Compte Rendu de la Conférence Internationale sur la Recherche en Matière de Transport

PREMIÈRE CONFÉRENCE

Bruges, Belgium
Juin, 1973

Proceedings of the International Conference on Transportation Research

FIRST CONFERENCE

Bruges, Belgium
June, 1973

COLLEGE D' EUROPE

TRANSPORTATION RESEARCH FORUM

An Overview of Demand Responsive Transportation Systems

by

*Daniel Roos**

DEMAND RESPONSIVE transportation systems provide a personalized public transportation service by offering customers direct point-to-point service. Although these systems have been referred to by many different names such as Dial-A-Ride, Dial-A-Bus, Telebus, Call-A-Ride, etc., they are very similar in operation. Customers call in their requests to a control center, where trips with similar origin and destinations are grouped together. Because several people share the use of a vehicle, the cost per trip is considerably less than taxi fares, where a single person has exclusive use of a vehicle. The vehicles do not have fixed routes and schedules; instead, they respond to individual travel requests as they are received.

Demand responsive systems are complementary to fixed-route bus systems. They can be operated in low- to medium-density communities where fixed route bus systems are infeasible because of low demand densities and widely dispersed origins and destinations. In those communities where no other transit service is available, demand responsive systems can serve all transit demands. If line haul services are available linking the community to larger metropolitan areas, demand responsive systems can provide feeder service.

Readers interested in a more extensive background on demand responsive systems can consult numerous published reports.[1, 2, 3, 4, 5, 6] The major purpose of this paper is to put recent developments relating to these systems in perspective and to reflect on anticipated future developments.

Demand responsive activities can be grouped into two distinct phases; basic research covering the period 1965-1970, followed by implementation of first generation systems during 1969-1973. The concept was investigated in a systems engineering project course at M.I.T. during 1964, and subsequently pursued on a small scale by Roos and Wilson during 1965 and 1966. A series of studies investigating the potential of new technology in urban transportation, undertaken by the U.S. Department of Housing and Urban Development during 1966-1968, identified demand responsive transportation as the most promising "new system" that could be implemented in a relatively short period of time. A major research grant was then given to M.I.T. by the U.S. Federal Government to investigate the concept. This research extended over a period of three years and culminated in a series of 12 reports. Other research groups, most notably Ford and General Motors, also undertook extensive internally-funded research efforts to investigate the concept.

The first system implementation occurred in 1969 in Mansfield, Ohio with a simple one-vehicle system.[7] Each year since then, the number of newly-implemented demand responsive systems has increased at an exponential rate. In 1973, already over 12 new systems have been implemented with many more planned. Table 1 lists some of the characteristics of the principal systems that have been operating for a year or more.[8, 9, 10, 11, 12, 13] These systems can be classified as first generation systems having the following characteristics: 1) Limited number of vehicles (10 or fewer); 2) Manual dispatching, and 3) Small area of coverage (10 square miles or less).

Based on operational experiences with these initial systems, certain important observations can be made with respect to the characteristics and impacts of demand responsive systems. The following sections contrast the implemented systems from a number of different perspectives.

Service Area Characteristics

The first generation systems have been implemented in the following three types of areas:

1) **Neighborhoods** — These represent the smallest scale systems typically utilizing 5 or fewer vehicles. Often, the systems are not operated by a transit company, but rather by some neighborhood organization. They are oriented typically toward one or more community services such as an old age center. Neighborhood systems have been implemented in Buffalo, Boston, Detroit and Columbus, to cite a few.

**Associate Professor of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts.*

TABLE 1
CHARACTERISTICS OF DEMAND RESPONSIVE TRANSPORTATION SYSTEMS

	Ann Arbor Michigan	Batavia New York	Bay Ridges Ontario	Columbus Ohio	Haddonfield New Jersey	Regina Saskatchewan
Population Served	17,000	17,300	13,700	55,000	27,500	35,000
Square Miles Served	2.4	4.75	1.34	2.5	8.1	5.5
Service Hours	6:30 am 6:00 pm	6:00 am 6:00 pm	5:00 am 1:00 am	6:00 am 9:30 pm	Continuous	6:45 am 11:35 pm
Number of Vehicles:						
Peak Hour	3	5	5	4	11	10
Midday	2	3	3	3	5	
Other				2	1	

