aration of a steady-state operation of all 8 systems. At that time, a full-scale evaluation program will be undertaken. Up until that point, OCTD management will be preparing contracts, arranging control center sites, registering vehicles, overseeing training programs, and reviewing procedures for managers and operators. The development of OCTD's DRT system represents one part of an innovative and aggressive program to provide the public with new and better transportation service.

## REFERENCES

1. Dial-A-Ride Expansion Plan for Orange County. DAVE Systems, Inc., and Orange County Transit District, June 1974.

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For integrated DRT and conventional transit systems, the issue of control is considerably more important than for single-module DRT systems. On the one hand the control problems are more difficult, and on the other hand more capital-intensive solutions can be considered because of the large number of vehicles under control. Unfortunately, because of the limited number of existing systems, drawing conclusions based on actual operation is difficult, although such information will soon become available from Ann Arbor and Santa Clara, in particular. This paper reviews the major control functions required and presents the alternatives that have been or are being implemented or are realistic possibilities for the near future.

The control problem may be subdivided into information transfer and decision-making functions. Decision making is related to the operation of DRT vehicles, and information transfer is related to service requests and vehicle activities. To facilitate decision making requires an information base that is continually maintained by incoming and outgoing information flows. The nature and extent of these functions depend on the operational characteristics of the service. The range is from highly decentralized decision making with minimal information flows, such as in many of the Canadian systems, to the highly centralized system proposed for expansion in Rochester. In general, the greater the degree of decentralization is the less is the need for sophisticated and expensive equipment, but the more limited is the flexibility of the system and the service.

## INFORMATION TRANSFER FUNCTION

The following information transfer functions can be identified: service request (from customer to control center), driver instructions (from control center to driver), and driver progress (from driver to control center).

### Service Request

In general a customer may request service either from a low-volume (e.g., home) or high-volume (e.g., shopping center, transfer terminal) location. In both cases the mechanism used will be the telephone system—in the low-volume case, general purpose lines with a standard headset and in the high-volume case probably leased lines and possibly a special input device. At the present time no digital input service request device is in use. This innovation, which would require computer control, would decrease the number of telephone operators for large systems, but is unlikely to be widely available for several years.

For integrated systems another service request option is receiving the request from the driver of a conventional fixed-route bus. This is a convenience for the passenger, who simply tells the driver the desired transfer point and ultimate destination. This requires communication either between the conventional dispatcher and DRT operators or between conventional transit drivers and the control center. Operationally either of these options may prove awkward or expensive or both, but the preferred alternative is to have direct communication between the DRT control center and the driver of any bus on a route interfacing with DRT.

## Driver Instructions

Independent of whether decision making is centralized or decentralized, information on vehicle assignments must be transferred from the control center to each driver. Unless the system can be decomposed into separate subsystems, each with its own many-to-one service and with the control function at the center, radio channels are used for this information transfer. The main design choice is whether to use voice or digital information on the radio channel. Although the great majority of existing DRT (and taxi) operators now use voice communication, digital communication will become the usual option for large integrated systems because of the amount of information that has to be transferred. Digital communication is preferred basically because of the more efficient use of radio channels possible over voice transmission. To illustrate this potential, the Diamond Taxi Company of Montreal reports dispatching as many as 300 cabs per channel with its Canadian Marconi computer-controlled radio system and only 50 to 100 cabs per channel with voice communication. Of course, the amount of information passed per vehicle-hour is lower in standard taxi operations than in DRT operations, but this improvement illustrates the potential.

Although the basic information to be sent from the control center to the driver involves passenger addresses, on occasion specific additional information, such as best routing to next stop, may have to be sent. All nonstandard messages such as this would be by voice communication for the foreseeable future. The impact of digital communication then is not to eliminate dispatchers but to reduce the required number of dispatchers for large systems. To realize this reduction requires an automatic interface between the digital transmitter and a computer, which as a minimum stores all addresses. The Diamond Taxi Company system mentioned above uses such an interface; the computer is responsible for allocation and control of mobile radios and radio channels. Even though voice communication is used for all driver messages, considerable manpower saving is reported through use of this computer-dispatch operation with digital radio control.

If addresses are encoded and transmitted digitally, some on-board decoder and display unit is required. Although relatively new in DRT operations, such mobile displays have been in use for several years, most notably in police operations. The type of device available tends to be either a printer (hard copy) or alphanumeric display (soft copy). In the Rochester DRT system, digital communication is used in conjunction with mobile printers. The system operates without a computer in the control center; a card reader is used to transmit addresses to drivers. In this case the communications system has functioned well from the operator's and drivers' viewpoints, and some increase in system performance is attributed to digital communications even though no manpower savings resulted.

In the planned Santa Clara integrated DRT and fixed-route system, digital communications will be used in conjunction with mobile displays and an automatic interface with a computer used for dispatching.

