DIAL-A-BUS SYSTEM FEASIBILITY

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Dial-a-bus, a public transportation system offering the desirable characteristics of automobile and taxi travel at a cost only slightly higher than conventional transit, provides door-to-door service with maximum waiting and travel time guarantees. This is made possible by a digital computer that schedules a fleet of small buses to efficiently serve passengers as requests are received.

The basic operational characteristics of dial-a-bus have been described elsewhere and will not be restated in this paper (1, 2, 3, 4). The principal objectives here will be to review the results of research conducted at the Massachusetts Institute of Technology for the Urban Mass Transportation Administration and related to the feasibility of dial-a-bus systems. In particular the following subjects will be discussed: algorithms to schedule dial-a-bus vehicles, alternative system designs for dial-a-bus, cost of dial-a-bus service, and anticipated demand for dial-a-bus.

SCHEDULING ALGORITHMS

The scheduling algorithm decides which vehicle should service each rider and what sequence of pickup and delivery each vehicle should follow. The objective in designing algorithms is to utilize a minimum number of vehicles that provide a given level of service for all riders without violating waiting, travel, and total service time guarantees for each rider.

Algorithm development work was first limited to many-to-one service, i.e., many origins to one destination or one origin to many destinations (5). More recent work has produced algorithms for a complete range of dial-a-bus service. Such algorithms are commonly classified as many-to-many, i.e., many origins to many destinations.

Initial algorithms utilized a single-stop, look-ahead scheduling technique whereby the next stop of a vehicle was selected by the computer whenever a pickup or delivery occurred. More recent work has utilized a provisional-tour approach where a new demand is provisionally or tentatively inserted in a planned tour when the demand is received. The provisional-tour technique considers the state of the entire system at all times, whereas the single look-ahead method utilized only a limited subset of all information. The more sophisticated provisional-tour technique has been able to improve system performance by up to 40 percent (6).

Basically the provisional-tour technique works as follows: When a new demand is received, the trip origin and destination must be inserted in some vehicle tour without violating the waiting, travel, and total time constraints of the new demand, or the constraints of any new demand already scheduled. The decision on where to insert the demand has 2 components: On which vehicle route should the origin-destination pair be inserted? and Where specifically on that route should the insertion take place? The algorithm techniques have been described elsewhere and will only be summarized briefly here (6, 7).

The technique is based on calculating a series of slack times for fulfilling the constraints of each demand. Slack times represent the difference between the latest possible time an event (pickup or delivery) can occur and the time an event is predicted to occur. Slacks are calculated for the waiting time, travel time, and total time of each demand on the system and represent time that could be used to serve other demands without violating the constraints of the examined demand.

In general, many possible choices exist for insertion of the new demand without violating service guarantees to existing demands. Some mechanism must, therefore, be established to decide which of the many possible insertions is best in terms of overall system performance, a difficult decision because of the dynamic nature of the system. If the insertion were to be made based only on the existing system state, the choice would be easy; however, this is not the case because unpredictable new demands will arise and affect the current decisions.

An important aspect of the work was, therefore, to develop and compare selection criteria for insertion of a demand once all feasible insertions were determined. Several