2) **Small Cities**—Small cities with 20,000 or fewer residents often have limited transit service with declining patronage or no transit service at all. In several cases, demand responsive service has been implemented as a replacement for an ailing transit system or introduced as a new transit system. Such systems have been implemented in Batavia, New York; Bay Ridges, Ontario; and Columbia, Maryland.[14]

3) **Portion of a Metropolitan Area**—Demand responsive systems have also been introduced in the lower- to medium-density portions of metropolitan areas where conventional fixed route services are not viable. In most cases, one of the important roles of the demand responsive service is to provide feeder service to conventional line haul transit facilities in addition to providing local point-to-point service within the area. In some cases, a rationalization of existing fixed route systems has been performed when the new demand responsive system is introduced. Thus, unprofitable lines have been eliminated or shortened, improving the overall financial implications of the total system. Cities where these systems have been introduced include Regina, Saskatchewan; Ann Arbor, Michigan; and Haddonfield, New Jersey.

Type of Service

A whole range of demand responsive systems exist between taxi service at one extreme and conventional fixed route service at the other extreme. The principal factors that determine the service characteristics are the degree of responsiveness with respect to space and time.

Examining space flexibility first, one can identify the following types of systems in order of increasing responsiveness and flexibility.

1) **Route Deviation Service**—Vehicles operate on a fixed route, but will detour from the route to pick up or drop off a passenger. After the customer is serviced, the vehicle will return to the fixed route. Many jitney operations incorporate this type of service. The demand responsive system in Mansfield, Ohio also had this characteristic.

2) **Point Deviation Service**—A number of checkpoints in a service area are established corresponding to principal activity centers. Vehicles stop at these checkpoints at a specified time to pick up or discharge passengers. In between the checkpoints, a driver is free to take any route, depending on whether there are customer requests to be served between the checkpoints. This type of service was implemented in Columbus, Ohio.

3) **Zone Service**—An area is subdivided into a series of zones where one or more vehicles serve each zone. Vehicles do not travel between zones; therefore, if a person wants to travel between zones, he must transfer at an interchange point which typically corresponds to a major activity center.

The following three different types of service can be provided in each zone:

Many-To-One—Service from any point to a single destination which corresponds to a high activity center (the return trip is a one-to-many situation).

Many-To-Few—Similar to the many-to-one case, except that several destination points are utilized.

Many-To-Many — Service from any point in the zone to any other point in the zone.

Zone systems have been implemented in Bay Ridges Ontario and Regina, Saskatchewan.

4) **Area-Wide Service**—All vehicles are available to serve customer requests without any zone restrictions. The same three service options are available as for the zonal system: many-to-one, many-to-few and many-to-many. Area-wide services have been implemented in Batavia, New York; Columbia, Maryland; and Haddonfield, New Jersey.

Several service options also exist with respect to time flexibility. The principal ones are summarized below in order of increasing flexibility:

1) **Subscription Service**—People subscribe for a minimum period of time (typically a week or month) to be picked up the same time each day and brought

to some high activity center (e.g., employment center, school or line haul transit transfer point). Routes and pick-up times are then determined for each vehicle which are modified only when subscribers change. Subscription services have been implemented in Peoria, Illinois; Flint, Michigan; Columbia, Maryland; and Batavia, New York.[15, 16]

2) **Discrete Run Times**—The system is designed such that vehicles leave a specified point at specified times. The vehicle driver must perform his pick-ups and drop-offs in such a manner that he can return to the specified point for the next departure. This type of service is most frequently utilized for zonal and many-to-one systems, where the specified point corresponds to the single destination. Bay Ridges, Ontario is an example where this technique is utilized.

3) **Continuous Run Times**—All vehicles operate continuously picking up and dropping off passengers. This technique is most frequently utilized for areawide many-to-many systems. Batavia, New York; Haddonfield, New Jersey; and Columbia, Maryland utilize this technique.

Many factors influence the degree of responsiveness with respect to time and space. The three most important factors are:

1) **Customer Requirements**—How much responsiveness is required to satisfy existing and anticipated travel demand.

2) **Cost of Service**—How much responsiveness can be provided at a reasonable cost. The more responsive a system, the fewer passengers it will carry; thus, the higher the cost per trip with a taxicab-like service representing an upper bound.

