OPERATIONAL EXPERIENCES WITH DEMAND-RESPONSIVE TRANSPORTATION SYSTEMS

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Demand-responsive transportation systems provide a personalized point-to-point service by responding to individual customer requests. There are no fixed routes and schedules. A dispatching center receives telephone requests from customers requesting service and assigns vehicles to service the customers. The objective is to provide efficient direct service to each customer but to group on the same vehicle customers with similar origin-destination pairs and thus reduce the cost of service to each customer. Demand-responsive transportation systems have been implemented in Ann Arbor, Michigan; Batavia, New York; Mansfield, Ohio; Columbia, Maryland; Columbus, Ohio; Bay Ridges, Ontario; Emmen, The Netherlands; and Regina, Saskatchewan. These new systems are examined with respect to vehicle dispatching, ridership, economic feasibility, type of service, and overall impact. The systems' similarities and all differences are compared. Future directions in demand-responsive transportation based on observed system performance are discussed.

• EXTENSIVE research on demand-responsive transportation systems has been conducted by many organizations during the past 5 years (1, 2). Recently, several deman responsive transportation systems have been implemented throughout the world. This paper describes initial experiences with these systems from a number of perspectives including technical feasibility, service characteristics, customer demand, and economic feasibility. Comparisons of the different operational systems and directions for the future of demand-responsive transportation are suggested.

Demand-responsive transportation systems commonly referred to by acronyms such as dial-a-bus, dial-a-ride, demand jitney (D-J), demand-actuated road transit (DART), computer-aided routing systems (CARS), and Genie provide a personalized point-to-point service by responding to individual travel requests. There are no fixed routes and schedules. Instead, a dispatching center receives telephone calls from customers and assigns vehicles to service the customers. The objective of the dispatching operation is to provide efficient, direct, point-to-point service to each customer but to group customers with similar origin-destination pairs on the same vehicle and thus reduce the cost of service to each passenger.

Research results suggest that demand-responsive transportation systems complement conventional fixed-route and scheduled systems. In low- and medium-density areas, they can provide a total transportation service where conventional fixed-route buses are not economically feasible. In higher density areas, they can provide feeder service to line-haul facilities and thus fill the existing void between conventional transit and taxi service. However, until these systems are implemented and tested, one can only speculate on their ultimate role.

IMPLEMENTED SYSTEMS

Eight recently implemented demand-responsive systems are described below. Many of these systems have been operating for only several months; hence, the data are of a preliminary and, therefore, tentative nature. Nevertheless, preliminary data are often sufficient to gain important insights into this potential new form of transportation.

Although all of the systems described can be classified as demand responsive, they differ from one another in many respects. One of the most significant differences relates to the type of service provided and the degree of demand responsiveness.

The 3 systems described first (Mansfield, Ohio; Emmen, The Netherlands; and Dayton, Ohio) are examples of route-deviation service where a vehicle follows a basic fixed route but deviates from the route to provide door-stop service on request. The next system described is (Bay Ridges, Ontario) an example of many-to-one service (many origins to one destination and vice versa). The 2 systems described next (Ann Arbor, Michigan, and Regina, Saskatchewan) provide many-to-few service (many origins to a few destinations and vice versa). The 2 systems described last (Columbia, Maryland, and Batavia, New York) are examples of many-to-many service (many origins to many destinations). Whereas the route-deviation services have limited demand-responsive characteristics, the many-to-many services represent completely demand-responsive systems. Many-to-one and many-to-few systems are progressively more responsive than route-deviation systems but less so than many-to-many systems.

MANSFIELD, OHIO, SYSTEM

A 13-month route-deviation experiment was implemented in Mansfield, Ohio, a community of 60,000 people (3, 4). The experiment was jointly undertaken by the Richland County Regional Planning Commission, the Transportation Research and Planning Office of Ford Motor Company, and Mansfield Bus Lines, Inc., with the cooperation of the city of Mansfield.

The regular Mansfield bus system consisted of 13 fixed-route bus lines radiating from a central point in Mansfield City Square. Twice an hour all buses met at the Square to allow easy transfer among bus lines. One of these bus routes serving 3,000 to 4,000 people in the Woodland area of Mansfield was discontinued in December 1969 because of a lack of patronage. This route was then reinstated at the end of the month as a route-deviation service.

The new service consisted of a combination of normal fixed-route and demand-responsive service. An 11-seat Ford Courier vehicle traveled a specified route but deviated from the route to pick up or drop off passengers within a prescribed area. The vehicle was equipped with the telephone communication equipment so that customers requesting service could directly call the vehicle driver. The driver would determine whether he had sufficient time to detour from his route and still maintain his basic commitment to rendezvous at the City Square each half hour. For this door-stop service, customers were charged an extra 15 cents above the basic 35-cent fare. The service was provided 6 days a week, 11 hours a day (7:15 a.m. to 6:15 p.m.) except on certain holidays.