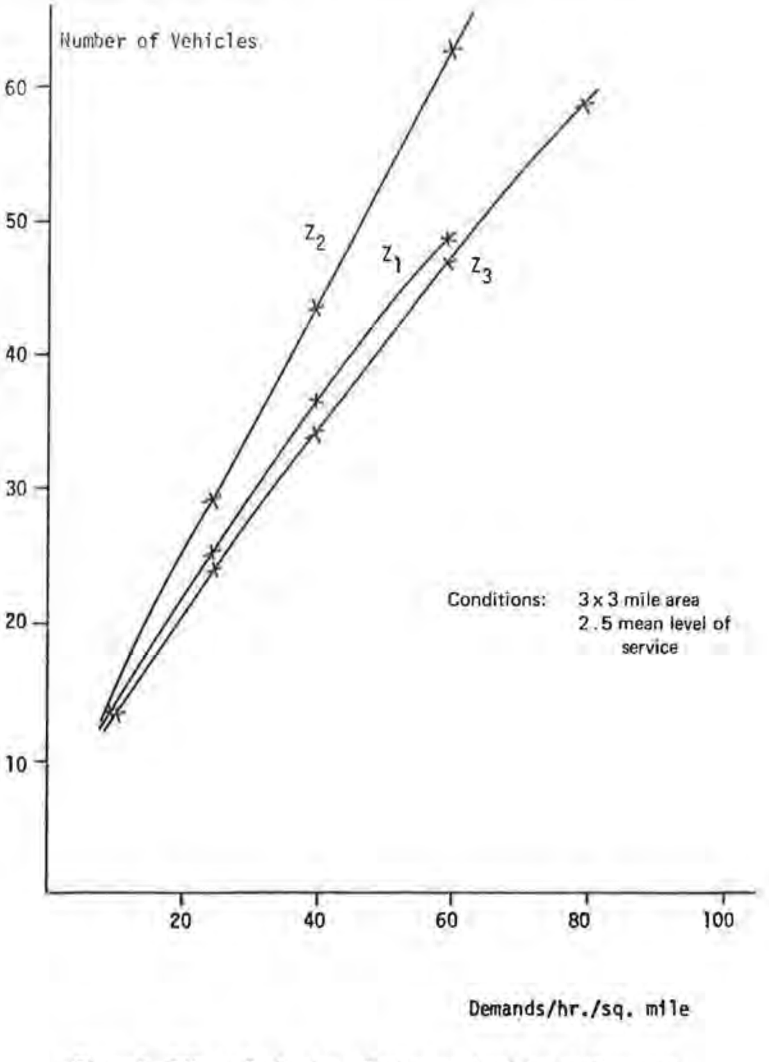

Figure 1. Effect of selection criterion on algorithm performance.

selection criteria were tested to see which produced the best results. Z_1, shown in Figure 1, is a selection criterion that maximizes service to the current system users, whereas Z_2 in contrast maximizes service for future users. The best result, Z_3, is a combination of Z_1 and Z_2 and maximizes service for both current and future users.

VEHICLE PRODUCTIVITY

A good measure of overall system efficiency is vehicle productivity: How many requests can be served by each vehicle in an hour? A large number of simulations were performed by using the provisional-tour algorithm for many-to-many service and objective function Z_3 to establish the effect of the following factors on vehicle productivity: demand density, service area size, and level of service.

Figure 2 shows the implications of demand density. Performance decreases considerably below 20 demands/sq mi/hr and then increases up to about 80 demands after which it diminishes and essentially becomes linear. These results have important implications regarding what type of areas a dial-a-bus system will best serve. More will be said about that later.