3) **Institutional Considerations**—Some systems have been purposely designed to be less responsive so they can be differentiated from taxi service. This was to avoid a potential legal battle with taxicab interests.

Several systems vary their responsiveness during the day, typically providing different services during the peak and off-peak periods. In the peak hours, where more travel occurs and travel habits are more repetitive on a daily basis, a less responsive system is provided. In the off-peak periods where travel tends to be more random and dispersed, a more responsive system is provided. In Batavia, subscription service is provided during the peak periods, while continuous many-to-many service is provided in the off-peak period. In Bay Ridges, peak-hour service is limited to many-to-one service while it is expanded to many-to-many service in the off-peak hours.

The degree of responsiveness can be specified as part of the system design or it can be influenced by the environment of use. An example of the latter occurred in Bay Ridges. People are permitted to request service up to one hour before they wish to travel. Most people, however, chose to prebook for services on a subscription basis, since they used the same train each morning. The result is that 80% of each morning's travel is basically subscription service, and only 20% of the requests are handled by the dispatcher. This simplifies the dispatching operation with a corresponding cost savings.

Dispatching Techniques

The dispatching operation is central to any demand responsive system. It significantly affects the quality and reliability of service provided to the customer and the cost of the service sustained by the system operator. Many factors influence the dispatching operation. The three most critical are:

1) **Centralized versus Decentralized Dispatching**—With centralized dispatching, a dispatcher in the control center is responsible for making all dispatching decisions. With decentralized dispatching, decision making is shared; the dispatcher assigns service requests to vehicles, while the driver is responsible for determining the best sequence of assigned stops. The principle utilized is that the driver will have the best knowledge of the street system and local characteristics and therefore be in the best position to make scheduling decisions. Decentralized dispatching is primarily utilized in conjunction with 1) zone systems where the coverage area for each driver is limited; 2) discrete run times so it is easy for a dispatcher to schedule a service request to a particular run; and 3) many-to-one or few systems—so the number of principal loading points is minimized.

Decentralized dispatching is utilized in Bay Ridges, Ontario and Regina, Saskatchewan. Most of the other systems utilize a central dispatcher who determines the best sequence of stops for all vehicles. The tendency toward a central dispatching operation increases as the scale of the system increases with respect to both area size and number of vehicles, and as the type of service provided becomes predominantly many-to-many.

2) **Manual versus Computer Control**—All of the systems implemented to date have utilized manual dispatching where the dispatcher uses a large map and markers to control the system operation. Most dispatchers base their dispatching decisions on intuition and experience

rather than following a prescribed set of rules.

Important questions yet to be answered are at what point computer dispatching is superior to manual dispatching and to what extent should the computer have sole responsibility in the dispatching (i.e., computer assisted versus computer controlled dispatching). Research results of the M.I.T. and G.M. studies indicate that for a many-to-many system, the point at which computer dispatching becomes more efficient and economic is approximately 200 demands per hour, or approximately a 10- to 20-vehicle fleet size.

Several computer systems have already been developed, the principal ones by M.I.T. and MITRE.[17, 18] Both are oriented toward computer control rather than computer assistance. The M.I.T. system is written in Fortran developed for general purpose computers and implemented on the IBM System/360,370 machines while the MITRE system is written in assembly language developed for a mini-computer and implemented on a Westinghouse mini-computer. Both are based on the dispatching algorithms developed by M.I.T. Neither has yet been introduced in full scale operation, although the MITRE system is being tested in Haddonfield and the M.I.T. system will be introduced in Rochester, New York.

3) **Voice versus Digital Communication**—Communications with the control center must be examined from the perspective of customers requesting service and drivers providing service. The primary mechanism for customer communication is the telephone. Push button phones enable digital communication to be utilized; however, it would get quite complex for a customer to transmit a trip request unless code numbers had been previously established for standard trips.

Vehicle communication can be accomplished with voice communication using mobile radios or with digital communication using mobile printers to receive messages and function key boards to transmit messages. Digital communications has the following principal advantages when compared with voice communications:[19]

a) **Accuracy and Safety**—The driver does not have to remember or write down messages;

b) **Channel Requirements**—More digital messages can be transmitted over a single channel. Channel space is often very difficult to obtain, particularly in large metropolitan areas;

c) **Economics**—Digital communications is cheaper than voice communications for large vehicle systems due to increased vehicle productivity and reduced control center personnel cost.