Significant results observed during the 13-month test were as follows:

1. The driver was able to perform as many as 8 deviations per 30-min period while maintaining his half-hour schedule. Generally, however, the driver performed fewer than 2 or 3 deviations for each run because of a lack of customer demand.
2. Nineteen percent of all passengers using the bus service chose the door-stop option. (A person could still board the bus along the fixed route and pay the normal 35-cent fare.) However, because only 75.9 persons/day rode the bus, the 14.4 people requesting door-stop service represented a small demand level.
3. Older females who had no driver licenses were the largest users of the door-stop option. A significant number of domestics traveling to Woodland, a high-income area, used the service.
4. The route-deviation service did not attract significant new ridership to the route. The primary users of the new service were people who previously used the fixed-route bus.
5. Addition of the route-deviation service improved the overall financial condition of the route compared with the previous fixed route, but it was still not able to cover direct operating costs.
6. The small Ford Courier vehicle performed extremely well. Daily operating costs were significantly lower than those for conventional transit equipment.

7. A survey of users and nonusers of the service indicated that the most desired improvement to increase patronage would be to provide additional destinations. That is, the users wanted a more generalized many-to-many service rather than the somewhat limited route-deviation service.

The Mansfield route-deviation service was discontinued in January 1971. Since then, problems developed relative to financing of the entire Mansfield Bus Lines system, and the system was discontinued in June 1971. This is unfortunate because the Mansfield system was quite innovative in many different respects and was successful from both a financial and service viewpoint up to its final day of operation.

EMMEN, NETHERLANDS, SYSTEM

BUXI (BUs, taXI) is a route-deviation type of service implemented in May 1970 in Emmen, The Netherlands, a town of 36,000 (5). The service runs among the small suburb of Emmenhout, containing 4,000 people, and the town center and railroad station in Emmen, a distance of only 1 to 2 miles. Service is provided daily from 5:41 a.m. to 12 midnight. Two 11-seat Mercedes Benz 0309 Minibuses are used, which carry 23 passengers including standees. Three different types of service are combined: a basic fixed-route service, a route-deviation service with the deviations preplanned by a dispatcher, and a one-to-many service with the stops determined by the driver. The vehicle operates in each of these 3 modes for different segments of its runs. A preliminary evaluation of the service reveals the following:

1. Seventeen percent of the families in Emmenhout have used the service; however, only 3.4 percent of the families are regular users.
2. Seven percent of all service requests are demand responsive. Eliminating those portions of the service where no demand-responsive service is available increases the percentage of demand-responsive patronage to 10 to 15 percent.
3. Revenue from the service does not cover operating costs. During the first year of operation, total expenses were 120,000 Dfl whereas income was 48,000 Dfl.
4. The portion of people requesting demand-responsive service is decreasing; however, the decrease occurred in the warm summer months.

In an evaluation of the BUXI system, the following factors should be considered: Only 50 percent of the households have a telephone; in almost all cases the maximum walk from a house to the fixed route is only 200 meters; and some residents have indicated confusion about how the system works.

COLUMBUS, OHIO, SYSTEM

A route-deviation service replaced a fixed-route bus operation in the Columbus, Ohio, Model Cities area on October 11, 1971. Twenty-one checkpoints are specified that correspond to major activity centers. A driver must stop at each checkpoint at a specified time. Between checkpoints, the driver can choose any route depending on existing customer demands.

The service area is 2.56 square miles and contains approximately 55,000 people. Service is provided from 6 a.m. to 9:30 p.m., Monday to Friday, and on a somewhat reduced schedule on the weekends. The Columbus Model Cities Agency has allocated $200,000 to run the experimental service from October 1971 through June 1972.

The Columbus Transit Service is using four 19-seat Flxette vehicles to operate the service. Labor rates for drivers are approximately $4.50/hour. Dispatching is performed by Model Cities residents. Two people dispatch during peak periods, whereas only 1 person is required in off-peak periods.

Ridership in December 1971 was 350 to 400 persons/day and increasing. Average vehicle productivity was 8 to 9 persons/vehicle/hour with maximum productivities during peak periods in the range of 12 to 15 persons/vehicle/hour. The planned fare for the new service was 35 cents, but because of the price freeze the old fixed-route fare of 20 cents was retained.

Ridership on the old fixed-route system at the time it was discontinued was approximately 600 passengers/day of which 450 to 500 trips were within the area currently served by the new route-deviation system. The new system is, therefore, currently carrying fewer passengers a day although ridership is increasing. The cost of providing service using the route-deviation system is lower, however, than that for the fixed-route operation because the number of daily route-miles traveled with fixed-route buses was almost twice the daily route-miles for the route-deviation service.

