TRANSPORTATION RESEARCH RECORD 718

Bus and Rural Transit

TRANSPORTATION RESEARCH BOARD

COMMISSION ON SOCIOTECHNICAL SYSTEMS
NATIONAL RESEARCH COUNCIL

NATIONAL ACADEMY OF SCIENCES
WASHINGTON, D.C. 1979

Transportation Research Record 718
Price $3.00
Edited for TRB by Susan Singer-Bart

modes
1 highway transportation
2 public transit

subject areas
12 planning
40 maintenance
54 operations and traffic control

Transportation Research Board publications are available by ordering directly from TRB. They may also be obtained on a regular basis through organizational or individual affiliation with TRB; affiliates or library subscribers are eligible for substantial discounts. For further information, write to the Transportation Research Board, National Academy of Sciences, 2101 Constitution Avenue, N.W., Washington, DC 20418.

Library of Congress Cataloging in Publication Data
National Research Council. Transportation Research Board.
Bus and rural transit.

(Transportation research record; 718)
Reports prepared for the 58th annual meeting of the Transportation Research Board.
1. Motor bus lines–United States–Congresses. 2. Local transit–United States–Congresses. 3. United States–Rural conditions–Congresses.
I. Title. II. Series.
TE7.H5 no. 718 [HE5623] 380.5'08s [388.3'22'0973]
ISBN 0-309-02968-6 ISSN 0361-1981 79-24607

Sponsorship of the Papers in This Transportation Research Record

GROUP 1–TRANSPORTATION SYSTEMS PLANNING AND ADMINISTRATION
Leon M. Cole, Library of Congress, chairman

Public Transportation Section
Kenneth W. Heathington, University of Tennessee, chairman

Committee on Bus Transit Systems
Herbert S. Levinson, Wilbur Smith and Associates, chairman
James C. Echols, Tidewater Transportation District Commission, vice-chairman
Richard J. Anderson, J.J. Bakker, Alvin G. Basmadjian, John W. Bates, Eugene T. Canty, Karen P. Damsgaard, Robert B. Deuser, Frank Dicesare, Curt M. Elmberg, Gordon J. Fielding, Edward R. Fleischman, Marvin C. Gersten, Jack R. Gilstrap, Andrew Hollander, Ronald I. Hollis, Linda Sue Hunkins, Carol A. Keck, Henry M. Mayer, Neil Craig Miller, Donald A. Morin, Martin C. Nizlek, Vasant H. Surti, F.V. Webster

Committee on Rural Public Transportation
Douglas J. McKelvey, National Transportation Policy Study Commission, chairman
Jon E. Burkhardt, Ecosometrics, Incorporated, secretary
Robert H. Bruton, Bernard F. Byrne, Ken E. Clary, Ronald E. Gargasz, Lawrence J. Harman, Andrew D. Jones, Robert G. Knighton, H. Thomas McCormick, Brian E. Noble, Ervin Poka, Jr., Arthur Politano, Peter M. Schauer, Lawrence L. Schulman, Bruce S. Siria, Robert L. Smith, Jr., Gregory C. Wilder

Committee on Transportation for the Transportation Disadvantaged
Arthur Saltzman, North Carolina A&T State University, chairman
William W. Millar, Port Authority of Allegheny County, Pennsylvania, secretary
Carol A. Arthur, Arthur J. Balek, William G. Bell, Jon E. Burkhardt, Adelph S. Butkys, Patricia Cass, Dolores A. Cutler, Karl W. Guenther, Douglas B. Gurin, Lester A. Hoel, Edward F. Howard, Donald M. Hubert, Ira Laster, Jr., Robert E. Paaswell, Joseph S. Revis, Martin Wachs

GROUP 3–OPERATION AND MAINTENANCE OF TRANSPORTATION FACILITIES
Adolf D. May, University of California, Berkeley, chairman

Committee on Maintenance Equipment
James E. Bell, Illinois Department of Transportation, chairman
Alfonso F. Alaimo, Rolin F. Barrett, W. Ray Brown, William Gere, Robert A. Hogan, Jack T. Kassell, Truman A. Keeney, James F. Kelley, Samuel F. Lanford, R.O. Lightcap, Harry G. Long, William R. Maslin, Jr., James Edwin Melone, A.I. Morris, Jack L. Percival, Rodney A. Pletan, G.L. Ray, John A. Reidy, Jr., Francis C. Staib, Edward L. Tinney, Raymond F. Vigue

W. Campbell Graeub, Stephen E. Blake, and Adrian G. Clary, Transportation Research Board staff.

Sponsorship is indicated by a footnote at the end of each report. The organizational units and officers and members are as of December 31, 1978.

Contents

Prediction of Effects of Bus-Priority Schemes by Using Computer Simulation Techniques

R. J. Salter, School of Civil Engineering, University of Bradford, West
Yorkshire, England
J. Shahi, Tehran Institute of Technology

This paper describes a computer program that predicts the effect of bus-priority measures applied to an urban highway network. The program predicts the travel times of buses and other vehicles along a highway network that has different types of intersection controls, with or without bus-priority schemes in operation. The paper describes how the program will allow transportation planners to assess the likely effects of proposed priority measures from a comparison of travel times through a complex highway system by use of a model that computes the journey times of buses and other vehicles over a network that is composed of highway links that have priority, roundabout, or signal control at the intersections. The model follows the progress of each bus along a given route as it repeats the cycle from one bus stop to the next for various traffic conditions. Details of the master computer program and the associated subroutines are given together with details of validation studies carried out on the outer ring road of the city of Bradford. To demonstrate the practical use of the program, details are given of the effect of bus-priority schemes on average delay, queue lengths, and bus travel times for the following highway and traffic situations: (a) priority intersections where the nearside lane of the minor road is allocated to buses for different traffic flow conditions and different lengths of priority lanes, (b) signalized intersections that have two or three approach lanes where the nearside lane of one approach road is allocated to buses for different traffic flow conditions and different lengths of priority lane, and (c) a 2-km length of bus route, which includes three signalized intersections and eight bus stops for differing traffic volumes and proportions of buses in the traffic flow. Details of the program output are given to demonstrate that the simulation model is flexible enough to study any particular section of a highway that may incorporate bus priority.

All developed countries have experienced growth of private automobile ownership and an increase in the amount of traveling undertaken by the individual. The result has been an increased role for the private automobile and a decreased role for public transport in fulfilling today's transportation demands. In urban areas more vehicles are using the street system, which has caused an accompanying growth in congestion, noise, fumes, and accidents. The resulting decrease in environmental standards has decreased considerably the attractiveness of towns as places of employment, recreation, and residence.

In an attempt to reverse (or at least halt) this trend, a particular effort has been made to make public transportation more convenient, more comfortable, and more reliable and so provide a level of service that is competitive with the private automobile.

A major attempt to restore the level of service of public transport in many cities has been the assignment of priority on the road system to public transport vehicles. These measures include simple traffic management (such as the introduction of a traffic-signal-priority scheme at a junction or a bus-only lane on a small part of the road network) and an extensive scheme that involves the combination of several bus-priority schemes on differing sections of the highway network.

