The effectiveness of coordination and control procedures for paratransit services will be one important determinant of the ultimate success of these services. This resource paper is intended to summarize the current state of development in these areas and to raise important issues relating to future developments. A basic premise is that paratransit services should be designed to complement one another as well as other transportation services. The aim is to provide a choice to the prospective user without encouraging unproductive competition. Control procedures are fundamental to many paratransit services and can play a central role in determining the attractiveness of the service, the productivity, and hence the cost per trip.

This paper is organized in 3 main sections that address technological innovation, coordination of paratransit service, and techniques for improving vehicle productivities. At the end of the paper the principal issues and suggested topics for discussion are restated.

TECHNOLOGICAL INNOVATION

It should be clear that technological innovation in paratransit as elsewhere is not worth pursuing unless the probable resulting benefits outweigh the costs of development, implementation, and operation. Although a considerable amount of technological development has taken place in the paratransit field in the last few years, a careful assessment of its potential has not been made. In this section some of the more significant developments are reviewed, and issues relevant to their evaluation are raised. The 2 principal areas in which work has reached the point of implementation are computer control and communication, and these are reviewed first. Finally, a brief review is given of the potential of automatic vehicle location systems.

Computer Control

Many paratransit services rely heavily on real-time control. Taxi and dial-a-ride systems, for instance, could not exist without this control function being performed. Similarly hybrid services like route deviation and point deviation could only function in a limited way without real-time control. Other systems based on pooling (using either cars or vans), although not using real-time control, also require manipulation of a large and fairly complex data base. With these problem characteristics, control seems to be an attractive possibility for the application of computer technology.
Computer-matching programs developed by the federal government and other agencies have already received extensive use in car and van pooling. Although their use does not add significantly to the cost of operating such a pooling program, their potential for making a major impact on the success of such a program is limited. Specifically the operator can efficiently serve a larger population base with these computer programs than with a manual matching procedure. However, it is unlikely that they can significantly increase the number or size of car pools formed through a comprehensive program. Active employer involvement is now widely recognized as being essential to a successful pooling program, and the provision of a computer-based area-wide matching program can remove much of the administrative burden from the individual employers. Thus, the existence of computer programs in their current state of development can play an important role in encouraging full participation in the program. The future role of computer control in pooling operations does not seem to be in the direction of concentrating on developing more sophisticated matching techniques. Programs to handle a large data base are the primary requirement, and these have already been implemented and proved. Implications are that further research and development in computer control is not a high priority and that governmental policy should be to encourage the use of existing computer programs with incremental improvements as experience dictates.

Paratransit services that require real-time control are a more significant area for potential application of computer control. Broadly speaking, any of these systems in the taxi and fixed-route bus spectrum have a component of their operation preplanned and a further component determined as the system is operating (i.e., in real time). In a fixed-route bus system the operation is basically preplanned with minimal real-time control. Taxi operations are totally determined in real time. The utility of computer control is related to the extent of the real-time control component and to the size of the system. Computer control is most useful for large systems based on real-time control. As expected, the greatest interest and the bulk of research, development, and demonstration in computer control have been in the range of taxi and dial-a-ride operations.

Before operating experiences with this type of computer-controlled system are reviewed, the main reason for considering the computer control option at all should be identified. This can then be used to evaluate past experience and to make a realistic reappraisal of its potential. Principal factors arguing for computer control are as follows:

1. Decisions are more effective,
2. Larger systems are feasible, and
3. Features can be extended.

The basic argument is that "better" decisions can be made by a good computer control procedure than by a good dispatcher, particularly in large systems. Specifically, service attributes desired by passengers can be provided more consistently and at an improved level by computer dispatching for a given number of passengers and vehicles (hence, productivity). This superior performance could be translated into a more attractive service resulting presumably in increased ridership or into a reduced vehicle fleet size with the quality of service preserved. In either case, higher productivities should be achieved by a computer-dispatched system than by a similar manually dispatched system. This advantage increases with system size as the limit of a single manual dispatcher is approached. Effectively this manual dispatcher limit bounds the economies of scale that may be achieved as the manual system expands. Further economies of scale may be achieved through computer dispatching. Extended features that computer control may make feasible include automatic billing, simultaneous provision of distinct services, automated interfaces with customer, and vehicle communication systems.