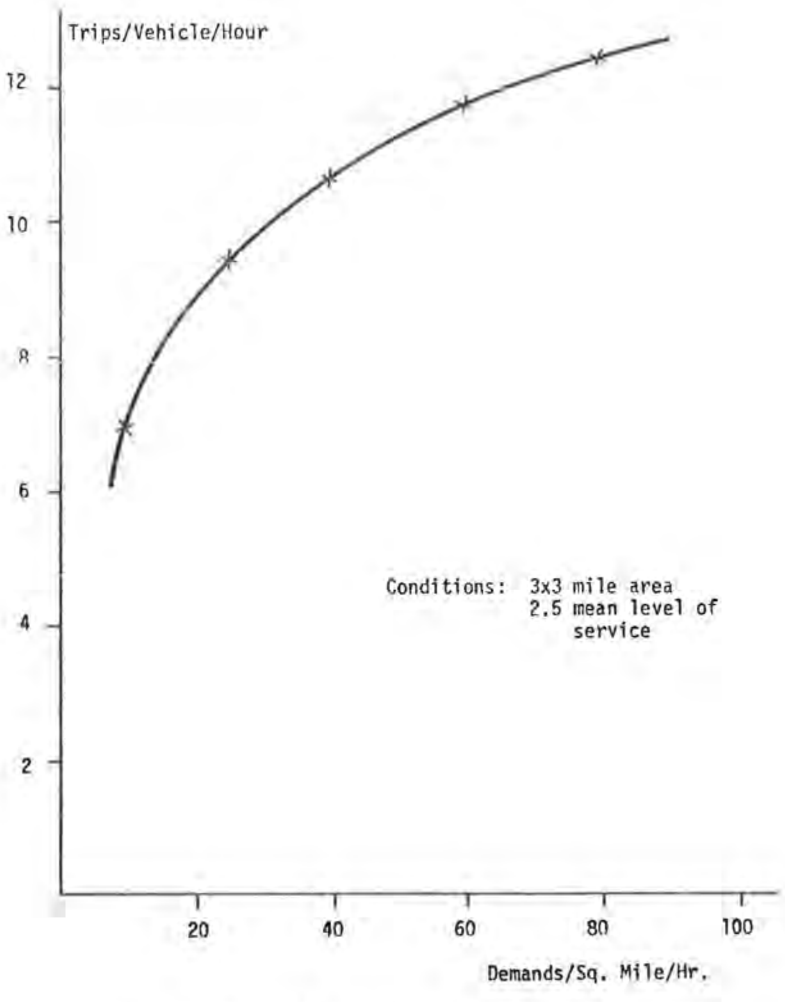

Figure 2. Effect of demand level on vehicle productivity.

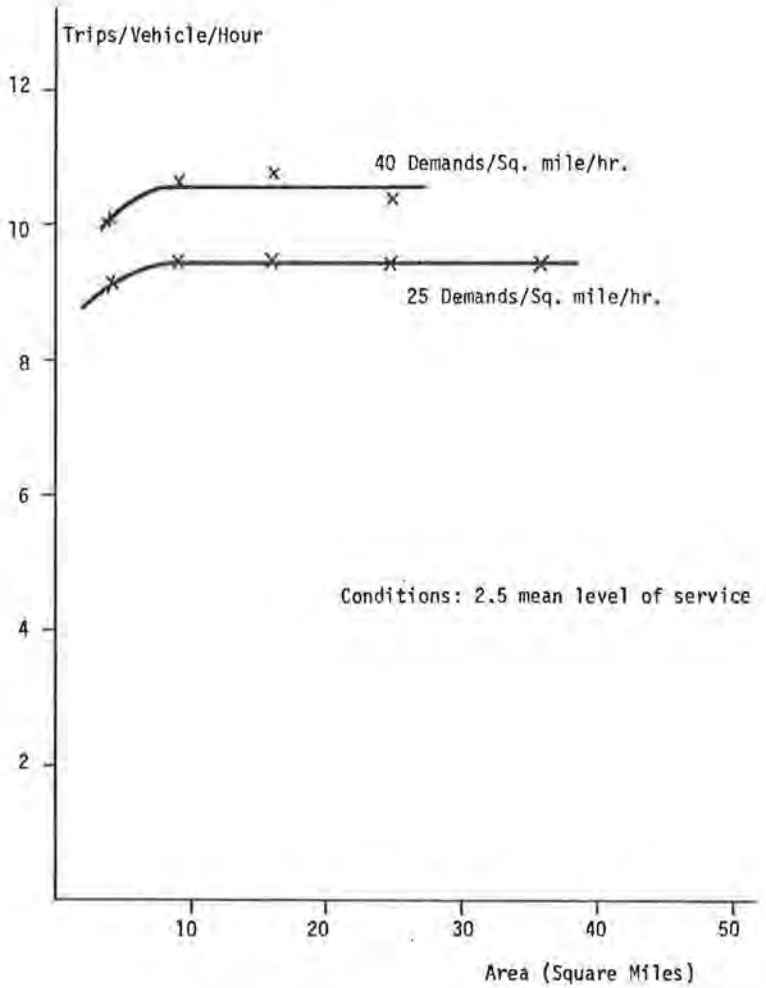

Figure 3. Effect of area size on vehicle productivity.