At the present time, the state of the art in mobile displays is evolving rapidly, and clearly lower cost and higher performance terminals will be available within the next few years.

### Driver Progress

The basic information the driver sends to the control center is the status of his or her progress. This is required if the control center is responsible for assigning future vehicle activities, but may not be required if a less centralized driver-based decision-making structure is used. For example, in many large taxi operations, requests for service are advertised to all drivers, and the dispatcher need not be aware of the status of each vehicle since there is no central decision-making role. Similarly in zonal DRT systems, the driver may have complete responsibility for deciding on the sequence of stops to make, and the dispatcher may just have to transmit new service requests from that zone, i.e., no feedback from the driver may be necessary.

More generally, however, the dispatcher will need to be aware of vehicle progress in order to make good decisions. This information is generally based on a driver's either making a stop or completing a set of stops previously sent out. This may be digital or voice; most existing systems use voice, but digital is becoming more attractive for larger systems. The Rochester DRT system, a hybrid, has the driver send a digital message whenever a stop has been made.

In these cases only 1 digital message is available to the driver, but equipment is now available for several distinct driver functions. Additional digital functions that could be used for all or that would otherwise be carried out by voice include passenger no-show and request driver breaks.

## DECISION-MAKING FUNCTION

The decision process in integrated DRT and conventional systems can be divided into several functional categories:

1. Control of the simple DRT (no interaction with conventional transit),
2. Control of the conventional system (no interaction with DRT), and
3. Control of transfer trips (where both modes are used).

An important consideration that applies to all is that of centralized or decentralized control, which is a characteristic rather than a function.

### Control of Simple DRT

Many systems now provide simple DRT service, usually in the context of single-module DRT systems, but there are some that are integrated with conventional transportation. Regina and Ann Arbor are prominent examples. This paper only generally describes the basic control issues involved and does not describe even a few existing systems. The control issue is to pick a vehicle to which the demand for transportation can be assigned and which provides the user with good service but does not commit so much of the system resources as to make future service unacceptable. The basic issues for such a control system are manual or automatic decision making, extent of future planning and commitment, and decentralization of decision making. In spite of the wide scope of these 3 issues, they are fundamentally independent.

Manual decision making has been demonstrated in numerous DRT systems, indeed in all except Haddonfield, which uses a computer to make all decisions during those hours of computer operation. In such systems, the dispatcher, given the customer's origin and destination, picks a vehicle that, on the basis of the dispatcher's previous decisions, will not suffer an excessive detour. In a completely automatic system, of which Haddonfield is the only example, the computer program accepts street addresses, translates them to internal coordinates, and uses an assignment algorithm to pick the "best" vehicle for that trip. The primary function of the people operating such a system is to present the computer with the basic information about the request rather than to make decisions.

There is of course a middle ground, and that is to have a computer or other equipment aid in manual dispatching either by handling the task of moving information from one point to another (e.g., from the telephonist receiving the request to the dispatcher making the decision) or by participating in the assignment by selecting a few likely vehicles that are then chosen manually. An example of the former case is the control room equipment soon to enter operation at Ann Arbor. It is designed to reduce the clerical and mechanical effort of personnel and to free them for decision-making roles. The latter case is best exemplified by the control equipment of Los Angeles Yellow Cab in which vehicles are offered to the dispatcher who picks the best one. Finally, there are 2 systems in which the assignment is automatic but address information is not given directly to the computer: Zone information is added by the telephonist, and the computer makes decisions based on these zone data. Both Diamond Cab in Montreal and the impending Santa Clara systems use this approach.

The extent to which a decision once made commits future performance of a system is an important aspect of DRT. For example, one can decide that the current customer will be picked up by a given vehicle without determining when or after whom that customer will be served. At the other extreme, decisions planning all stops in both order and time can be made for each customer as he or she calls for service. The former case is most frequently found in those systems that are decentralized to the extent that the vehicle driver decides the order of stops for those customers assigned to his or her vehicle, but this is not always true. In Ann Arbor, for example, the dispatchers typically establish a sequence for a DRT tour just before a vehicle is set to make a series of stops, the requests for service having been made long before. The case in which there is a strong future plan is best typified by the Haddonfield computer operation in which the sequence of stops once decided is rarely changed except through addition of new stops. Current analysis of Haddonfield operation indicates a need to relax this policy somewhat but without changing it fundamentally. In general, the extent of future planning and the firmness of that future plan can have significant repercussions on the manner and frequency of communication between the control center and vehicle drivers.