BAY RIDGES, ONTARIO, SYSTEM

Bay Ridges, a community of 4 square miles and 14,000 people and 20 miles from Toronto, is serviced by the GO Transit Commuter Railroad. A many-to-one demand-responsive service to and from the commuter railroad station was begun in July 1970 by the Ontario Department of Highways (6, 7). The service, provided 7 days a week from 5 a.m. till 1 a.m., is designed to meet all trains, which operate on an hourly schedule in the off-peak hours and on a 20-min schedule in the peak-hour periods of 7 to 9 a.m. and 5 to 7 p.m. Four 11-seat Ford Econoline vehicles are used and cover 4 zones of Bay Ridges. A fare of 25 cents is charged, which is expected to cover 50 percent of the basic operating costs (a general policy for the Department of Highways). The basic wage at the beginning of service was $3.02/hour for drivers and $3.30/hour for dispatchers. All dispatching is performed by a single person. Users must call at least 1 hour before making a trip so that the manual dispatching operation is somewhat simplified.

Weekday ridership during the first year of operation has increased from approximately 200 to 465 passengers/day. Maximum productivities of 20 to 25 passengers/vehicle/hour are achieved during the afternoon peak hours. Saturday ridership averages 185 trips/day, while Sunday ridership is approximately 90 trips/day. Recently, a many-to-many service was added during the off-peak hours and carries 75 to 80 passengers/day.

The cost of operating the system during the first year was $7.19/vehicle-hour. Recently, driver wages were increased, and the new wages increase the cost to $7.75/vehicle-hour.

GO Transit has compared the costs associated with its demand-responsive operation with a comparable fixed-route bus operation, as follows:

	Cost per Revenue Mile (cents)	
Expense	Demand Response	Fixed Route
Capital	9	7
Overhead	28	21
Maintenance and fuel	9	21
Operators' wages	33	33
Total	79	82

The 2 significant differences in the GO Transit figures are for overhead and for maintenance and fuel. The difference in overhead represents the cost of the dispatching operation. The differences in maintenance and fuel reflect the newness of the dial-a-bus vehicles and the less expensive operating costs of the smaller vehicles.

During the first year of operation the average cost per trip was 69 cents. Based on existing patronage, that figure is now reduced to 60 cents/trip. The economic objective is for the service to cover 50 percent of its costs. With the current fare of 25 cents, this objective is almost being realized. To ensure that it will be satisfied in the future, GO Transit is proposing the following 3 changes in the service:

1. Increase the fare from 25 to 30 cents;
2. Eliminate Sunday service where there is low patronage and the average cost per trip is approximately $1.35; and

3. Eliminate the dispatching service after 9 p.m. on weekdays and 4 p.m. on Saturdays.

Currently, only 1 or 3 people call in for service after 9 p.m. during the week and after 4 p.m. on Saturday. Most service during these hours is prebooked earlier in the day or on standing request for the same service each day.

Current plans are for the municipality to take over the service from GO Transit, which plans to implement several additional similar services throughout Ontario.

REGINA, SASKATCHEWAN, SYSTEM

A many-to-few telebus service was started in Regina, Saskatchewan, on September 7, 1971 (8, 9). The service is being sponsored by the Provincial Department of Highways and Transportation and operated by the Regina Transit System. Engineering and development costs are being shared equally by the federal, provincial, and city governments; capital costs and administrative costs are paid by the city. Revenues from the system are expected to cover direct operating costs.

The telebus service area is approximately 2½ square miles and contains 18,000 people. It is a nonhomogeneous area; 1 corridor in the area has densities as high as 25,000 persons/square mile. The primary objective of telebus is to serve as a feeder to a fixed-route arterial bus line. Several other major activity centers are also served, although 90 percent of the use is for feeder service.

Telebus service is available from 6:45 a.m. to 11:35 p.m. Monday through Saturday. Six buses operate during the peak hours, and 3 buses operate during off-peak hours. The schedules are established by the use of manual dispatching techniques so that telebuses rendezvous with the fixed-route buses every 15 min during the peak-hour period and every 30 min during the off-peak-hour periods. Standard 42-passenger buses are currently being used for telebus service, although smaller minibus vehicles are being investigated.

Users of telebus are encouraged to book their trips in advance. Currently, 40 percent of the riders are prebooked, while the remaining 60 percent call when service is desired. A call for service must be made at least 20 min before pickup time. One person handles the manual dispatching operation.

The cost of telebus service is 35 cents; a free transfer is provided to the arterial bus, whose normal fare is 25 cents. A monthly pass may be purchased for $12.00, and special rates for students and children are also provided.