Figure 3 shows that the somewhat surprising result that, if demand density is held constant, vehicle productivity varies linearly with area size. This implies that there are no economies of scale to be gained by designing dial-a-bus systems to serve larger areas. The principle justification for having large area coverage would be to ensure that all origin-destination pairs were included in the service area.

Figure 4 shows the importance of level of service—the ratio of total service time by dial-a-bus to total travel time by an automobile. The rate of curvature increases sharply between levels 2 and 3. If a better level of service is achieved, the vehicle fleet size would have to be significantly increased. If dial-a-bus were offered with various levels of service at different costs, level-of-service curves would assist in determining the relative costs to be charged.

Many other factors affect vehicle productivity; these include vehicle speed, time required to pick up and discharge passengers, trip length, and the demand pattern used. The last factor is particularly important because vehicle productivity for many-to-one service is almost twice that of many-to-many service. Typically a situation may exist where high activity centers in an area will produce some many-to-one situations even

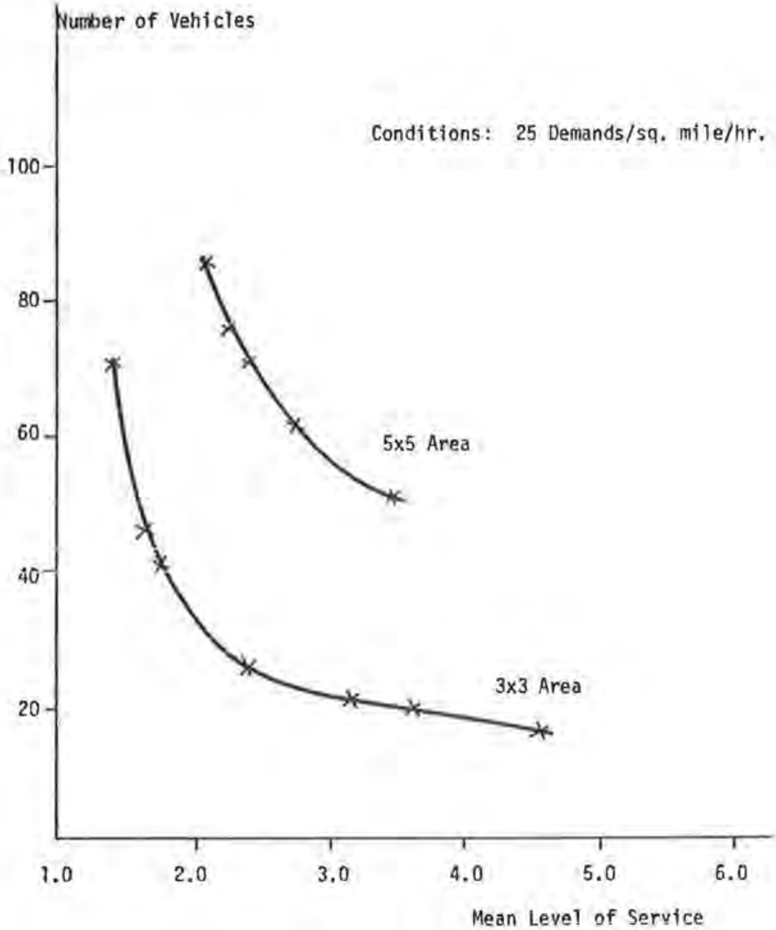

Figure 4. Relationship between number of vehicles and level of service.

when a general many-to-many service is offered. In this case, vehicle productivity will fall somewhere between the pure many-to-one and many-to-many situations.