The key issues in evaluation of computer control for these highly responsive paratransit services are the extent to which those expectations are realized and the cost. Computer control will increase the control component of the system operating cost, but, since this represents a relatively small percentage of total system costs, an in-
crease in vehicle productivity may well justify such an investment. It is to begin to answer this basic question that existing operating experience is reviewed here.

Of the taxi and non-shared-ride systems, Los Angeles Yellow Cab Company has the most experience in use of computer-control procedures. Since 1971, this company has used a variety of automated-control procedures and has reported favorably on the results. In this case the principal function of the computer is to validate all types of incoming service-related orders, to assign each request to the appropriate cab stand, and to display the order for the appropriate dispatcher. The control function is fairly straightforward and corresponds to the straight translation of the manual process. Principal conclusions drawn by the company from this experience are that computer control

1. Is technically feasible,
2. Is economically feasible for a minimum of 2,700 orders per day,
3. Provides a useful management tool,
4. Improves the service provided, and
5. Reduces dependency on a few key dispatchers.

Another example of computer control in taxi operations is the Diamond Cab Association of Montreal that uses a computer to control communication between the dispatcher and the individual cab drivers. The principal objectives of the scheme are to prevent calls that are assigned to a given cab from being "pirated" by another cab that gets there first and to overcome favoritism by the dispatcher in assigning calls. This system seems to have been accepted by drivers, dispatchers, and management, all of whom see its direct benefits. Earnings of drivers were estimated to have increased by about 20 percent as a result of greater operating efficiency.

These 2 examples are the only existing examples of computer control in conventional taxi operations although others are also close to implementation. Both examples are for large fleets of cabs, and in both cases the automation has been aimed at overcoming specific shortcomings in the existing manual operation. Both must be judged a success in terms of more than achieving their specific objectives. As analyses of these successes are publicized, a logical evolution would be the more widespread use of computer control in the large metropolitan-area cab companies. As experience with these techniques grows and the effectiveness of computer technology and control software increases, the minimum fleet size for computer control will decrease at least to the point of the capacity for a single dispatcher, which is between 50 and 100 cabs. Clearly the minimum feasible size of operation will depend on the benefits realizable from computer control as well as the associated cost.

In ride-sharing systems such as dial-a-ride and shared taxi, the potential advantages are even more appealing as the dispatching function becomes more complex. Operating experience to date, however, is as limited here as it is for conventional taxi systems. The first reported experience was for a shared-taxi operation by the Royal Cab Company in Davenport, Iowa, which used computer dispatching for a short period during 1972. Reported results indicate an increase in revenue per cab mile from 32 cents with manual dispatching to 44 cents with computer dispatching—a favorable experience. This dispatch system, which controlled about 20 vehicles, however, has been withdrawn from service because the computer was unable to keep up with the volume of service requests. Despite the favorable initial operating experience with the computer, this system is now manually controlled.

Rather more meaningful results were obtained from the Haddonfield Dial-A-Ride Demonstration Project, which used both manual and computer dispatching. The computer control procedures, which left the total control of the system to the computer, provided a higher quality of service under essentially identical conditions. Improvement was noted in the mean and variance of customer wait time for service. Since the computer-control phase of the demonstration did not occur until the end of the project, it was not possible to see to what extent this improved service could be converted into increased productivity. Furthermore, because of the demonstration nature of the system, a benefit-cost analysis of computer dispatching was really infeasible; there-
fore, no final judgment is possible based on this project alone. This computer-dropping system is no longer in use.

The only other substantial experience obtained to date was from Santa Clara County, where an areawide integrated dial-a-ride and fixed-route bus service was operated for a period of about 6 months under computer control. Since there is no comparable system operating elsewhere and since this system never operated under manual control, the contribution of computer dispatching in this case cannot be assessed. It is safe to say that such an ambitious project would not have been undertaken without computer control.