Ridership as of December 1971 was 1,000 passengers/day and increasing. As many as 22 passengers were being carried on a single run, and peak-hour productivities as high as 30 passengers/vehicle/hour have been achieved. Average vehicle productivities throughout the day are 15 persons/vehicle/hour.

One portion of the area was previously served by a fixed-route bus that ran 7 hours/day, cost 25 cents, and carried 50 passengers/day. Currently 400 passengers/day from that neighborhood are using the new service even though the fare is 10 cents higher.

The labor rate for drivers is $3.83/hour and for dispatchers is $4.75/hour. Direct operating costs are approximately $7/vehicle-hour. If the entire 35-cent fare is credited toward Telebus operations, approximately 75 percent of the operating costs would currently be covered by fare-box revenue.

ANN ARBOR, MICHIGAN, SERVICE

A 3-vehicle, many-to-few demand-responsive service was started on September 22, 1971, in a 2.3-square mile area of Ann Arbor, Michigan, containing approximately 10,000 people. The service is being sponsored by the state of Michigan to determine demand and cost implications of providing demand-responsive service. Funding of $56,000 is provided from the state, and $33,000 is provided from local public and private sources to conduct the experimental service. The service is expected to generate $91,000 in revenues during its first year of operation.

The system is operated by the Ann Arbor Transportation Authority from 6:30 a.m. to 6 p.m., Monday to Thursday and on Saturday. On Friday, the service runs from

6:30 a.m. till 9 p.m. Ten-seat Ford Econoline and Ford Courier vehicles pick up people anywhere in the service area and then proceed to the downtown area where they drop people off at specified points around a loop. A fare of 60 cents/trip or 10 rides for $5.00 is charged.

Vehicle scheduling is performed by a single person who answers the phone and establishes the vehicle routes. This dispatcher is paid a basic wage of $4.35/hour. Drivers are paid $4.15/hour.

By December 1971, patronage had increased to 190 passengers/day. Vehicle productivities during the peak-hour periods have been as high as 20 passengers/vehicle/hour; average vehicle productivity is 8 passengers/vehicle/hour.

An interesting aspect of the Ann Arbor service concerns a recent court decision brought by the local taxi companies against the proposed new service. The taxi companies lost the case, and the service was allowed to begin. The judge ruled that dial-a-ride was different from taxicab service because the vehicle carried several people and a dial-a-ride passenger was not free to specify a desired route.

COLUMBIA, MARYLAND, SERVICE

Columbia, Maryland, is a new community midway between Washington, D.C., and Baltimore, Maryland, planned to have a population of 110,000 by 1980. Currently, the population is approximately 16,000 people. In January 1971, a demand-responsive transit system replaced a fixed-route system that was carrying only about 30 to 60 passengers/day before it was discontinued (10, 11). The new demand-responsive system provided 2 different types of service. Easy Rider service was basically a home-to-work type of subscription service similar in concept to the Premium Special service in Peoria, Illinois (12), and the Maxi Cab Commuter Club in Flint, Michigan (16). The service was provided during the morning and evening peak-hour periods (7:30 to 8:30 a.m. and 5:00 to 5:30 p.m.) to employment locations in Columbia for a fare of 35 cents/ride or 10 rides for $3.00. Between 8:30 a.m. and 11:00 p.m., a many-to-many service called CAR (call-a-ride) was provided for 25 cents/trip or 10 trips for $2.25. Initially, 2 minibus vehicles were used, although a third vehicle was quickly added in February 1971 to handle increased demand. Vehicle dispatching was manually operated from a central control facility. Analysis of the service indicates:

1. A significant demand for CAR occurred very quickly. After the first month daily patronage averaged 250 to 300 passengers/day compared with only 50 passengers/day on the discontinued fixed-route service. The patronage for Easy Rider was 35 passengers/day.
2. Technical difficulties were encountered in the dispatching operation. Only a single phone line was provided with no facility to hold incoming calls (over 500 busy signals were recorded in a single day). Dispatching was performed by nonprofessionals using minimal disptaching aids (a map with pins and slips of paper).
3. The level of service provided often deteriorated as the demand for service increased. Several hours a day the wait time before a vehicle arrived was 1 hour or more. Even the addition of a third vehicle did not markedly improve service. Analysis of a typical day's operation indicated that 65 percent of the passengers were picked up within 15 min, 19 percent were delayed 15 to 30 min, and 16 percent waited more than 30 min.
4. The vehicle productivity averaged 5 to 6 people/vehicle/hour.
5. The system provided an important public service. A survey of Columbia residents asked them to rate 22 services provided by the community. Fifty-nine percent rated CAR very important, and 21 percent rated it somewhat important. The only 2 other services to get higher ratings were maintenance of open space and providing early childhood education.
6. The system was extremely expensive to operate. During its final month of operation it is estimated that the average cost was $2.10/trip.