At present, it is estimated that, for generalized dial-a-bus service, vehicle productivities of 10 to 20 requests per hour are feasible. Because more than one passenger may either board or get off at any stop, it is highly likely that the number of passengers carried per hour will be greater than these figures. Vehicle productivities can be increased by algorithm improvements and service variations. In particular, algorithms could be designed that allow for prescheduled trips. The demand responsive characteristics would then be superimposed over the prescheduled trips.

DIAL-A-BUS SYSTEM DESIGN

The principal components of a dial-a-bus system include customer communication to allow the customer to request service, vehicle communication to allow the vehicle driver to receive scheduling instructions, vehicles to provide service to the customers, and a computer to supervise the operation of the total system. Each of these system components is briefly reviewed here and explained in more detail elsewhere (8).

Customer Communication

The major device to be used for customer communication is an ordinary telephone. Generally, customers will use a private or public telephone; however, in high activity centers direct lines can be provided. Either voice or digital communication is possible. With voice communication, an operator receives trip requests from the customer; with digital communications, the customer uses the buttons of his touch-tone telephone to enter his trip request directly into the computer. Standard or repetitive trips made by the customer will be assigned a simple code number for easy insertion of the requests.

If digital communication is provided, voice communication is still needed for those without touch-tone telephones or those who choose to talk to an operator. An analogy can be drawn with the present long distance system where both direct dialing and operator assistance are available. Because digital communication is less expensive than voice, a customer could be given a cost incentive for exercising the digital option.

Vehicle Communication

A similar choice between voice and digital communication is also available for vehicle communication. The voice operation will be similar to existing taxicab dispatching. The digital operation will utilize small printers in the vehicles for drivers to receive instructions and keyboards for them to transmit messages. Digital operation offers the following major advantages over voice operation (9):

1. Far fewer channels are required (channels are currently very difficult to acquire from the Federal Communications Commission);
2. The vehicle printer provides a permanent record, whereas with voice communication the driver must remember his instructions; and
3. For large systems, digital communication is cheaper because it reduces the number of dispatchers required.

Vehicles

Simulation results indicate that vehicles with seating capacities of 10 to 20 are required. Within this range, a wide variety of possible vehicles exist, varying primarily with respect to comfort, maneuverability, endurance, life, operational and capital costs, and safety. At one extreme are the converted van vehicles costing approximately \$4,000 to \$6,000 and having limited seating, comfort, and endurance. At the other extreme are minibus vehicles costing between \$10,000 and \$20,000 and having greater capacity, better comfort, and longer endurance. Because dial-a-bus will operate in low-density areas on residential streets, the appearance of a medium- or large-sized bus might cause objections. Although a large amount of equipment currently exists that could be used for dial-a-bus operation, no vehicle has been specifically designed for that purpose (10).

Computer

Major computer considerations include performance, reliability, and cost. With regard to performance, the machine must have adequate storage and processing capabilities to run the system in real time. Reliability is essential to maintain customer satisfaction. Fail safe-fail soft capabilities must be provided through identical or functional redundancy. Within adequate performance and reliability standards, one would also like to minimize cost (11).

Several options exist with regard to computer systems. These include the following:

Dedicated Versus Time-Sharing Operations—Time-sharing provides the opportunity for dial-a-bus to utilize only that portion of the computer it requires. Dial-a-bus must have, however, a high enough priority use with respect to the other time-sharing users that service requests can be promptly handled. A far more important problem is the decreased reliability of a time-sharing system because any other user can cause the system to crash. For these reasons, time-sharing computers are not recommended.

Integrated Versus Separate Communications—The digital communications functions can be handled by a small communications-oriented computer or integrated as part of the scheduling computer. If a separate computer is utilized, schemes can be developed whereby the communications computer can assist in scheduling operations when the main computer is down. Many different configurations of scheduling and communications computers can be developed with different costs and varying degrees of reliability. Some possible configurations are 2 integrated scheduling computers, 1 communications computer and 2 scheduling computers, 2 communications computers and 1 scheduling computer, and 2 communications and 2 scheduling computers. It is anticipated that most dial-a-bus systems will utilize reasonably simple computer configurations, but in a few cases in larger metropolitan areas the larger more complex systems will be justified.