Two new examples of computer control are just starting in ongoing dial-a-ride systems in Rochester, New York, and Ann Arbor, Michigan. The Rochester system was converted to computer control from manual control as part of a demonstration project in the fall of 1975, and full evaluation of this change will be possible including the longer run impact on vehicle productivity. The Ann Arbor system will allow evaluation of a slightly different approach to control of an integrated dial-a-ride and fixed-route system. In this case the computer system will be assisting the dispatcher in making decisions, and the service concept involves the dial-a-ride vehicle cycling through the feeder zones on a regular basis. This tends to simplify the control problem and also to provide greater predictability to service times.

Computer control can be expected a priori to play a more significant role in dial-a-ride than in taxi systems since the decision-making problem is much more complex. If large-scale paratransit services are to be implemented involving a large amount of real-time control, then computer control will be essential—the real issue is at what size of system for each paratransit service does computer control become preferable. Computer control will become more important as the service provides more options and as the system size increases.

Communications

In most paratransit systems communication is an important facet of the operation. Most relevant to the discussion of technological innovation are those services that rely heavily on real-time control; it is in these areas that the greatest communications requirements are imposed and that the pressure for innovation is the greatest. Thus, this discussion will focus on dial-a-ride and taxi systems in which communication has 2 components: between the customers and the control center and between the control center and the vehicles.

Customer communication is amenable to technological innovation in a fairly limited way through the combination of touch-tone phones and computer control. It is feasible to allow requests to be input in digital form, bypassing the telephone operator. This would be effective only for frequent users of the system and would, of course, require computer control. Although no system with this digital customer communication feature has yet been implemented, development of these techniques is now under way.

More attention has been paid to vehicle communication, for it uses radio channels, a scarce resource in urban areas. Technology for digital communication and mobile displays of information has been used extensively in police operations, and it is now beginning to find application in the paratransit field. Mobile printers have been used experimentally in the Batavia, New York, dial-a-ride system and have been used for the past 2 years in Rochester. They form an integral part of the planned expansion in both Rochester and Ann Arbor, and both of these systems will demonstrate an integrated computer digital communications control system.

The advantages of digital communications are principally in terms of increased capacity for each radio channel. Once again, large systems are possible only with digital communications because large numbers of channels are simply unavailable. A less obvious but also significant impact of digital communications is that effective vehicle speeds can be increased and dwell time can be decreased because the drivers no longer have to stop to write down addresses. Similarly, if digital communications is combined with computer control, response time should be decreased for sending drivers next-stop
instructions, further improving effectiveness. The net impact of these improvements is unclear, but amounts to at least 5 percent based on the Batavia experience.

If digital communications alone are implemented, control costs will clearly increase because of the additional mobile and control center equipment. This is probably also true if integrated computer control digital communications are used, but in this case the additional equipment cost can be partially offset by a decrease in dispatcher requirements for large systems.

Vehicle Location Systems

The 2 previous technological innovations applied to components of the system that would be required in some form anyway. The issue was whether the technologically sophisticated approaches are preferable, and if so under what circumstances. Vehicle location systems, however, are not a necessary part of any paratransit system, and the issue is whether it is a worthwhile addition to the basic system. This discussion is somewhat more speculative than the previous discussion because development and application to paratransit have not yet occurred. No previous or current vehicle location systems have been applied to paratransit. Furthermore, any vehicle location system would probably be used by more than paratransit services and, hence, assessing the overall potential of vehicle location systems based on this discussion alone would be inappropriate. The focus here will be to describe the potential benefits to paratransit of vehicle location systems.

Paratransit services likely to benefit are those involving a large degree of real-time control, notably taxis and dial-a-ride systems. For these systems, better control decisions should result from more accurate and current data on each vehicle location. In particular taxi operations in which central control is frequently weak could benefit greatly from vehicle location information. This information could permit dispatchers to make significantly better fleet allocation decisions, presumably increasing productivity. In this case, the vehicle location system would substantially alter the control of the system.

In dial-a-ride, vehicle location systems would have a more marginal effect because the basic nature of the control process would be unchanged. Simulation studies have indicated that vehicle location systems might increase vehicle productivities by 5 to 10 percent, but this can only be viewed as a first approximation. Additional studies or tests may well be appropriate to evaluate the potential of vehicle location systems for improving paratransit service.

