82 for all others, the system could be open to everyone in the service area and also maintain the subsidy at the lower $17 900/month. Coupons sold at a discount could be used for the lower fare. Thus, a marginal-cost fare policy allows the subsidy to be held at the level of a service for the elderly and the handicapped while mobility is provided to other users. The marginal cost per passenger is lower for added passengers because productivity increases as demand density increases and thus the cost per ride decreases. The marginal cost illustrated here is applicable only if the size of the service area and the hours of service do not change. Different marginal costs would result if the increase in ridership came from such changes.

Both overall subsidy and marginal-cost fare depend on operating cost per vehicle hour, which in turn depends on wage rates, overhead, and work rules. If the cost were $16.32/h, twice El Cajon's $8.16, the marginal-cost fare would double to $1.64 but would still be less than typical exclusive-ride taxi fares for the same trip length. At costs above $20/h, the marginal-cost fare for the shared-ride system becomes greater than the exclusive-ride taxi fare.

TAXI-RELATED IMPACTS

Paratransit offers taxi operators an opportunity to improve productivity, by means of ride sharing, and an opportunity to take part in publicly funded transportation programs. At the same time, paratransit, if publicly operated, threatens to reduce the market for taxi service—possibly, in some locations, to the point where taxis cannot survive.

The productivity of shared-ride services is often 50 to 100 percent higher than that of exclusive-ride taxis. Improved productivity can mean shorter waits for service, higher income for drivers and owners, and lower fares. The future well-being of the taxi industry depends on improving productivity; ride sharing and its associated computer and communications technology appear to provide a major opportunity comparable to the earlier advent of radio dispatching.

Restrictive regulations prohibiting shared-ride taxi services are a major barrier. However, lack of enthusiasm on the part of taxi operators can be a significant reason why the regulations are not changed. Taxi operators function in the restrictive environment of a tightly regulated industry with low profits; in any industry, such an environment is not conducive to risk taking and innovation. Many taxi operators have neither the resources nor the tradition of innovation to encourage substantial changes in methods of operation and the deployment of complex new technology.

Shared-ride operations are significantly more complex than exclusive-ride taxi operations. Shared-ride scheduling for effective aggregation of trips has little counterpart in exclusive-ride dispatching where drivers schedule themselves. An exclusive-ride taxi dispatcher can handle 100 or more vehicles; shared-ride schedulers lose their effectiveness with fleets of 10 to 15 vehicles.

Few taxi operators are experienced in the use and maintenance of computers and digital communications equipment. Such technology is sufficiently important that UMTA is sponsoring research and development to remove some of the uncertainty in its use.

Although participation in public transportation funding may be necessary for survival, it too is accompanied by problems and risks. Acceptance of public funding can be expected to be accompanied by strict accounting requirements, tighter controls on service quality, and public scrutiny of profits. Local and federal labor laws can be expected to be tied to public funding. The impact of these laws is uncertain, but there is no expectation that they will increase the operator's flexibility in dealing with employees nor that they will reduce costs. On the contrary, the concern is that costs will increase beyond what improvements in productivity justify.

FUTURE OUTLOOK

The integration of conventional transit and paratransit is a significant issue for UMTA, local urban areas, and transit and taxi operators. The market for public transportation (i.e., transportation other than by private automobile) is too small to support destructive competition among operators. Transit operators can benefit from the adoption of services that are more responsive to users, such as subscription commuter services, to improve routine efficiency and guarantee seats. On the other hand, there is little or no expectation of public operators taking on express package deliveries or special, doorstep, elderly-and-handicapped services, whereas taxi operators can integrate package delivery, shared-ride, and exclusive-ride services so as to better utilize personnel and equipment.

The most promising opportunities for the near future appear to be the following:

1. Expand services to the elderly and handicapped and coordinate social-service transportation. Transportation for the disadvantaged is a visible problem in many urban areas. Paratransit has the opportunity to show that it can be a solution to the problem, not just another competitor for scarce public funds. The inefficiency of multiple special-purpose transportation providers is beginning to be recognized. The paratransit operator has the opportunity to demonstrate a reduction in total cost by sharing personnel and equipment among services. The improved productivity resulting from aggregation of services can help to lower costs.
2. Expand transit by use of subscription commuter service. Subscription commuter services are the paratransit services most similar to conventional transit. These services appear to have potential productivities high enough to support conventional transit wages and might provide a better means than low-density dial-a-ride for familiarizing transit operators with paratransit. Techniques now being investigated for integrating subscription bus service with multiple working shifts offer promise of efficient 8-h/d utilization of drivers.
3. Expand taxi operations by use of ride sharing.

Taxis can get into ride sharing by contract with public agencies or on their own initiative. Public agencies and taxi operators need to learn much more about how to work together. UMTA is interested in learning more about the characteristics of shared-ride taxis, but there are too few such systems. UMTA intends to fund shared-ride taxi demonstrations, but such funds bring with them unresolved labor issues. Cautious expansion into ride sharing by private operators would add needed experience.

4. Formalize van pooling. More extensive commuter ride sharing can reduce the cost of commuting for both employees and employers if a sufficient number of people can be grouped together. Driver incentives often lacking in informal ride-sharing arrangements can encourage higher load factors. A transportation "broker" can provide supporting information services, such as locating existing pools for new riders, and can assist regular riders in finding needed alternative transportation. Insurance and other problems of formal pooling arrangements need to be addressed.

Other promising services are feeders to line-haul transit, the expansion of public transportation coverage to suburban areas, and the replacement of high-cost conventional transit line segments or very low-density service.