In general, the objective has been to determine the most beneficial scheme for all users of the highway. It is therefore desirable to be able to evaluate such a priority scheme before it is implemented rather than to use the traditional method of comparing before-and-after traffic-flow characteristics.

THE COMPUTER SIMULATION MODEL

Considerable research has already been performed by a variety of research organizations on the effects of affording priority to buses at intersections controlled by traffic signals. Salter and Memom previously reported (1) research on the effectiveness of a curb-side bus-priority lane on a consideration length of a radial highway that had three traffic-signal-controlled intersections. For bus-priority measures to produce significant benefits on an urban bus route, it is frequently necessary for the priority to extend over a considerable length of the route and, with this in mind, we have developed a computer simulation model that will evaluate the effects of a variety of priority measures for the whole or part of the route. The model considers the effects of priority measures both on buses and on their passengers and also on nonbus traffic. Particular attention is given in the model to the consequence of bus priority at intersections that may be priority, rotary, or signal controlled as these are usually the critical parts of the highway network.

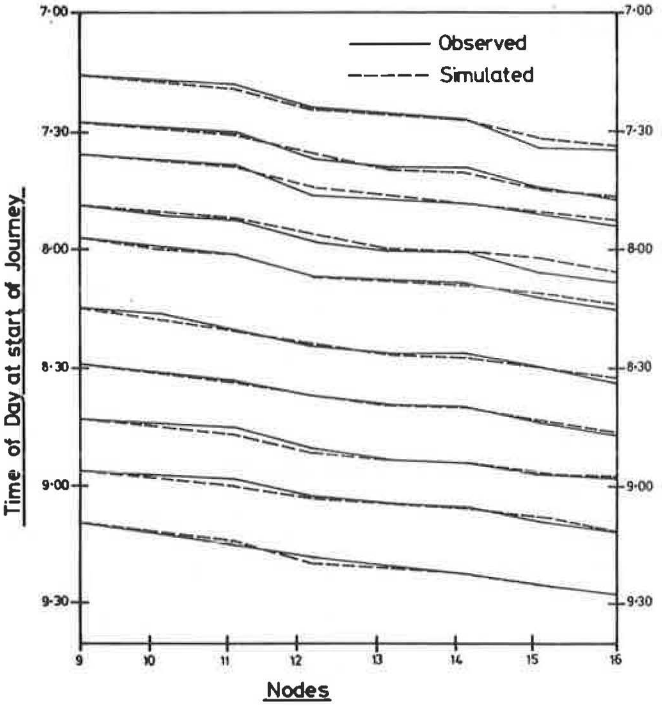
The model follows the progress of each bus in service along a particular route as it moves from stop to stop on the service route. The model incorporates the following distributions:

1. A distribution that represents the distribution over time of passenger arrivals at each bus stop;
2. A distribution of passenger-boarding times and a mechanism that regulates the number of passengers that board in accordance with available space in the bus (if passengers cannot board the first bus then they form the initial queue for the next bus); and
3. A distribution of passenger alighting times (both this distribution and the previous one are varied according to the fare collection system and bus type that are in operation).

As a bus travels along the road network, it accelerates away from a bus stop, travels at the running speed on the highway (provided it does not arrive at a junction), decelerates to the next bus stop, and then remains stationary while passengers alight and board. If passengers are not waiting, then the deceleration and waiting periods are omitted. The running speed for buses between intersections is determined from a speed-flow relation. If, however, a bus has to pass through an intersection, then the progress of the bus ceases to be determined by a speed-flow relation and instead microscopic simulation is employed.

Before the bus reaches the area of influence of the junction, simulation of nonbus vehicles commences and vehicles are generated to predetermined flows and

Figure 1. Observed and simulated time-distance diagram for buses traveling on a section of the Bradford ring road.



turning movements. This ensures that the junction is at the correct level of service as the bus passes through the junction. The program logic prints out delays and queue lengths for buses and other vehicles for each intersection. Vehicles are generated to a predetermined headway distribution at a point distant from the junction, generally the bus stop immediately prior to the junction. Each vehicle is assigned a turning movement, a speed, and an acceleration and deceleration rate. Uniform time scanning is used for this microscopic section of the simulation.

In addition to the more usual consideration of the effect of bus priority at signal-controlled intersections, this program also allows the effect of bus-priority measures at priority and roundabout intersections to be evaluated.

A considerable amount of data have to be input to define the bus route to allow considerable variation in the service routes that can be simulated. This information includes a schedule of bus stops, distance between stops, scheduled departure times, and location of junctions relative to adjacent bus stops. Each bus is given a maximum speed and a speed-flow relation appropriate to the section of the service route on which the bus is traveling together with acceleration and deceleration rates. Parameters that describe the nature of passenger arrival times, boarding and alighting times, and bus capacity are also required.

Details of the highway also have to be input. These include an activity index that describes the traffic char-

Table 1. Observed and simulated bus travel times between bus stops and bus waiting times for bus stops 43-46.

Time (a.m.)	Bus Stop Numbers											
	43-44 (234 m)				44-45 (123 m)				45-46[a,b] (307 m)			
	Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
7:35	42.33	44.66	12.66	9.66	29.00	29.66	33.66	29.66	48.33	55.00	29.66	25.66
7:45	45.00	43.33	8.00	7.00	25.00	26.00	11.33	10.00	49.00	50.66	11.33	10.00
7:55	42.33	46.66	11.66	9.33	24.33	25.33	8.66	6.00	55.66	56.66	10.33	9.00
8:05	41.66	44.00	13.00	7.00	24.00	25.00	12.00	9.33	44.66	63.00	12.66	10.00
8:15	42.33	43.66	9.33	8.66	25.66	25.33	26.33	18.00	49.00	45.33	12.00	22.00
8:25	41.33	45.00	8.00	7.00	26.33	25.33	11.33	7.66	42.00	43.00	13.00	6.66
8:35	40.00	41.33	14.00	8.66	27.00	24.00	17.00	14.66	52.33	41.66	24.00	18.66
8:45	39.66	41.33	11.00	7.00	23.33	24.66	11.00	12.33	37.33	41.33	12.00	21.66
8:55	46.00	39.00	10.33	9.00	24.00	27.66	8.66	8.00	36.66	42.33	10.00	10.00
9:05	43.00	39.66	8.00	7.00	24.00	27.33	10.66	12.00	43.00	40.00	17.00	21.66

[a] Priority junction.

[b] Distance from the bus stop before the junction to the stop line = 258 m; distance from the stop line to the next bus stop = 49 m.

Table 2. Observed and simulated bus travel times between bus stops and bus waiting times for bus stops 46-49.