Coordination of Paratransit Services

Paratransit plays an increasingly important role in the total urban transportation system, and it might be expected to become still more significant as the real cost of automobile use grows. As paratransit grows, several important issues arise in terms of coordination among different paratransit services and between paratransit and other elements of the transportation system, notably conventional transit. This subject can be viewed at two levels: (a) the coordination problem for a single operator and (b) coordination among several operators.

Single Operator

The coordination problem for a single operator depends on the type of services provided. If, as is often the case, the operator provides only one type of paratransit service, the principal issue is coordination of different elements involved in the service. If a single operator provides different types of service, then the additional issue is the coordination of services provided.

In most paratransit services, coordination is provided through the central control
facility, and frequently each vehicle can be treated independently and extensive coordination is not needed. Examples in which coordination requirements are minimal are car pooling, van pooling, taxi, and many-to-many dial-a-ride services. However, some systems require vehicle rendezvous at specific times and locations, such as dial-a-ride systems involving transfers and any system in which driver reliefs occur. In these cases, one of the functions of control is to ensure that activities are coordinated. Frequently, decisions will involve making trade-offs between benefits and costs to different groups of passengers or between user benefits and operator costs.

One significant challenge in paratransit coordination is the problem of obtaining effective car-pooling and van-pooling services for the set of small employers. No one of these may be able to justify or support such a program independently; but, if a group of contiguous employers acted cohesively, a successful program might be established. It is at this level that most current pool coordination is focused.

More substantial issues arise when a single operator is providing more than one service. For example, if a transit operator is providing both dial-a-ride and conventional fixed-route bus services, real coordination problems may arise in both the planning of the services and their operation. Presumably the aim of the operator is to minimize conflict and competition between the services by operating each in its most effective situation. When introducing the new paratransit services, the operator must be prepared to reassess the existing fixed-route network with a view to providing each with nonoverlapping, but mutually supportive functions. If this is not done, then the result of the new system might well be an overall reduction in cost effectiveness of the total system.

Given that the services are designed to be mutually reinforcing, then they must be operated for ease of transfer between systems. This raises the issue of how best to coordinate a dynamic unscheduled service with a preplanned scheduled operation. Three different approaches have been taken to this problem:

1. Uncoordinated services,
2. Restriction of demand-responsive system, and
3. Fully coordinated services.

The first approach does not consider optimization of the transfer part of the trip; each leg is optimized independently. This approach (essentially, the Santa Clara approach) certainly simplifies the control problem, but at the expense of the effectiveness of the service provided. Operations are simply not coordinated, which implies that serious attention must be paid to making the transfer facility as comfortable as possible.

Another approach is to make the demand-responsive service operate on a semi-scheduled basis with scheduled rendezvous at the transfer point. This has the additional advantages of reducing the real-time control burden and making the service more predictable from the user's viewpoint. Regina has successfully demonstrated this type of coordination, and Ann Arbor is relying on a similar approach for its expanded service.

Fully coordinated service implies optimization of the total trip with an explicit attempt to minimize transfer times. This is the approach being attempted in Rochester with the benefit of computer control. To obtain this degree of coordination, a heavy real-time control burden is imposed, and computer control becomes mandatory for all but the smallest systems.

Several Operators

The coordination problem becomes much more difficult when several operators are involved in providing different types of paratransit service. A principal problem that arises is that the operators are most interested in optimizing their own performances, and that may not result in an efficient overall system for users or in the most effective use of total system resources. In the absence of coordination, each operator will focus services where advantage can be taken of economies of scale, which may well result in several similar services being provided in the same place at the same time. Tradi-
tionally, where taxis and fixed-route transit have been the only options, this lack of coordination has not been a problem because these services are well differentiated in terms of types of service as well as cost—hence, they attract basically different markets.

However, if one major objective of the paratransit movement is to reduce energy use and reliance on the single-occupant automobile, all paratransit modes should be coordinated for reasons of both efficiency and service quality. A simple example will demonstrate the problem that coordination must be able to resolve. A large employer would be a good candidate for service by van pools, subscription bus provided by a private operator, and fixed-route transit. Each of these services provided by different operators may be viable alone, but none may be viable in competition with the others. How will it be decided what service or services are to be provided? Many other realistic cases could be cited in terms of competition and still others in terms of the potential of complementary operations that may never come to light without explicit attention to coordination. An example of the possibilities of complementary operations is a combined, reduced fare for a trip involving access to a station by shared-ride taxi with line-haul service by fixed-route transit. Another is replacing a fixed-route bus by a private jitney service at periods of low demand. How are these issues and opportunities to be resolved when several operators are involved?