A one-month experiment utilizing digital communications was conducted in Batavia, New York. Results indicated that vehicle productivities increased between 4-11%. A new Dial-A-Bus system in Rochester, New York is the first such system to primarily use digital communications.

The coupling of computer and digital communication capabilities provides considerable potential since the human interface for vehicle communication can be almost totally eliminated. Transmission of messages would be sent by the computer directly to teleprinters in the vehicles and reverse communications can be transmitted to the computers by the drivers using a function key board. The only need for human intervention would be when an unusual situation occurred. The driver would then talk with the control center using voice communications.

Vehicles

Although standard buses were used briefly in the Regina system, all other systems utilize smaller vehicles. Many different vehicles have been used which can be grouped into the following 2 general classes: 1) Van-type vehicles costing approximately $6,000-$16,000 seating 10-15 people; and 2) Small bus vehicles costing approximately $16,000-$36,000 seating 15-20 people.

All system operators appear dissatisfied with their vehicles. Since in the past the market for small buses has been extremely limited, the quality of the vehicles has suffered. Most have been offshoots of truck or mobile home product lines and as such, are not well-suited for transit use. If demand responsive systems continue to expand, it is essential that improved small vehicles be developed.

Ridership

The average daily patronage for the principal systems is shown in Table 2. These figures should be considered in light of the following:

1) In Ann Arbor, fixed route buses continued to serve the area at a lower cost. Thus, the demand responsive system was serving a different market willing to pay more for a better level of service.

2) The Batavia demand responsive system replaced a fixed route system. Although the fare for the new service was almost 2½ times the fixed route fare (60¢ versus 25¢), ridership increased by 30%.

3) The Bay Ridges system was successful in attracting riders whereas a

TABLE 2
SYSTEM PERFORMANCE

	Ann Arbor Michigan	Batavia New York	Bay Ridges Ontario	Columbus Ohio	Haddonfield New Jersey	Regina Saskatchewan
Average Daily Patronage	200	340	700	355	730	2,000
Average Passengers per Vehicle Hour	6.0	13.0	17.0	8.4	6.1	20
Average Service Demands per Square Mile per Hour	7	6	30	9	4	21
Average Cost per Vehicle Hour	$14.60	$12.50	$8.45	$16.06	$15.40	$13.43
Average Cost per Passenger	$ 1.74	$ .92	$ .60	$ 1.53	$ 2.48	$ .71

fixed route system had been unsuccessful and was phased out 3 years before the demand responsive system was initiated.

4) The Columbus demand responsive system replaced a fixed route system. It carries approximately the same number of passengers, but incurs only ½ of the route miles incurred by the fixed route system.

5) The Haddonfield system is basically a new service.

6) The Regina system is also basically a new service, although some minor fixed route lines were replaced. In those areas which were served by the fixed route lines, ridership has increased as much as 500%.

A significant number of people using demand responsive systems own one or more cars. For example, in Ann Arbor 47% of the users own one car and 45% own two or more cars. In Bay Ridges, 61% of the users own one car and 34% own two or more cars.

Economic Implications

It is extremely difficult to compare the implemented systems from an economic perspective, since each has different objectives. Some systems were planned as demonstration systems, while others were implemented as production systems. Some systems were designed to break even, while others were designed to incur a deficit. Some demand responsive systems have no relation to any fixed route transit operations, while others are part of a larger overall system. Furthermore, each system uses different costing techniques which can have a significant impact on the overall economies.

An important indicator of economic performance is the cost per trip, which is dependent on the total cost of providing service and the vehicle productivity. Demand responsive systems are labor intensive so the wage rate is a very major factor influencing the total cost of service as reflected in the cost per vehicle hour. Vehicle productivities are dependent on many factors, such as the type of service provided, demand density and distribution, dispatching efficiency, trip length, boarding time, etc. Table 2 shows the considerable variation in the cost per trip, ranging from a low figure of $.60 in Bay Ridges to a high figure of $2.48 in Haddonfield.