Time (a.m.)	Bus Stop Numbers											
	46-47[a,b] (297 m)				47-48 (270 m)				48-49 (258 m)			
	Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
7:35	55.00	46.66	16.00	15.00	35.66	35.33	53.66	50.33	39.00	41.00	13.66	12.33
7:45	60.66	70.00	7.66	7.00	39.66	35.33	18.33	15.33	40.66	33.66	13.66	15.00
7:55	66.00	70.00	13.33	13.33	43.11	45.66	30.00	28.66	39.33	40.33	42.00	36.66
8:05	58.00	66.33	8.00	7.00	39.66	41.33	7.66	20.00	40.66	36.33	7.00	7.00
8:15	57.33	55.00	9.66	9.33	34.66	38.00	23.66	18.66	38.66	39.00	15.00	19.00
8:25	56.33	60.33	8.00	7.00	42.33	33.60	7.00	12.33	35.00	34.66	14.33	7.66
8:35	73.33	63.33	11.00	8.66	35.66	36.66	22.66	16.66	39.33	40.00	2.00	13.00
8:45	68.00	67.00	11.00	12.00	39.66	40.33	22.68	24.66	40.00	39.33	29.00	10.00
8:55	62.33	62.66	8.00	7.66	40.33	41.33	18.00	22.33	36.66	38.33	12.33	16.33
9:05	56.66	59.66	11.00	27.00	42.10	40.00	22.33	13.00	36.33	37.66	21.33	33.00

[a] Signalized intersection.

[b] Distance from the bus stop before the junction to the stop line = 240 m; distance from the stop line to the next bus stop = 57 m.

Table 3. Observed and simulated bus travel times between bus stops and bus waiting times for bus stops 49-53.

	Bus Stop Numbers															
	49-50[a,b] (253 m)				50-51 (310 m)				51-52 (345 m)				52-53[a,c] (314 m)			
	Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)		Average Bus Travel Time Between Stops (s)		Average Bus Wait Time at Each Stop (s)	
Time (a.m.)	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
7:35	41.33	49.33	55.66	52.33	45.33	47.66	20.66	17.00	42.00	44.33	12.66	11.00	58.33	41.00	7.66	7.00
7:45	51.00	40.66	19.00	21.00	48.33	49.33	17.66	17.00	42.66	43.33	9.33	10.00	37.33	45.66	20.00	14.33
7:55	47.66	66.33	31.00	28.66	46.33	49.00	10.66	9.00	41.00	47.66	27.33	12.00	38.66	38.33	9.00	7.00
8:05	40.66	38.00	8.66	9.00	47.00	46.66	7.66	7.00	43.66	62.66	30.66	19.66	56.33	42.66	32.00	25.00
8:15	54.00	46.33	13.66	17.00	43.00	43.00	7.33	7.00	47.33	41.33	24.00	18.66	55.33	60.33	12.00	0.00
8:25	72.00	68.00	14.00	8.66	41.66	47.33	11.00	7.66	41.66	41.66	32.66	28.00	61.33	60.00	77.00	34.00
8:35	59.66	59.00	27.66	24.00	45.66	51.00	14.33	19.66	49.66	47.33	32.66	28.66	53.33	57.00	10.33	8.66
8:45	49.66	48.66	29.00	30.66	47.00	49.00	21.66	24.66	46.00	47.33	33.00	32.66	47.66	59.00	10.00	32.66
8:55	47.00	62.33	13.33	9.00	42.66	47.33	10.33	19.33	43.00	44.66	19.00	13.33	65.33	63.00	10.00	9.66
9:05	60.00	54.33	29.00	25.00	45.66	47.00	19.33	33.00	40.66	42.66	33.00	13.00	43.00	65.00	10.00	8.00

[a] Signalized intersection.
[b] Distance from the bus stop before the junction to the stop line = 218 m; distance from the stop line to the next bus stop = 35 m.
[c] Distance from the bus stop before the junction to the stop line = 252 m; distance from the stop line to the next bus stop = 62 m.

Table 4. Observed and simulated bus travel times, bus waiting times, and average bus speeds for a section of the route.

Time at Start of Journey (a.m.)	Total Bus Running Time (min)		Total Bus Waiting Time (min)		Total Bus Travel Time (min)		Average Speed (km/h)	
	Observed	Simulated	Observed	Simulated	Observed	Simulated	Observed	Simulated
7:35	7.272	7.242	4.27	3.83	11.52	11.07	14.25	14.83
7:45	7.32	7.30	2.27	2.11	9.59	9.41	17.12	17.45
7:55	7.41	8.00	3.23	2.66	10.64	10.66	15.43	15.40
8:05	7.27	7.77	2.32	2.02	9.59	9.79	17.12	16.77
8:15	7.46	7.29	2.55	2.31	10.01	9.60	16.40	17.10
8:25	7.67	7.65	3.27	2.11	10.94	9.76	15.00	16.82
8:35	7.93	7.69	2.93	2.69	10.86	10.38	15.12	15.82
8:45	7.31	7.63	3.17	3.47	10.48	11.10	15.66	14.79
8:55	7.40	7.81	2.00	2.08	9.40	9.89	17.46	16.60
9:05	7.23	7.56	3.02	3.21	10.25	10.77	16.01	14.24
Mean	4.73	7.59	2.90	2.65	10.33	10.24	15.96	15.98
SD	0.218	0.25	0.656	0.65	0.69	0.624	1.06	1.12

Figure 2. Simulated average delay to minor road vehicles at a priority junction that incorporates a bus lane.

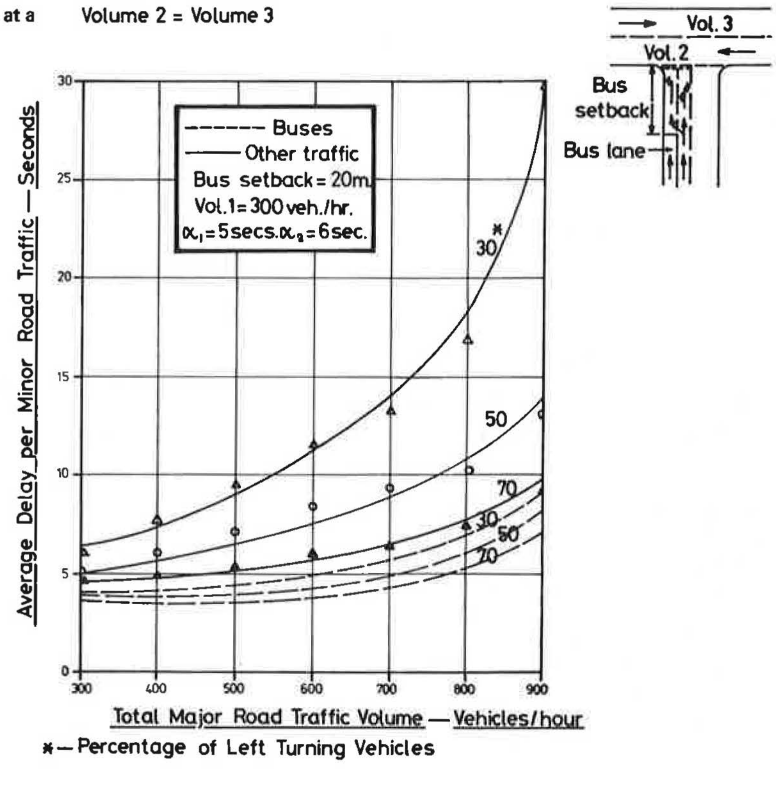


Figure 3. Schematic plan of bus route 1 between bus stop 46-53.