The most straightforward approach to coordination among different operators is to create a nonoperating authority with regulatory control over all the operating agencies. Such a framework should allow the transportation authority to resolve disputes among operators and to encourage complementary activities by different operators. This is the approach to be taken in the Knoxville demonstration project. Clearly establishing such an authority will not resolve all problems; however, it does create a framework within which solutions can be developed. Just one example of the major problems that would have to be resolved is the role of van pooling to employer locations well served by transit. One point of view is that van pooling would cut into the most productive element of transit service—the peak-hour work trip. But another argument could be made that van pooling will reduce peak-hour transit requirements, and that would be a benefit to transit since it would reduce the current imbalance between peak and off-peak service. Resolving such issues will be a complex problem, but without a coordinating transportation authority satisfactory resolution would probably be impossible.

### IMPROVING VEHICLE PRODUCTIVITY

The issue of vehicle productivity is central to the future success of paratransit services. In nonpaid driver modes such as car pooling and van pooling, the vehicle occupancy is an inverse measure of the energy intensiveness of the service and as such is certainly a proxy for success. In paid driver modes such as taxi and dial-a-ride, the productivity (measured in passenger trips per vehicle hour, passenger-miles per vehicle hour, or passenger-miles per vehicle mile) is critical in determining the cost effectiveness of the service. This discussion will concentrate on paid driver services, but first a few comments on the pooling modes.

Vehicle occupancy is principally related to the ability to attract people to pools. As the incentives toward pooling are increased, then people will accept more inconvenience in forming the pool and hence occupancy will increase. For instance, if free parking is provided to pooled vehicles and fees are charged for single-occupant vehicles, not only will the number of pool riders increase but presumably the occupancy level for preexisting pools will also increase. Similarly, as the density of prospective poolers increases, the occupancy level will also increase since for the same level of inconvenience it becomes possible to collect a larger number in one pool.

For paratransit modes using paid drivers, improving vehicle productivity is a major concern. Productivities of existing paratransit services cover a wide range, depending heavily on the service concept. Typical productivities range from taxis with 1.5 to 2.5 passenger trips per vehicle hour to fixed-route bus services with more than 30 passenger trips per vehicle hour. Within this range lie shared-ride taxis, dial-a-ride, subscription bus, and point-deviation and route-deviation services in order of increasing...
productivities. Once this is said, however, it must be recognized that these are observed productivities based on where these systems now operate. If a dial-a-ride system operating in a suburban area with a vehicle productivity of 6 is replaced with a fixed-route bus service, a productivity of 30, for instance, would not be achieved. The density of demand in this situation simply would not support such high productivities. However, it is also possible that by changing the service concept in a given situation productivities can be increased.

For example, switching from non-shared-ride to shared-ride taxi service will result in productivity increases of 50 to 100 percent, but the service provided would of course also be affected. Similarly switching from a many-to-many dial-a-ride service to a limited-stop checkpoint or loop service could also result in productivity increases of as much as 50 percent, but again the service quality would be changed. The issue of improving vehicle productivity can, therefore, be viewed in terms of changing the service concept or simply improving the effectiveness of the given service concept.

Several distinct possibilities arise for improving the effectiveness of a particular service concept:

1. Increasing vehicle effective speed,
2. Decreasing effective dwell time,
3. Improving control decisions, and
4. Increasing demand for the service.

To increase effective vehicle speed implies providing the vehicle with priority at traffic lights and points of congestion or improving acceleration and deceleration characteristics of the vehicle. None of these seems to have great potential for making any significant impact on vehicle productivities, and this does not seem to be a promising area for further research.