The Haddonfield and Ann Arbor systems were primarily designed as demonstration systems, and thus major attempts were not made to minimize costs. Although the cost per trip in Columbus is high, it is nevertheless less than the cost of a fixed-route bus system that it replaced. The objective of the Batavia system is to break even. Currently, it is covering its operating costs and as ridership increases, it is beginning to also cover capital costs. The introduction of Telebus in Regina resulted in a decrease of $45,000 per year in the overall transit deficit due to a combination of increased passenger revenues and decreased costs resulting from modification of the fixed-route bus system following the introduction of Telebus. The objective in Bay Ridges is to cover 50% of their costs out of the farebox. With a cost per trip of $.60 and a fare of $.30, they have achieved that objective.

Even when wage rates are low, the cost per trip of demand responsive service is considerable (generally $.75-$1.50). If a low fare is charged, then a deficit is inevitable. However, in terms of the benefits of the demand responsive system on the entire system and the social benefits derived by the users of the demand responsive service, the deficit may be desirable. The Regina experience gives some indication of the overall system-wide impact of demand responsive transit in a metropolitan area achieved through rationalization of an existing fixed-route bus system.

A newly-implemented demand responsive bus system in Rochester, New York is charging a fare of $1.00, which is considerably higher than any other fare (the next highest fare is $.60). It will be interesting to see the impact of the fare on ridership and overall economics.

Appraisal

An evaluation of implemented demand responsive systems indicates that:

1) Small manually-dispatched systems are technically feasible;

2) New transit ridership can be generated if an attractive service is provided;

3) The type of service provided and dispatching operation are critical in terms of balancing peak/off-peak usage, generating high productivities, low costs per trip and good quality of service;

4) The cost per trip is moderate to high, typically varying between $.75 and $1.50.

5) Economic results have been variable. The Regina, Batavia and Bay Ridges systems have all achieved their economic objectives, whereas the Ann Arbor, Columbia and Haddonfield systems have all had exceedingly high costs and deficits.

6) Demand responsive transit systems can have a significant impact on conventional fixed route systems by providing feeder service and enabling changes to be made in existing fixed route lines.

The number of new small scale manually-dispatched systems will continue to grow. These systems will play an important role in small cities and portions of metropolitan areas. At the same time, many limited first generation demand responsive systems are being expanded into more comprehensive systems. For example, the Regina system is doubling in size, the Ann Arbor system will be expanded to serve the entire metropolitan area, the Batavia system is being expanded throughout the Rochester Metropolitan Area, and the Bay Ridges system is being expanded within Metropolitan Toronto.

Hopefully, these planned expansions will provide answers to the following significant questions:

1) **The role of demand responsive systems in larger metropolitan areas**—The Regina experience has provided some appreciation for the system integration role of demand responsive systems. As demand responsive systems are introduced, existing fixed-route systems should be modified or eliminated. The proper balance and pricing structure between fixed-route and demand responsive systems should be better understood. Decisions must be made as to whether a metropolitan area should have one large demand responsive system covering the entire area or several small systems covering portions of the area.

2) **The role of automated dispatching**—All of the systems undergoing expansion intend to incorporate some degree of computer assistance. Questions that must be resolved include: a) computer assisted versus computer controlled dispatching, b) optimal scheduling algorithms, c) necessity and type of fail soft and fail safe capabilities, and d) computer equipment requirements.

3) **Types of services**—Each of the implemented systems is different from the other with respect to the type of service provided. We must develop a better understanding of these systems so that we can match the degree of time and space responsiveness with the needs of the area.

4) **System operation**—Demand responsive transportation theoretically bridges the gap between taxi and fixed-route bus operations. Practically, critical questions are raised whether taxi or transit companies will operate these systems. In Ann Arbor, a court case has already resulted and more are inevitable. In the long run, demand responsive transit should serve to better integrate and coordinate taxi operations with other transit operations. However, in the short run, many problems will arise.

5) **Social Needs**—Demand responsive systems can play an important role in serving the needs of transit dependent groups, particularly the young, elderly and disabled. The door-to-door aspect of the service provided overcomes many of the problems these groups face. To date, the potential use of demand responsive systems for these groups has been limited. It should increase considerably as larger scale systems in metropolitan areas are introduced.