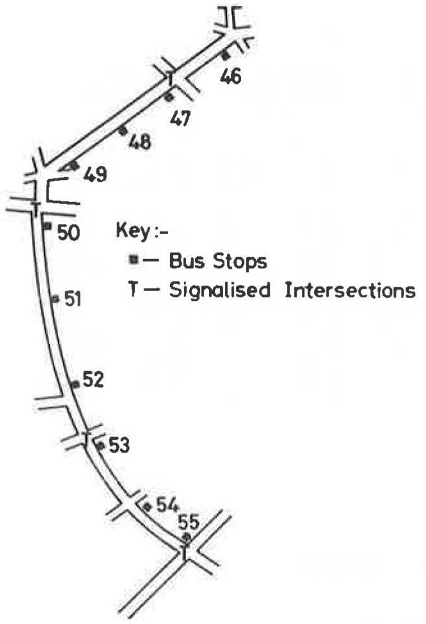
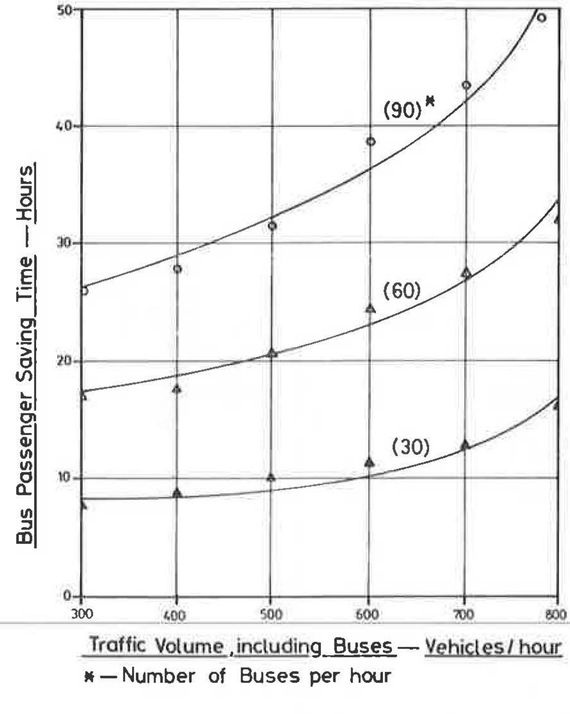
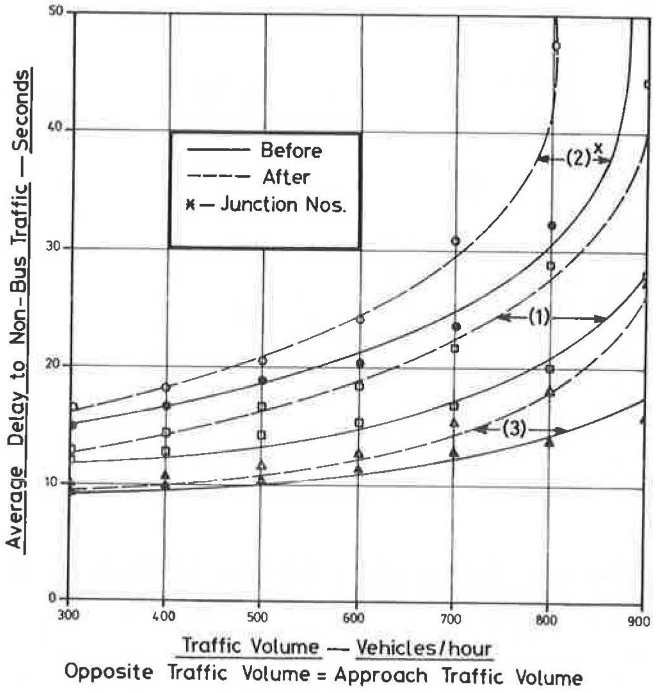


Figure 4. Time saving for passengers during 1 h of bus operation between bus stops 46 and 53, assuming 45 passengers/bus and a bus setback distance at signalized intersections of 40 m.



acteristics of the route and influences the speed-flow relationship and the traffic flows on each of the links together with maximum, mean, and minimum speed on each of the links. For each of the junctions it is necessary to define the proportions of turning vehicles and the type and size of the junction. For priority junctions, including rotary intersections, details of the gap acceptance distribution are required. For signal-controlled junctions the cycle time and the effective green times for each installation are required.

Figure 5. Average delay to nonbus traffic at signalized intersections before and after the introduction of the bus-priority scheme.



After the simulation is complete, the program outputs information relating to the performance of the simulated system. Included in the normal output of the program are

1. Bus travel time between successive bus stops,
2. The number of passengers that board and alight at each stop together with the maximum queue length that occurs at the bus stop during the simulation period,
3. Bus occupancy along each part of the service route,
4. A measure of the variation of the actual bus time schedule from the input schedule, and
5. A listing of delays and queue lengths for buses and other vehicles at intersections.

The program has been used for an investigation of the effects of hypothetical bus-priority measures on the outer ring road of the city of Bradford. This ring road forms the service route for a bus service that has a route length of 17 km. During a complete orbit of the route a bus passes through 10 signalized intersections, four priority junctions, and five roundabouts.

Data were input into the program to represent the layout of the ring road and the bus service along the route. Observations were made to determine bus running times, passenger arrival distributions at bus stops, and alighting and boarding times. The model was then run to test its ability to reproduce actual bus journey times under nonpriority conditions.

A comparison between observed and simulated bus journey times over a section of the ring road during the morning peak hour is shown in Figure 1. Good agreement can be noted between observed and simulated values in this nonpriority case.

A second comparison was made between the observed and simulated bus travel times. In this case a relatively small part of the bus route was taken into account. This part of the highway (2.74 km in length) includes three signalized intersections, one priority junction, and 11 bus stops. The first bus stop (bus stop number 43) is a timed bus stop, which makes it possible to record the exact departure time of buses from this bus stop.

Observations were carried out during morning peak periods (7:30-9:00 a.m.) to consider bus waiting times at each bus stop and bus travel times between each two successive bus stops. Three different observations were carried out for each bus departure time from the first bus stop on different weekdays. Subsequent simulation results were obtained from the model under the same conditions as were observed, and the results were compared with observed data in Tables 1-4.

This comparison shows that the observed and simulated data are quite close to each other and that the model is adequate to represent their vehicle behaviors according to the purpose of the study.