Depending on the service concept, dwell time can be a significant portion of total time and can represent a real barrier to improving vehicle productivities. For instance, several dial-a-ride systems have reported dwell times of approximately 2 minutes, including overhead associated with finding the correct address to stop at. Such large stop penalties imply that productivity larger than 10 is simply out of the question because of unproductive vehicle time. This in itself will limit the potential of door-to-door services unless it can be overcome. One technique would be to notify the user just before (maybe 30 seconds) the vehicle arrives so that he or she will be ready and waiting. This notification could be through a callback from the control center or possibly through a device on the vehicle itself. Failing this, investigation of pickups and deliveries being made only at street intersections should be made to see whether the improvement in productivity outweighs the loss in service provided.

If control decisions can be improved (as described earlier in this paper), it is reasonable to expect higher productivities, and evidence on this will be an important output from computerization such as that in Rochester. Other ways in which control can be used to improve productivities are to strategically dispatch empty vehicles before demands occur and to arrange for dynamic driver reliefs so that vehicle operations are uninterrupted. The control area is probably the most promising way to improve productivity without changing the concept, and it is being quite vigorously pursued.

All paratransit services experience economies of scale in terms of vehicle productivity to some extent. As the density of demand for any of these services increases so does the maximum achievable productivity. The extent of these economies and the range over which they exist are different, however, for each service. For taxis, only minimal economies of scale are realized at demand densities greater than 5 passengers per square mile per hour. Dial-a-ride services experience economies of scale up to much higher demand densities. Thus, if demand for these services can be increased, a higher productivity operation is possible. However, most dial-a-ride services have not proved attractive enough to the general public to be able to take advantage of these possible economies of scale. Most dial-a-ride systems, for example, operate at demand densities of less than 5 passengers per square mile per hour and produce productivities in the range of 4 to 7 passenger trips per vehicle hour. These vehicle pro-
ductivities could be doubled if the density of demand could be increased by a factor of 3 or 4. The future of the dial-a-ride concept is tied to this issue of improving productivities. If this cannot be effected, then this service concept will probably be restricted to special markets for which expensive low-productivity operations may be justified.

Changing the service concept likely has the greatest potential for increasing vehicle productivity. In some cases changing the service concept to increase productivity may also make the service more attractive and thus increase demand density, which in turn will tend to further increase productivity. For example, going from a many-to-many dial-a-ride system to a focused many-to-one semischeduled loop service may attract more users because of higher service predictability and reliability. This seems a likely outcome in many situations based on the success in Canada of several of the more structured many-to-one services.

Similarly moving from a door-stop service to a limited-point service seems to have potential for improved productivity because of reduced dwell time. This step would be contingent on a highly reliable service so that exposed wait times would be minimized. Hence, this service might well be offered in combination with the previously mentioned scheduled-loop or point-deviation services. There is a real need for examining the full range of services between taxi and fixed-route bus because several of these services might be more widely applicable than many-to-many dial-a-ride service. Exploration of these possibilities should remain a high priority in the UMTA Service and Methods Demonstration Program.

SUMMARY

This paper reviewed the current state of development and some of the major issues in the area of control and coordination of paratransit services. Much of the attention given to this subject to date has been focused on technological solutions, principally in the control of these services. To a great extent it is still too early to make definitive judgments on the contribution of control technology to paratransit potential, but the indications are that technology will play a significant role in those systems relying most heavily on real-time control. A key question that remains is the extent to which technological innovations can be translated into improved system effectiveness, and particularly vehicle productivity.

The issue of coordination of paratransit services is one that, until recently, received much less attention than it merits. Although coordination by a single operator is now just within the state of the art, it remains to be seen what effect coordination will have on overall system effectiveness. Coordination among different operators is a good deal more complex and is still being tackled experimentally. The most effective approach seems to be to establish a nonoperating authority with control over all operating agencies; this would establish a framework within which compromises and resolution of interagency disputes can be developed.

Cost effectiveness, and specifically the question of vehicle productivities, is like a large ominous cloud hanging over the future of paratransit. Unless means can be found to improve productivities, the future of several of these modes is questionable. Principal avenues for improvement seem to be improvements in control and further evolution of the service concepts. The central issues here are the range of systems providing efficient combinations of service quality and productivity and the extent to which they can take advantage of the economies of scale conceptually feasible by attracting the sizable support of the public.