Basic revisions were made in Columbia's transit system in September 1971 to correspond with the opening of a major new shopping center in downtown Columbia.

Easy Rider was discontinued, and CAR is now offered only between the hours of 6:30 and 8:30 a.m. and between 5:30 and 11:00 p.m. From 8:30 a.m. to 5:30 p.m., fixed-route buses serving the mall have replaced CAR service. The fare for CAR was increased to 50 cents but was then rolled back to 25 cents as a result of the price freeze.

BATAVIA, NEW YORK, SYSTEM

On October 11, 1971, a 3-vehicle demand-responsive service replaced a 2-vehicle fixed-route operation because of declining ridership and increasing costs. The service was planned by the Rochester-Genesee Regional Transportation Authority and is operated by Batavia Bus Lines. The new many-to-many demand-responsive system provides service Monday to Friday from 6:00 a.m. to 6:00 p.m. to the population of 18,000 people anywhere within the city limits of 4.3 square miles. In addition, a community college and a shopping center just outside of the city limits are served. During the morning and afternoon peak periods, subscription service is offered consisting of home-to-work and return and home-to-school and return. During the off-peak hours the same 23-seat Flxette vehicles provide many-to-many service.

Manual scheduling is performed by a telephone operator and dispatcher. Because both people are frequently idle, consideration is currently under way to use only 1 person in the off-peak periods. The average pickup delay is 10 to 20 min. During peak periods maximum waiting times of 30 min have occurred. The average travel time is approximately 10 to 15 min.

Ridership has increased constantly since the introduction of the service. In December 1971, ridership totaled approximately 360 passengers/day of which 180 were subscription customers and 180 were many-to-many customers. A fairly large increase in ridership occurred when cold weather began. The average vehicle productivity is 8 passengers/vehicle/hour for many-to-many service and 12 passengers/vehicle/hour for subscription service.

Fares are 60 cents for many-to-many service and 40 cents for subscription service. The economic objective of the service initially is to do no worse than the former fixed-route service, which lost approximately $10,000/year. The eventual objective is to produce a break-even operation. Based on the current ridership figures and continuing upward trends, these objectives appear attainable. The base driver wage of only $2.35/hour is quite low; thus, a break-even situation may be easier to obtain than in some other systems.

Current plans are to add 2 additional vehicles in the near future and to continue adding buses as the demand increases.

COMPARISON OF IMPLEMENTED SYSTEMS

The systems in Bay Ridges, Mansfield, Columbia, and Emmen have operated for 1 year or longer, whereas the systems in Ann Arbor, Batavia, Columbus, and Regina have operated for only several months. These later systems have not yet reached steady-state conditions. Nevertheless, it is interesting to compare the various systems to see what preliminary conclusions regarding demand-responsive transportation can be formulated. The various implemented systems are contrasted below from several standpoints.

Vehicles

Although different brands of vehicles have been used, they can be grouped into 3 basic categories: van vehicles with approximately 10 to 12 seats, minibus vehicles with approximately 19 to 25 seats, and standard buses with approximately 40 seats. Only Regina is using the large buses and has indicated plans to switch to smaller vehicles. Vehicle capacities of 10 appear sufficient for many-to-many service and for some many-to-one applications, although Bay Ridges and Regina do carry as many as 20 passengers at one time on a vehicle. Route-deviation and subscription service generally require vehicle capacities of 20 seats, if sufficient passenger demand exists. The smaller van and minibus vehicles are favored because they are more acceptable on residential streets in lower density areas and have operating costs somewhat lower than those of standard vehicles. All operators have indicated the need for improved small bus design.

Type of Service

Although all of the implemented services can be classified as demand responsive, each of the systems offers a somewhat different type of service. As previously stated, Mansfield, Emmen, and Columbus are different variants of the route-deviation idea. Toronto began as a many-to-one service with a many-to-many service recently added in the off-peak hours. Ann Arbor and Regina provide many-to-few services, although most service in Regina is to one point. Columbia was and Batavia is basically a many-to-many service with subscription service during the peak hours.

Three of the systems provide different demand-responsive services at different hours of the day. With a combination of different types of demand-responsive services, the system can better meet the changing needs of the users during the day and achieve a better utilization of personnel and equipment during the service hours. The peak-hour services tend to be less dynamic but handle more people, whereas the off-peak services are more dynamic but handle fewer people. The concept of system balancing is already important in the design of demand-responsive transit services.

It is not surprising to see so many different types of service represented in the implemented systems. Different communities have different needs, so different types of demand-responsive transportation systems should naturally develop. Conventional fixed-route and scheduled systems provide few options. A basic capability of demand-responsive transportation is the overall flexibility of the system and can be used in different ways to achieve different goals.