The model is able to predict the effects on all vehicles of bus-priority measures at intersections. In addition to the usual form of bus-priority measures at traffic-signal-controlled intersections, the model also has the ability to predict the effects of bus-priority measures at priority junctions. Figure 2 shows the simulated variation of average delay to buses and other vehicles at a priority junction when the priority bus lane terminated 20 m from the "give way" line. The mean gap accepted was input as 5 s for left-turning vehicles and 6 s for right-turning vehicles. Equal flows were assumed in both directions on the major road and the simulation was carried out with 30, 50, and 70 percent of left-turning vehicles (left-hand rule of the road).

A section of bus route 1 along the ring road was selected for study in order to assess the usefulness of the program in estimating the effect of a bus-only lane on bus and passenger travel times. The part of the route chosen was located between bus stops 46 and 53 (as shown in Figure 3). It had a length of approximately 2 km and included three signalized intersections and eight bus stops. A curb-side bus-priority scheme was introduced along this section of the ring road. The priority lane terminated 40 m from the signal stop lines.

Reductions in bus-passenger journey times between bus stops 46 and 53 due to the introduction of the priority scheme for the three cases of 30, 60, and 90 buses/h in each direction are shown in Figure 4. Frequently when bus-priority schemes are introduced travel time is increased for nonbus vehicles. Figure 5 shows the increase in delay at the three signalized intersections along the priority route after the introduction of the bus-priority scheme.

We believe that the model has demonstrated its ability to simulate the effects of bus-priority schemes on travel time and delay. We intend to continue the work and evaluate future priority schemes.

REFERENCE

1. R. J. Salter and A. A. Memon. Simulation of a Bus-Priority Lane. TRB, Transportation Research Record 626, 1977, pp. 29-32.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Evaluation of Active Bus-Priority Signals

A. J. Richardson and K. W. Ogden, Department of Civil Engineering, Monash University, Clayton, Victoria, Australia

This paper describes the development and application of a methodology for the evaluation of an active bus-priority signal system. Results from a demonstration project show the impact of a bus-priority scheme on intersection delay and delay variability. Two new measures, perceived delay and budgeted delay, are introduced and are shown to have important implications in the evaluation of bus priority and other transportation system management schemes. We conclude that active bus priority is justified under a wider range of conditions than has hitherto been considered to be the case.

In recent years, a number of interrelated factors have combined forces to change the direction and emphasis of transportation planning. The days of seemingly unlimited expansion of the transportation system are gone. In its place are the tasks of maintenance and management of the existing transportation system. Although some may consider that these tasks are not as exciting as the previous growth phase, they are nevertheless equally, or perhaps more, demanding of initiative and intellectual effort.

The factors that have brought about this change are basically fourfold:

1. The increasing awareness of the magnitude of private transportation as a consumer of liquid fossil fuels,
2. The role of transport vehicles as mobile pollution sources,
3. The economic recession that affected most Western countries in the first half of this decade and has caused spiralling inflation rates and increasing unemployment to be the dominant domestic concerns of many governments, and
4. The emergence of citizen participation as a feasible and necessary planning technique.

For these reasons, and possibly others, this reversal in planning directions has taken place. One important consequence has been the emergence of transportation system management (TSM) as a planning philosophy in its own right. As described by Patricelli (1), TSM is "preeminently a process for planning and operating" whose key objective is the conservation "of fiscal resources, of energy, of environmental quality, and of the urban quality of life".

TSM has been defined to include a large number of project types; however, one category of particular interest is the use of traffic management techniques to give priority to high-occupancy vehicles (HOV). The types of priority technique may include the reservation of lanes on freeways or arterial roads, the granting of priority access at freeway on-ramps, or the granting of priority, by one means or another, at signalized intersections. This paper will concentrate on the final category and, in fact, will consider only one particular type of intersection priority. However, many of the issues raised could be applied equally well to other priority techniques.

BUS-PRIORITY SIGNAL SYSTEMS

Two essentially different techniques are available to grant priority to buses at traffic signals. These techniques may be classified as passive or active detection and granting of priority. Passive priority systems are characterized by the fact that the flow of buses need not be recorded at a particular instant in order to grant priority. Rather, the intensity of bus movements (or, more generally, HOV movements) is deduced from long-term measurements of traffic flows. These traffic flows, when expressed in terms of person movements, then form the basis of signal design.

The essence of active priority systems is that the passage of an individual bus is detected and priority is awarded to the bus as a result of this detection. Such detection may be accomplished by means of an ordinary loop detector if the bus is in a special bus right-of-way (such as a bus-only lane or a bus street) or by means of a unique transponder-interrogator communication link if the bus is moving in mixed traffic. Once the passage of a bus has been detected, priority treatment can be given in several different ways.

The two principal methods of active bus priority are phase extension and recall. If a bus arrives at a detector on the approach to a signalized intersection and that approach is currently being shown a green signal, by the time the bus reaches the stop line the signal may have changed to red. In such a situation, it would be desirable to extend the green period by a small amount of time to enable the bus to pass through the intersection in that phase. The effect of this phase extension is to reduce the bus delay from that of the total red time on that approach to no delay. This type of priority treatment also has negligible effects on other road users.

When a bus arrives at an approach detector and that approach is being shown a red signal, a different strategy is employed. In this case the bus phase may be restarted earlier than normal in one of two ways. The hurry-call strategy involves giving minimum time to all other demanded phases in sequence, starting with the phase currently being served. The skip-phase strategy involves giving minimum time to the phase currently being served and then skipping directly to the bus phase. This obviously results in lower delays for the bus than would be the case with the hurry-call strategy (except, of course, when there are only two phases per cycle, in which case the two strategies are equivalent). The minimum time for each phase is taken as equal to the minimum green time of each phase, providing, of course, that pedestrians are also given adequate clearance time.

After the award of a bus-priority phase, control may then be returned in one of three ways:

1. Control may always be returned to a particular phase if, for example, for safety reasons one particular phase must always follow the bus phase;
2. Control may be returned to the phase that was interrupted; or
3. Control may be returned to the first skipped phase.

The choice of strategy after awarding priority will, in most cases, depend on the circumstances that prevail at the particular intersection in question.

Irrespective of which phase control is returned to, it may be desirable, especially in peak periods, to compensate the nonbus phases for time lost while awarding priority to the bus phase. This may be done by adding the time lost by each phase to the maximum green time in the next cycle. However, if another bus arrives in this cycle and is awarded priority, then the nonbus phases will again lose time, which will have to be added on in the next cycle. If this is allowed to continue, then the nonbus phases will simply accumulate a large amount of green time that is never repaid. Hence, effective compensation involves not only the repayment of lost green time but also the refusal of priority demands for buses that arrive in the next cycle following the award of a priority phase. In this way, the original green time balance is preserved over a period of two cycles.

The above description of bus-priority signal systems is necessarily brief and serves only to place in context the priority scheme that is the subject of evaluation in this paper.

BELL STREET DEMONSTRATION PROJECT

In November 1977, the Road Safety and Traffic Authority, in conjunction with the Melbourne Metropolitan Tramways Board (MMTB), installed the first active bus-priority system at traffic signals in Victoria, Australia, at the intersection of Bell Street and Oriel Road in Heidelberg.