6) **Long term impacts**—Even the small scale systems have been able to attract people who previously used their automobile. Thus, demand responsive systems could influence automobile ownership decisions, particularly in multiple car families. These systems also make accessible for the first time portions of metropolitan areas where people without automobile access could not live, since no transit service was available. Thus, transit dependent groups will have a greater freedom of choice as a result of the new mobility that demand responsive systems provide them with.

Developments in demand responsive transit have occurred rather slowly. The small scale manual systems have little technical sophistication and could have been implemented many years ago. Relatively little federal government money has been allocated for demonstration or capital grant projects. With the exception of the Haddonfield demonstration, all other systems in the United States did not involve any federal funds. As a result they were quite modest.

Based on results to date, it appears appropriate to greatly increase government funding of these systems, particularly at the demonstration level. Since they involve little new hardware, private industry is not about to make major investments. The principal push must come from the government. Demand responsive systems lack much of the glamour of other "new systems" where significant funding efforts have already been made. However, whereas the technical and economic feasibility and potential transportation role of these other systems is still very questionable, demand responsive transportation has already demonstrated that it serves important needs. Much remains to be learned about the potential role of these systems, particularly in large metropolitan areas.

REFERENCES

1. Roos et. al., **Summary Report: The Dial-A-Ride Transportation System**, MIT Report USL-TR-71-03, March 1971, Cambridge, Massachusetts.

2. ———— "Demand-Actuated Transportation Systems," Highway Research Board Special Report 124, Washington, D.C.

3. ———— "Demand Responsive Transportation Systems," Highway Research Board Special Report 136, 1973, Washington, D.C.

4. Institute of Public Administration and Teknekron Inc., "Demand Activated Road Transit (DART) Performance and Demand Estimation Analysis," March 1969, Washington, D.C.

5. Bauer, H. J., "A Case Study of a Demand Responsive Transportation System," General Motors Research Laboratory Publication GMR 1084, September 1970, Warren, Michigan.

6. Guenther, K., "Incremental Implementation of Dial-A-Ride Systems," Ford Transportation Research and Planning Office Publication 70-18, September 1971, Dearborn, Michigan.

7. Richland County Regional Planning Commission and Transportation Research and Planning Office, Ford Motor Company, "The Mansfield, Ohio Dial-A-Ride Experiment Final Report," August 1970.

8. Guenther, K. W., "Summary Report, Phase 1 Results, Ann Arbor Dial-A-Ride Program," Transportation Research and Planning Office, Ford Motor Company, 1972.

9. Aex, Robert P. et.al., "How the Batavia B-Line Dial-A-Bus System Came To Be," Highway Research Board Special Report.

10. Ontario Department of Transportation and Communications, "Dial-A-Bus, The Bay Ridges Experiment," Ontario, Canada, August 1971.

11. Habig, W. C. et.al., "A Report on the Columbus, Ohio Model Cities First Year Transit Project," Mid-Ohio Regional Planning Commission, November 1971.

12. ———— "Haddonfield Dial-A-Ride—First Progress Report," UMTA Report NF-06-002-78-1, Washington, D.C., 1973.

13. Atkinson, W. G. et.al., "Regina Telebus Study—Summary Report," Regina Transit System, Regina, Saskatchewan, September 1971.

14. Bartolo, R. and F. Navin, "Demand Responsive Transit: Columbia, Maryland's Experience with Call-A-Ride," Conference—West American Institute of Planners Annual Meeting, San Francisco, California, October 1971.

15. ———— "Mass Transportation Demonstration Projects Ill. MTD 3, 4—Final Report," U.S. Department of Housing and Urban Development, Washington, D.C., 1968.

16. ———— "Mass Transportation Demonstration Project Mich. MTD-2—Final Report," U.S. Department of Transportation, Washington, D.C., 1970.

17. Wilson, Nigel et.al., "Computer Configurations for a Dial-A-Ride System," MIT Report USL-TR-70-14, March 1971, Cambridge, Massachusetts.

18. Wilson, N. H. M. and B. T. Higonnet, "General Purpose Computer Dispatching System," Demand Responsive Transportation Systems, Highway Research Board Special Report 136, Washington, D.C., 1973.

19. Ward, John et.al., "Vehicle Communications For a Dial-A-Ride System," MIT Report USL-TR-70-15, Cambridge, Massachusetts, March 1971.