Service Areas

All implemented systems utilize 6 or fewer vehicles and serve populations of no more than 20,000 people. In contrast, the research results (1) indicated that dial-a-ride would be most promising in communities with populations between 25,000 and 250,000 people. There are several reasons why smaller systems have been implemented first. They are cheaper and simpler to implement and require minimal capital investment, an important factor for many small communities. Manual-disptaching techniques are sufficient to operate the systems. A small dial-a-ride fleet can cover an entire community and serve most of the origin-destination requests, whereas a small vehicle system can only service a portion of a large city. (Some of the more recent systems in Regina, Dayton, and Ann Arbor serve portions of the entire city.) Because there are generally fewer institutions to deal with in small cities, the institutional constraints are less severe.

Dispatching Techniques

All of the implemented systems utilize manual-dispatching techniques. In Mansfield, the relatively simple dispatching was performed by the vehicle driver, whereas in the other systems dispatching was performed at a control center. In all cases, largely intuitive techniques are used including dispatching aids such as maps with pins or a magnetic map board. One or 2 people are employed to answer phone calls from customers, make dispatching decisions, and communicate dispatching information to vehicle drivers.

Manual-dispatching techniques appear adequate for the existing vehicle fleet sizes and customer requests. This is not surprising because research results indicated that manual-dispatching techniques are clearly superior to automated techniques for fewer than 10 vehicle systems (1). It will be interesting to observe how well manual dispatching performs as the current systems grow and larger new systems are introduced.

Customers using a demand-responsive system can be grouped into the following 3 basic categories: demand requests, customers who call up when they want service; standing requests, customers who call once to request repeat service the same time each day; and prebooked requests, customers who call several hours before they wish to make a single trip.

In most systems as many as 20 percent of all trips are standing requests. The most extreme case occurs in Bay Ridges where during the peak hours fewer than 15 percent of all trips are demand requests. During other hours of the day significant numbers of standing requests also occur. This not only simplifies the dispatching operation but also results in more efficient vehicle assignments. In many respects, these systems start to have the same characteristics as subscription services where all stops are preplanned on a repetitive basis.

Many trips are also prebooked several hours ahead of time. In some cases, the prebooking is a necessity during peak periods to minimize delays that would occur if service were requested at the time a person wanted to make a trip. In the other cases, people are calling several hours before making a trip to assist in the overall system efficiency.

The large number of standing requests and prebooked trips indicate that many people do not require extreme flexibility with respect to time. These people are primarily interested in the space flexibility provided by a demand-responsive service (i.e., point-to-point service). This is extremely important to consider in the design of new demand-responsive systems where decisions must be made as to how much flexibility should be provided. As the flexibility and dynamic characteristics of the system increase, the cost of providing the service generally increases while the passenger-carrying capacity decreases. A system should, therefore, provide no more flexibility than is required for a given application.

Fare

There is a considerable variation in the fares being charged. Columbia, Toronto, and Columbus all charge very low fares (25 to 35 cents) even by conventional fixed-route bus standards. The Toronto fare is purposely low because only 50 percent of operating costs are expected to be covered out of the fare box. The Columbus fare is low because the system is designed to serve low-income residents of a Model Cities area. The low fare in Columbia was a major reason that the cost of the operation exceeded the allocated budget. When the service in Columbia was recently changed, the call-a-ride fare was increased to 50 cents.

Higher fares of 60 cents are charged in Ann Arbor and Batavia, and a fare of 50 cents was charged in Mansfield for the route-deviation service. Even these fares tend to be somewhat low. The M.I.T. and GM research work indicated that a fare of $0.50 to $1.25 is required to cover all fixed and operating costs in a dial-a-ride service (1, 2). The low end of the spectrum (50 to 75 cents) represented service provided by taxi companies where labor rates are far less than for transit operations.

Ridership

Of the 3 route-deviation systems, Mansfield represented expansion of an existing fixed-route service, Columbus represented a replacement of fixed-route service, and Emmen represented a totally new service. For the first 2 cases, route-deviation service did not result in an increase of ridership. In fact, the ridership in Columbus appears to have decreased although that conclusion might be premature. The Mansfield experiment did illustrate that a significant number of existing riders (20 percent) were willing to pay more money (15 cents) for a higher quality door-stop service. A smaller percentage of people use the door-stop option in the BUXI system even though there is no additional charge. There is, however, a real question, if one considers the small size of Emmenhout and the proximity of people to the route, whether any form of demand-responsive service was warranted.