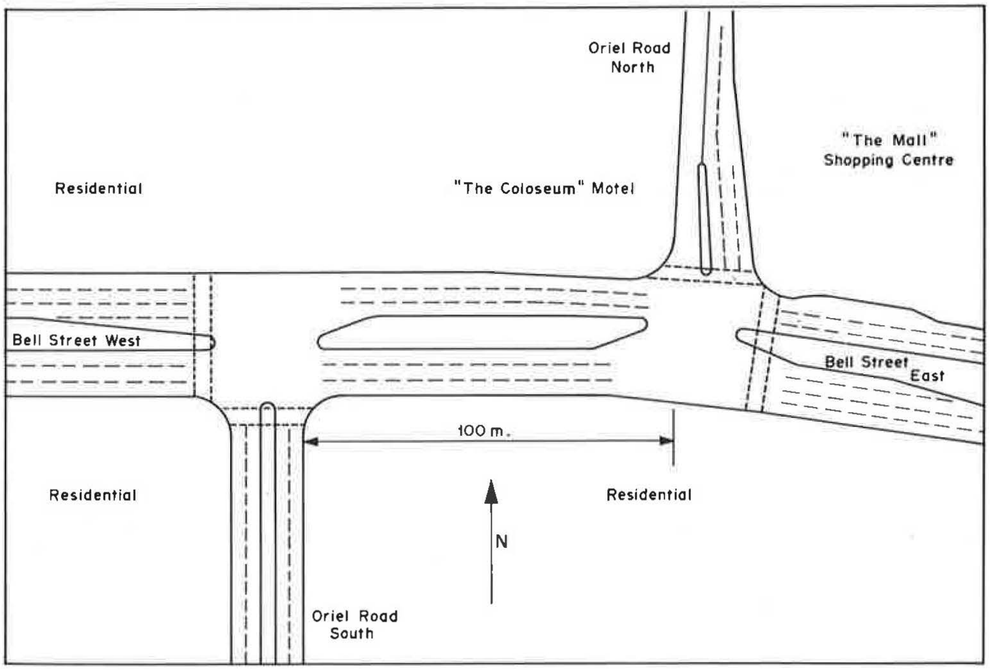
The intersection is located approximately 11 km northeast of the Melbourne central business district (CBD), in a predominantly residential area. Bell Street is an important east-west circumferential route that links residential and industrial areas and is the most important nonradial arterial route in this part of Melbourne. Oriel Road is a comparatively minor north-south subarterial route, so far as general traffic is concerned, but it carries a substantial flow of buses. The intersection is of a staggered twin-tee configuration, as shown in Figure 1. (Note that traffic in Australia drives on the left-hand side of the road.) The intersection was originally controlled by stop signs on Oriel Road, which caused considerable delays to buses on Oriel Road. As a result of these delays, the decision was made to install traffic signals at the intersection and, subsequently, to install bus-priority signals on a demonstration project basis. Monash University was engaged to develop and apply an evaluation methodology to assess the impact of the priority signals (2).

Following operation of the signals in a conventional, nonpriority manner for approximately two months, bus priority VETAG equipment was installed. The VETAG system is composed of

1. A vehicle-borne semipassive transponder,
2. A loop antenna buried in the road surface, and
3. An interrogator, which is connected to the loop.

Low-power interrogation signals are constantly radiated through the loop by the interrogator. As a bus passes over a loop on either approach in Oriel Road, the transponder is activated by the interrogation signals

Figure 1. Bell Street-Oriel Road site details.



and transmits a vehicle identification code to the interrogator via the loop detector. This code is then decoded by the decoder and, if valid, is passed to the intersection controller as a priority demand.

The response of the controller to a priority demand is one of extension or skip-phase recall, as described earlier. Extension of the phase is granted by allowing a set time interval after detection to enable the bus to cross the stop line. Compliance with this minimum set time interval may necessitate exceeding the maximum green time. The time interval is adjustable and is currently set at 10 s, in accordance with the distance from the stop line to the bus detector. Compensation is provided to Bell Street through traffic by means of two-cycle balancing of green time allocation, as described earlier.

EFFECT ON TRAVEL TIME AND TRAVEL TIME VARIABILITY

The impacts of bus-priority schemes on travel time (or delay) and travel time variability have traditionally been the factors considered in most detail. The present study also considered a number of other factors; however, the results for travel time and travel time variability are presented here because these factors continue to be important evaluation factors. Also, the results offer some point of comparison with previous studies. The method of using these factors is radically different in this study and deserves consideration in itself, free from the extraneous influence of other factors.

The objectives of this evaluation are twofold: (a) to ensure that buses do, in fact, obtain a significant advantage after installation of the signals and (b) to ensure that the net benefit after installation of the priority signals is, in view of the limited scope for mode switching, nonnegative.

Bus Delay Changes

Data for the calculation of bus delays were obtained by means of a travel time survey in which the time at which a bus passed a point upstream and downstream of the intersection was recorded (among other things). After allowing for synchronization errors, a comparison of these two times revealed the travel time for that particular bus to pass through the intersection. Subtraction of a free travel time gave an estimate of the delay incurred by that bus. The mean and standard deviation of delay were then calculated for each survey period. The number of buses in each period and the average passenger occupancy were also calculated from recorded information.

Table 1 shows the results obtained from surveys conducted on two days in December 1977: one when the priority signals on Oriel Road were switched on and one when the conventional signals were switched on. The passenger flow is given in terms of the number of buses multiplied by the average bus occupancy during that period. The results are given for two bus groups; the MMTB buses, which were fitted with transponders, and buses from the Ivanhoe Bus Company, which also ran along Oriel Road but were not fitted with transponders and hence acted as a control group.

Several features of the table deserve comment. First, note that the average bus occupancy levels are very low. At most, they correspond to a 25 percent load factor. This is consistent, however, with the position of the intersection, close to the outer extremities of the bus routes that pass through the intersection. These low bus-loading figures make it difficult, on the basis of net benefit, to justify bus-priority measures at such an intersection. Second, the introduction of the priority signals appears to have the desired effect of reducing both mean delay and standard deviation of delay for transponder-equipped buses. On the other hand, the effect on nonpriority buses appears rather variable.

More complete statistical testing of the changes in means and variances confirms this initial impression. Four out of the 12 priority bus flows experienced significant reductions in variance of delay at the 5 percent level, but none of the nonpriority bus flows experienced such reductions. Similarly, 4 out of 12

Table 1. Bus flow summary.