The degree to which decisions are made centrally can vary greatly. Usually, though by no means always, the more decentralized the decision making of a DRT system is, the more manual decisions are made. In many DRT systems that operate on a zonal basis, the driver in a zone is given a customer request and is left free to service it when he or she deems best. In such a case, the control center makes only part of the assignment decision, and the driver makes the smaller, final decision. Decentralized decision making can also involve review of decisions already made. In Ann Arbor, the dispatcher normally sequences DRT trips, but drivers may pick an order other than that determined for them. Conversely, by its very nature, a highly centralized decision process leads rapidly to the use of automatic equipment, for people have difficulty making all (or even most) of the decisions affecting numerous customers and a large fleet of vehicles. However, the ability of a computer to centralize information and decision-making rules makes automation and thus centralizing the DRT control process attractive. The best example of this is the computer at Haddonfield, which ordinarily does not allow, and in fact discourages, autonomous decisions by drivers and allows control center personnel to make decisions only in special cases (e.g., whether to wait for a customer who is late).

## Control of Conventional System

Control of the conventional transit service is already well-known as the use of the word "conventional" implies. One can, however, envisage some small changes that might prove beneficial to integrated DRT and conventional systems and that would not change the conventional elements so much as to make them unrecognizable. Such a change, such as automatic means of determining the progress of a vehicle along a fixed route, might be invisible to the user and most of the system's personnel. Another change that might come about in integrated systems is varying the timetable of fixed-route services on a demand-responsive basis. Neither of these suggestions is new, but they might find considerable application in integrated systems.

## Control of Transfer Trips

Control of transfer trips in integrated systems is the most challenging aspect of integrated systems, for it is obviously the core of the integrated nature of the system and the procedures for effecting these transfers have not been put to the test for want of integrated systems. Perhaps the best issues to use in analyzing this function are

1. The extent of information pertinent to one subsystem known to the other subsystem and
2. The extent of dependence of one subsystem on another.

A relatively simple way of integrating DRT with conventional transit is to establish a set of transfer points on the conventional routes where transfer passengers are deposited by DRT vehicles on the first leg of the journey and are picked up by DRT vehicles for the final leg (unless the trip ends at a transfer point located at a shopping center, for example). This can be done without knowledge of the fixed-route schedule (and, consequently, without knowledge of the time at which the second DRT leg will or should commence). Such a procedure is that planned for transfer trips in the Santa Clara system for those trips that cannot be served by a single DRT vehicle. In such a case, the control center need only inform the passenger of the appropriate fixed route to take and the place to best resume the DRT mode. Simply stated, the control procedure is to operate the conventional service and DRT service as independent systems.

It is possible, without modifying the conventional service as suggested in the discussion of non-DRT trips, to make more use of knowledge of the conventional service. In particular it should be possible for the DRT subsystem, be it manual or computer controlled, to know both the routes and schedule of the other subsystem. Such information would permit the DRT subsystem to provide equally good service (meeting the same fixed-route bus) at lower system cost (by not attempting to get the customer there as soon as possible if this is useless). In addition, knowledge of schedules would, in large complex systems, permit one of several fixed routes to be chosen as a function of the schedule of each. The proposed Rochester demonstration, which will include a fixed route connecting 2 DRT modules, plans to use such a technique, which has been developed in connection with the existing computer algorithm evolved by M.I.T.

Knowledge about the conventional subsystem can yield an unexpected benefit in the DRT subsystem. If as described above the DRT controller has cognizance of the fixed-route schedule, the same DRT controller has knowledge of the desired starting time of the second DRT leg. That is, the second DRT trip can be planned well in advance of the arrival of the passenger at the second transfer point. In such a case, the transfer can be made much less painful and discouraging by either having a vehicle wait for the passenger or arrive shortly after the passenger arrives. Such a procedure obviously presupposes that the 2 DRT modules are controlled jointly or have good means of communication. The Rochester demonstration, in which the 2 DRT modules in question are controlled by 1 computer program, expects to take advantage of such information.

In the preceding section on integration, complete autonomy of the 2 systems (but not complete ignorance) was assumed. The operations of the 2 subsystems can be meshed more closely. Since bringing the conventional subsystem under direct control would deprive it of its "convention" character, this section will be restricted to adapting the DRT subsystem to the conventional one. The best examples of such organization are Regina and Ann Arbor. In those systems, DRT vehicles are constrained to loop through a transfer point on the same schedule as the fixed-route buses. In other words, as long as the DRT vehicle is present at the transfer point when the line-haul vehicles are, integration requirements have been met. At all other times, the DRT vehicle is free to service many-to-many trips as well as to collect passengers planning to transfer at the next junction of the 2 types of vehicles. As Karl Guenther of Ann Arbor described it, "The schedule of the fixed-route buses is the gear which drives the other satellite (dial-a-ride vehicles) gears." Though this limits the freedom of action of the DRT vehicles, it makes the transfers efficient and is well suited to a decentralized operation, which is manually tractable.

As might be expected, the novelty of integrated DRT and conventional transit system services is responsible for the small number of implemented or even planned control procedures. There is little doubt that, after as much experience in the field of integrated systems has been garnered as has already been garnered in the field of simple DRT, more control procedures will appear as different groups attempt to solve the integration problem. Nonetheless, considerable work has been done, and some avenues, which appear promising, give the prospect of more integrated systems for the future.