Whereas route-deviation service does not greatly increase the area coverage, other forms of demand-responsive service do increase potential travel opportunities. The Columbia, Regina, and Batavia experiences seem to support this conclusion. Replacement of the limited fixed-route service in Columbia with a more flexible many-to-many service resulted in a dramatic 500 percent increase of ridership. In 1 neighborhood of

Regina where telebus replaced a fixed-route service, ridership increased 800 percent from 50 passengers/day to 400 passengers/day. In Batavia, current ridership on the demand-responsive system surpasses the ridership on the old fixed-route system even though the fare for the new service is 2½ times the fare for the fixed-route service. The Bay Ridges service has attracted significant patronage whereas a fixed-route system operated from 1967 to 1968 did not attract many riders and was discontinued.

Ridership on demand-responsive systems is subject to both short- and long-term fluctuations. None of the systems has been able to overcome completely the peak/off-peak problem although it is less severe than in previous fixed-route operations. In several cases new peak hours are developing as new users and new travel demands are served. As previously mentioned, the combination of different demand-responsive systems at different hours of the day has helped significantly to reduce the peaking problem.

Variations of ridership throughout the year is most observable in northern areas subject to severe winter weather. Preliminary results indicate that weather plays a far greater effect on demand-responsive ridership than it does on fixed-route ridership. Door-to-door service is particularly appealing during unpleasant weather.

Vehicle Productivity

Vehicle productivity is extremely important when system efficiency and the cost of the service to each user are determined. Vehicle productivity can be either supply or demand limited. The Mansfield and Emmen cases are examples of situations where more people could have been served by the system but the additional demand did not develop. Ignoring these 2 systems for a moment, we will only consider vehicle productivities where supply characteristics have constrained the system. Average vehicle productivities on these systems have varied from a low value of 5 to 6 passengers/vehicle/hour in Columbia to a high value of 15 passengers/vehicle/hour in Regina. Most systems have average vehicle productivities of approximately 8 to 9 persons/vehicle/hour. Maximum vehicle productivities of 20 to 30 persons/vehicle/hour have been achieved in both Bay Ridges and Regina. The differences between average and maximum vehicle productivities reflect that all the system capabilities are not fully utilized during all the service hours.

The factors that most affect vehicle productivity appear to be the following:

1. Type of service. The potential for high vehicle productivity is greatest in route-deviation services and lowest in many-to-many service. The more flexible and dynamic the system is, the lower the potential maximum vehicle productivity will be. This is illustrated by the high vehicle productivities in Regina and Toronto compared with lower productivities in Batavia, Ann Arbor, and Columbia.
2. Service requests. Vehicle productivity increases as the percentage of standing requests and prebooked trips increase. Given sufficient time for preplanning, more efficient vehicle assignments can be developed. In Bay Ridges and Regina where vehicle productivity has exceeded 20 passengers/vehicle/hour, a significant percentage of customers use standing requests or prebooking.
3. Dispatching efficiency. If efficient dispatching techniques are used, more people can share the use of a single vehicle. This intuitively obvious conclusion has not yet been quantitatively verified by a comparison of the existing systems.
4. Demand density. The higher the demand density is, the higher the vehicle productivity will be. Although this was verified in simulation experiments, data from the initial operational systems have not yet been analyzed (2, 14).
5. Trip length. The shorter the trip length is, the higher the vehicle productivity will be. Here again, as in factor 4, this has been observed in simulations but the operational data have not yet been analyzed (2, 14).
6. Boarding time. The vehicle is unproductive when it must wait for passengers to enter and leave the vehicle. In most systems boarding time rarely exceeds 30 sec, whereas in Columbia a vehicle sometimes waited more than 2 min for a passenger to leave her home and board. One reason for the long vehicle boarding time in Columbia might have been the unpredictability of the waiting time. As previously noted, some

people had to wait as long as an hour for service and thus were not inclined to be ready for a vehicle to arrive.

7. Multiple pickups. As the number of multiple pickups increases, the vehicle productivity increases. Most systems service an average of 1.1 to 1.3 persons/pickup.

Economic Implications

The cost per trip is dependent on the total cost of providing service and the vehicle productivity. The cost of providing service is largely dependent on the driver cost. For a system with few vehicles, the cost of the manual-dispatching operation is also a significant portion of the total cost. As more vehicles are added, this largely fixed cost is spread over more vehicles. Demand-responsive systems are very labor intensive. The labor rates in the implemented systems vary considerably from low figures of approximately \$2.50/hour in Batavia, Columbia, and Mansfield to high figures of more than \$4.00/hour in Ann Arbor and Columbus.

The costs of demand-responsive transit services are significantly different. The average operating cost of service in Columbia exceeds \$2/trip, whereas the average operating cost in Bay Ridges is only 60 cents/trip, even though the labor rate of \$3.04/hour in Bay Ridges exceeds the labor rate in Columbia of \$2.50/hour. The significant difference between the cost of these 2 systems is vehicle productivity and the efficiency of the dispatching operation.

In Mansfield, the additional revenue from route deviation more than paid for the small added dispatching cost. The new route deviation was, therefore, economically more viable than the previous fixed-route system. However, the new system did not produce sufficient revenue to cover operating costs.