			Without Priority			With Priority				
Time Period	Bus Flow	Direction	Passenger Flow	Average Delay (s)	Standard Deviation (s)	Passenger Flow	Average Delay (s)	Standard Deviation (s)	Variance Reduction (%)	Mean Reduction (%)
7:15-8:15 a.m.	MMTB	Northbound	13 × 6.5	52.38	27.37	12 × 5.8	30.42	10.98	5[a]	5[a]
		Southbound	19 × 9.3	68.74	36.48	18 × 10.6	31.89	28.56	5	5[a]
	Ivanhoe	Northbound	4 × 8.1	37.25	37.70	4 × 7.5	50.50	29.72	5	50
		Southbound	5 × 7.8	91.60	9.69	5 × 12.3	38.40	35.60	5	5[a]
8:15-9:15 a.m.	MMTB	Northbound	12 × 8.1	41.25	22.97	11 × 7.3	31.45	17.55	5	50[a]
		Southbound	10 × 14.5	56.30	24.16	8 × 16.5	39.88	25.32	5	20[a]
	Ivanhoe	Northbound	4 × 7.8	37.75	15.63	4 × 4.7	30.25	27.68	5	50
		Southbound	3 × 9.0	45.33	13.61	1 × 3.0	22.00	-	-	50[a]
11:00 a.m.-12:00 n.	MMTB	Northbound	9 × 11.2	46.67	33.94	8 × 10.4	35.38	19.14	5	50[a]
		Southbound	8 × 10.0	44.13	29.24	8 × 9.4	22.00	9.80	5[a]	10[a]
	Ivanhoe	Northbound	3 × 4.3	58.67	40.87	3 × 6.7	40.00	16.52	5	50
		Southbound	3 × 5.5	36.67	27.93	3 × 3.5	28.33	32.81	5	50
1:30-2:30 p.m.	MMTB	Northbound	8 × 9.1	62.13	17.88	8 × 9.6	31.75	15.23	5	5[a]
		Southbound	8 × 7.6	35.50	18.80	8 × 7.9	24.50	13.47	5	20[a]
	Ivanhoe	Northbound	3 × 5.3	49.67	29.40	4 × 1.7	58.25	26.83	5	50
		Southbound	3 × 2.7	43.67	22.03	3 × 1.8	35.33	31.88	5	50
3.15-4.45 p.m.	MMTB	Northbound	11 × 11.6	79.55	26.49	10 × 9.1	50.20	22.77	5	5[a]
		Southbound	10 × 7.9	39.30	34.27	10 × 11.5	24.00	9.68	5[a]	20[a]
	Ivanhoe	Northbound	5 × 4.9	103.60	43.41	4 × 5.1	47.20	24.48	5	10[a]
		Southbound	4 × 9.7	10.50	12.45	5 × 2.9	38.50	34.46	5	50
4:45-5:45 p.m.	MMTB	Northbound	15 × 11.2	111.47	117.86	19 × 12.4	64.32	40.47	5[a]	20[a]
		Southbound	9 × 10.0	25.33	26.60	11 × 8.9	26.36	18.91	5	50
	Ivanhoe	Northbound	4 × 5.9	82.00	44.23	4 × 5.7	59.00	40.92	5	50
		Southbound	4 × 6.9	26.75	27.63	4 × 5.0	21.50	17.82	5	50

[a] Significant.

priority bus flows experienced significant reductions in mean delay at the 5 percent level and another 5 priority bus flows were found to have significant reductions in mean delay at the 20 percent significance level. None of the nonpriority bus flows experienced reductions in mean delay at the 5 percent level and only two experienced significant reductions at the 20 percent level.

In view of these results, it seems reasonable to conclude that priority bus flows experienced significant reductions in both mean delay and variance of delay, but nonpriority bus flows experienced no such reductions. Hence, the priority system is capable of giving differential priority to vehicles on an approach to the intersection.

Nonpriority Vehicle Delay Changes

The granting of priority within the context of a positive net benefit is a little more complex to analyze. To do this, information is needed on the delay suffered by nonpriority vehicles at the intersection. These data were obtained by conducting surveys on the same two days as the bus survey, by use of a survey technique described by Richardson (3). The survey method is based on the measurement of queue length on each approach at various times within a signal cycle. The results of these surveys are shown in Table 2 for one of the survey periods. Similar tables exist for the other five survey periods (2) but, for brevity, are not included here. An explanation of the terms used in Table 2 is given below.

Vehicle flow—vehicular flow as measured in survey (vehicles/h).
Passenger flow—passenger flow using average automobile occupancy of 1:30 as measured at site for automobiles, and using observed average bus occupancies for buses.
Total vehicle stops—total number of effective vehicle stops.
Average number of stops—total vehicle stops divided by vehicular flow.
Average delay—average delay per vehicle (or person) on each approach (s).
SD delay—standard deviation of delay for vehicles on each approach (s).
Average + SD—sum of average delay and standard deviation of delay, which is defined in this paper as budgeted delay (s).
Δ Average number of stops—change in the average number of stops per vehicle between the without priority case and the with priority case.
Δ Average delay—change in the average delay per person.
Δ (Average + SD)—change in the budgeted delay per person.
(Δ Average)^2—square of the change in the average delay per person, which accounts for the perceived value of this change.
[Δ (Average + SD)]^2—square of the change in budgeted delay per person, which reflects the change in perceived, budgeted delay.
Δ Total stops—total change in the number of effective stops obtained by multiplying the change in the average number of stops per vehicle by the vehicular flow.
Flow × ΔA—total change in delay obtained by multiplying the change in delay per person by the passenger flow (s).
Flow × Δ(A + S)—total change in budgeted delay obtained by multiplying the change in the budgeted delay per person by the passenger flow (s).
Flow × $(\Delta A)^2$—total change in perceived delay (s^2).
Flow × $[\Delta(A + S)]^2$—total change in perceived, budgeted delay (s^2).

Results are presented individually for the seven distinct vehicle movements (as shown in Figure 2) and for the four bus movements along Oriel Road.

Flows that are in direct conflict with the priority bus movement (i.e., movements 1, 2, 4, and 5) may be ex-

Table 2. Summary of survey results for survey period 1.