Remote Versus Local Site Locations—The scheduling computer can be located in the city where dial-a-bus service is offered, or it can be located any distance from that site. In the latter case, either the communications computer or a message concentrator would transmit the message received over telephone lines to the remote computer. The additional communications cost must be considered when a decision is made on the best location for the scheduling computer.

Summary

An operational dial-a-bus system that has been developed by M.I.T. uses the IBM 360 computer. This program can easily be adapted to any community that desires to operate a dial-a-bus service. It is, however, an experimental system with limited backup and capacity and, as such, should be used for only initial demonstration purposes.

The principle conclusions involving system design are as follows:

1. Dial-a-bus is technically feasible for it uses existing equipment and state-of-the-art technology;
2. The computer and communications costs are only a small portion of the total costs (this is discussed on a later section); and
3. A wide variety of systems are feasible. For example, one can envision small computers such as a Varian 620-I controlling 20 to 50 vehicles, medium-sized computers such as the IBM 360 Model 40 or 50 controlling several hundred vehicles, and large-scale computers such as the IBM 360 Model 85 controlling several thousand vehicles.

DIAL-A-BUS COSTS

The cost of operating a dial-a-bus system should be equal to the cost of a conventional bus operation plus the additional cost for the vehicle scheduling and communication operations. (The use of smaller minibus vehicles for dial-a-bus will result in some reductions in operating costs, but these differences are small in terms of total costs.) The cost for vehicle scheduling and communication operations will depend largely on the available technology and the efficiency of the operation. For this reason, costs have been developed for 2 separate systems: (a) an initial system utilizing existing algorithms and computer programs and voice communication and (b) a production system utilizing improved algorithms and computer programs and digital communication. The costs used are based on the research findings (12).

TABLE 1

EXPECTED COSTS FOR DIAL-A-BUS

Item	Initial System	Production System
Basic bus operating cost per hour	$5 to $12	$5 to $12
Anticipated vehicle trips per hour	8 to 16	12 to 20
Basic operating cost per trip	$0.31 to $0.150	$0.25 to $1.00
Additional dispatching cost per trip	$0.30 to $0.50	$0.15 to $0.30
Total cost per trip		
Range	$0.61 to $2.00	$0.40 to $1.30
Expected	$1.30	$0.85

Cost ranges for initial and production systems are given in Table 1. Ranges are used because of the sizable cost differences between transit operations due primarily to differences in labor rates. The basic cost in both the initial and production systems varies between $5 and $12 per hour. (These figures are based on an analysis of many existing bus systems.) If we assume that productivities in an initial system are 8 to 16 passengers per hour, then the base cost per trip varies between $0.31 and $1.50. (These productivities were chosen to reflect some underutilization during the off-peak hours.)

The additional cost for dispatching in the initial system (30 to 50 cents per trip) consists of the following components:

Component	Cost (cents)
Customer communication	10 to 20
Vehicle communication	5 to 10
Computer processing	15 to 20
Total	30 to 50

For production systems, these costs will decrease as a result of economies provided by digital communication and improved algorithms operating in newer more economical computers. The estimated dispatching costs of 15 to 30 cents consists of the following components:

Component	Cost (cents)
Customer communication	5 to 10
Vehicle communication	2 to 5
Computer processing	8 to 15
Total	15 to 30

As a result of the improved productivities and decreased dispatching costs, the cost per trip in a production system should decrease to a range of from $0.40 to $1.30 with an expected cost of $0.85.