Based on the low ridership to date, there is a real question whether the Emmen route-deviation service is an economically viable operation. Because the author is unaware of the overall objective of that system, it is not possible to make a more definitive evaluation at this time.

Although the Columbia system was a significant success in terms of generating new ridership, it was an economic failure because its costs exceeded the allocated budget. The recent changes in fare and service are intended to produce an economically viable operation. The author must, however, question the decision to run many-to-many service in the morning peak hour when demands are repetitive and fixed-route service in the off peak when demands are far more random.

The Bay Ridges system was designed so that fare-box revenue would pay for 50 percent of the operating cost. Currently, the system is approaching this objective because the fare is 25 cents and the average operating cost is 60 cents. The newly initiated many-to-many service is covering approximately 80 percent of the marginal operating costs. The planned 5-cent fare increase and elimination of late evening dispatching and Sunday service should produce the desired economic objectives.

It is premature to judge Batavia, Regina, Ann Arbor, and Columbus, for they have been operating only several months. The operators of these systems appear pleased and feel that they are approaching the predetermined economic objectives. We should, however, reserve judgment because some of these operators might be overly optimistic.

FUTURE DIRECTIONS

In many respects it is remarkable how slowly demand-responsive systems have been implemented in terms of both demonstration projects and production systems. Encouraging research results have been reported during the past 5 years. The New Systems Study of the U. S. Department of Housing and Urban Development recommended dial-a-ride as the most promising short-term concept, yet, relatively little has happened since that study (15). The few demand-responsive systems that have been implemented are relatively small and modest. A major reason for this development pattern has probably been that the U. S. Department of Transportation, responsible for the major research in the area of demand-responsive transit, is only now about to begin service of a manually dispatched dial-a-ride demonstration project in Haddonfield, New Jersey.

In many ways this approach of initial demonstrations not involving the federal government might be appropriate, particularly in a free enterprise country. However, there are 2 real dangers. First, if many of the initial systems are poorly conceived, a promising new concept might be incorrectly dismissed. The government is in the best position to ensure that the proper demonstrations are implemented in the proper areas so that the full national significance of the concept can be evaluated. None of the implemented systems described in this paper had an extensive data collection and evaluation phase or site selection analysis associated with it. It is, therefore, difficult to gain maximum information from an analysis of the operations.

The second potential problem concerns the possibility that a large subset of demand-responsive systems may be prematurely overlooked. The initial experiences reported here give some indication of the potential for the new concept. However, one must be quite careful in interpreting these results. Smaller scale, manually controlled dial-a-ride systems may not be representative of larger scale, computer-controlled dial-a-ride systems. Although manual-dispatching techniques are most efficient for dispatching 10 or fewer vehicles they become too expensive and less reliable as the number of demands and vehicles increases.

Small manually controlled dial-a-ride systems have an important place in providing urban transportation service. However, this author believes that larger scale, computer-controlled systems will have even more impact. An operational computer-dispatching system developed by M.I.T. to run on the IBM System 360 and System 370 computers has been completed and is in the public domain. Another computer-dispatching system is currently being developed by the MITRE Corporation to operate on a Westinghouse minicomputer. The federal government has indicated that if the Haddonfield experiment is successful it will computerize it and implement a second computer-controlled dial-a-ride system in Rochester, New York. With the availability of computer-based dispatching systems and an active government program, we should shortly see the implementation of the first computer-controlled, demand-responsive transportation systems.

SUMMARY

Eight new demand-responsive transportation services have recently been implemented. The principal conclusions relating to these systems are as follows:

1. No 2 systems provide identical types of service. This suggests that we might expect many different types of demand-responsive service to be developed based on the particular needs of the community for which it is implemented.
2. All of the implemented systems are small manually dispatched systems serving relatively small areas. These types of systems were the easiest and cheapest to implement initially and entailed the least risk.
3. All systems except one use small vehicles with seating capacities of 10 to 25 people. Route-deviation and subscription services require approximately 20 seats, whereas general many-to-many services require fewer seats.
4. Fares for the services vary between 25 and 60 cents. The services most recently implemented tend to have fares at the upper end of this range. It would not be surprising to see newer systems with even higher fares approaching or even exceeding $1/trip.
5. Average vehicle productivities vary between 5 and 15 persons/vehicle/hour. Maximum vehicle productivities of 20 to 30 persons/vehicle/hour have been achieved in 2 systems.
6. People are willing to spend more money for higher quality service. Many-to-one and many-to-many service can attract new riders, whereas the more limited route-deviation services have considerably less potential to attract new ridership.
7. Many implemented systems have achieved or are achieving their economic objectives. These objectives are quite different for each of the systems.

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