These cost figures compare quite favorably with existing transit and taxi operations. Transit fares of 30 to 50 cents are now common for the base trip; an additional charge is frequently made for transfers between lines. In many cases, the fare-box revenues are only covering operating costs, and in some cases even a portion of the operating costs are subsidized. Therefore, actual costs for bus transit can often run as high as 75 cents or more per trip. Taxi fares vary from city to city, with a 2- to 3-mile trip generally costing between $1.10 and $1.90 plus tip. Dial-a-bus, therefore, appears to fall where it should, somewhere between the cost of conventional fixed-route buses and taxis.

DIAL-A-BUS SERVICE APPLICATIONS

Dial-a-bus will complement conventional transit service in two ways. First, it will serve as a feeder to line-haul transit stations. As new rapid transit express bus services are provided, the potential feeder role of dial-a-bus becomes increasingly important. The limited transit dial-a-bus service recently begun in Toronto, Canada, illustrates the importance of dial-a-bus in its feeder role to a commuter railroad (13).

Second, dial-a-bus will serve areas that cannot justify conventional public transportation. The number of these areas is sizable and should continue to increase as urban densities decrease and travel patterns become more diverse. As previously stated, dial-a-bus can operate with demand densities as low as 20 demands/sq mi/hr. If conservative modal split and ridership figures are assumed, that implies densities as low as 4,000 people/sq mi. In contrast, conventional transit usually requires at least 8,000 people/sq mi along its corridor of operation. In the range of 4,000 to 8,000 people/sq mi, the range in which growing urban areas and small cities fall, dial-a-bus should have a significant impact.

Models can be developed and people can conjecture about the potential demand for dial-a-bus; M.I.T. and other groups have engaged in these activities. One can also point to successful transit systems with limited demand-responsive characteristics (e.g., Peoria, Illinois; Mansfield, Ohio; Toronto, and numerous shared taxi and limousine services, 13, 14). However, the only way to accurately determine the dial-a-bus potential is to run a series of carefully controlled demonstration projects in real time, on real streets, with real vehicles.

SUMMARY

Scheduling algorithms were developed to provide many-to-many service by using a provisional-tour technique that resulted in an improvement of up to 40 percent when compared with simpler, less efficient techniques. The best algorithm performance was obtained by using a technique that attempted to maximize service for both current and future system users. System performance increased linearly with area size and was most cost effective between 20 to 80 demands/sq mi/hr and levels of service from 2 to 3 times that of automobile travel. Vehicle productivities of 10 to 20 passengers per hour can be achieved by using existing algorithms. These figures should improve as new and better algorithms are developed.

From a technical viewpoint, dial-a-bus is feasible for it uses existing equipment and state-of-the-art technology. In all but the smallest systems (fewer than 20 vehicles), digital communications are more desirable than voice communications. Computer requirements depend primarily on the system size. Time-sharing computers should be avoided because of reliability and priority problems. Vehicles with seating capacities of 10 to 20 should be utilized. Every effort should be made to provide a good reliable system design because the cost of the computer and communication components comprise less than 15 percent of total costs.

The cost per trip in an initial demonstration system with existing algorithms and voice communication should vary between \$0.61 and \$2.00, of which 30 to 50 cents is required for the dispatching operation. Later production systems utilizing improved algorithms and computer programs should reduce the cost per trip to between \$0.40 and \$1.30 and the associated dispatching costs to between 15 and 30 cents a trip. The major cause for the large cost variation is the different labor rates for the vehicle drivers.

Dial-a-bus will be complementary to existing public transportation by providing feeder service to line-haul facilities and providing service in low- to medium-density areas that cannot justify conventional public transportation. Whereas conventional transit generally requires demand densities of at least 80 demands/sq mi/hr, dial-a-bus can operate with demand densities as low as 20 demands/sq mi/hr.

Dial-a-bus, apparently technically and economically feasible, could serve an important role in providing necessary transportation to a sizable group of people and is one of the few new concepts in transportation that can be implemented in the very near future without significant investment in research, development, or capital equipment.

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