	Vehicle Group Movement—7:15-8:15 a.m.							Bus Group Movement—7:15-8:15 a.m.				
Measure	1	2	3	4	5	6	7	MMTB Bus North-bound	MMTB Bus South-bound	Ivanhoe Bus North-bound	Ivanhoe Bus South-bound	Σ
Without priority												
Vehicle flow	794	54	583	1 980	13	149	216	13	19	4	5	
Passenger flow	1 032	70	758	2 574	17	194	281	84	177	33	39	
Total vehicle stops	424	52	544	1 040	13	124	156	12	23	4	9	
Average number of stops	0.53	0.96	0.93	0.53	1.00	0.83	0.72	0.92	1.21	1.00	1.60	
Average delay	20.77	64.91	47.43	22.50	50.69	42.54	32.39	52.38	68.74	37.25	91.60	
SD delay	25.35	52.79	40.21	28.13	34.66	36.52	32.37	27.37	36.48	37.70	9.69	
Average + SD	46.12	117.70	87.64	50.63	85.35	79.06	64.66	79.75	105.22	74.95	101.29	
With priority												
Vehicle flow	848	55	540	1 915	29	156	205	12	18	4	5	
Passenger flow	1 102	72	702	2 490	38	203	267	70	191	30	62	
Total vehicle stops	549	41	424	1 444	24	126	148	12	16	5	4	
Average number of stops	0.65	0.75	0.79	0.75	0.83	0.81	0.72	1.00	0.89	1.25	0.80	
Average delay	22.95	50.60	40.82	31.37	74.21	42.47	30.96	30.42	31.89	50.50	38.40	
SD delay	26.67	56.74	38.77	33.72	74.67	40.99	31.73	10.98	28.56	29.72	35.60	
Average + SD	49.62	107.34	79.59	65.09	148.88	83.46	62.69	41.40	60.45	80.22	74.00	
Comparison												
Vehicle flow	821	55	562	1 948	21	153	211	13	19	4	5	
Passenger flow	1 067	71	730	2 432	28	199	274	77	184	32	51	
ΔAverage number of stops	+0.12	-0.21	-0.14	+0.22	-0.17	-0.02	0	+0.08	-0.32	+0.25	-0.80	
ΔAverage delay	+2.18	-14.31	-6.61	+8.87	+23.62	-0.07	-1.33	-21.96	-36.85	+13.25	-53.20	
Δ(Average + SD)	+3.50	-10.36	-8.05	+14.46	+63. 53	+4.4	-1.97	-38.85	-44.77	+5.27	-27.29	
$(\Delta\text{Average})^2$	+4.8	-204.8	-43.7	+78.7	+557.9	0	-1.8	-482.2	-1 357.9	+175.6	-2 830.2	
$[\Delta(\text{Average} + \text{SD})]^2$	+12.3	-107.3	-64.8	+209.1	+4 036.0	+19.4	-3.9	-1 509.3	-2 044.4	+27.8	-744.7	
ΔTotal stops	+99	-12	-79	+429	-4	-3	0	+1	-6	+1	-4	+422
Flow × ΔA	+2 326	-1 016	-4 825	+21 572	+661	-14	-364	-1 690	-6 780	+424	-2 713	+7 581
Flow × Δ(A+S)	+3 735	-736	-5 877	+35 167	+1 779	+876	-540	-2 991	-8 238	+168	-1 392	+21 951
Flow × $(\Delta A)^2$	+5 122	-14 541	-31 901	+191 398	+15 621	0	-493	-37 114	-249 688	+5600	-144 330	-260 326
Flow × $[\Delta(A+S)]^2$	+13 124	-7 618	-47 304	+508 531	+113 008	+3860	-1086	-116 193	-368 736	+890	-37 980	-60 496

Figure 2. Intersection movement numbers.

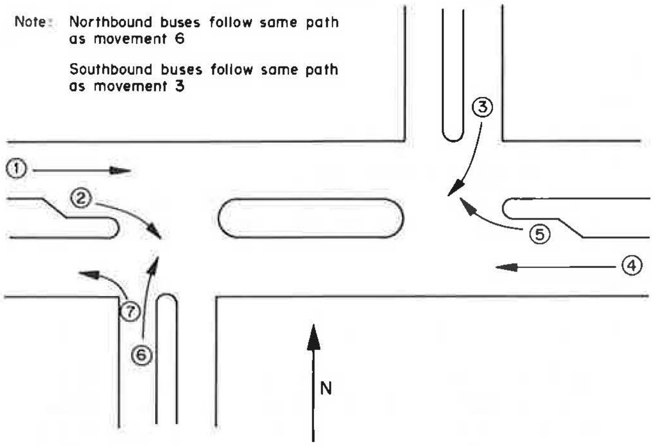


Table 3. Effect of priority system on delay suffered by various traffic movements.

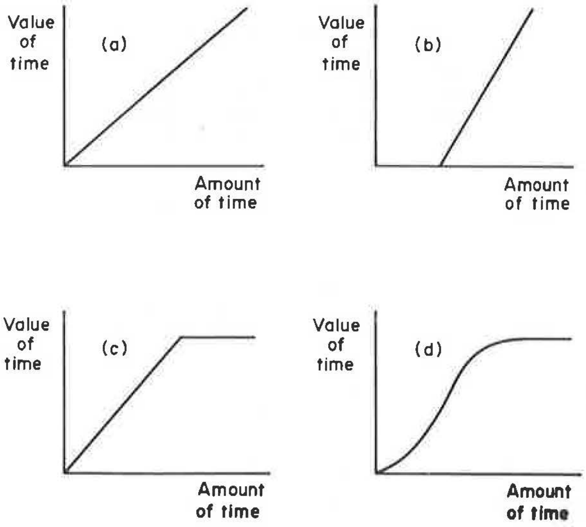
Movement	Increase Delay	Reduce Delay		Total
		Number	Percent	
Priority buses	1	11	91	12
Nonpriority buses	3	9	75	12
Complementary movements (3 and 6)	5	7	63	12
Movement 7	5	1	17	6
Conflicting movements (1, 2, 4, and 5)	18	6	25	24
Total	32	34	52	66

pected to suffer additional delay. Flows that run in the same phase as the priority bus movements might be expected to obtain a reduction in delay; however, this reduction in delay would be offset by the fact that, although some of the vehicles in these flows would obtain secondary priority, others would suffer the effects of the compensation cycles and hence suffer additional delay. Thus, while it might be expected that, overall, these movements would receive some priority, they would not receive the same degree of priority as the priority buses. This should apply both to the vehicular flows (movements 3 and 6) and the nonpriority bus flows. The remaining vehicular flow (movement 7) should lie somewhere between these extremes, since it shares a phase with a conflicting movement (movements 2 and 5) and hence will be adversely affected, but also shares the phase with the priority buses and hence might expect some benefit.

If the results of Table 2 (and the results for the other five time periods) are examined, the above speculation is largely borne out. Consider the effect of the priority scheme on the delay suffered by the 66 recorded movements at the intersection (11 traffic movements × 6 time periods). As shown in Table 3, the probability of obtaining a reduction in delay decreases as the degree of conflict with the priority bus movement increases. Hence, the measured effect of the bus-priority system appears to be logical, insofar as the direction of the change in delay is concerned.

Consider next the effect of the priority system on the magnitude of these changes in delay. Although the priority system has quite substantial effects on the delay suffered by priority buses (most changes in the range -10 to -40 s), the effect on the nonpriority vehicular flows was much less marked (generally in the range +1 to +10 s). In fact, statistical testing was unable to reveal any significant changes in delay for

Figure 3. Value of time and amount of time relationships.



nonpriority vehicles because of the effects of the relatively large variances in delay and the relatively small changes in mean delay. At this stage, it is tempting to conclude that a Pareto improvement has been achieved, since significant reductions in delay were obtained for buses without causing significant increases in delay for nonpriority vehicles. However, because of the very consistent pattern of changes revealed in Table 3, it seems unlikely that the observed changes in delay, although small, were due entirely to chance.

Hence, in determining the net benefit of the priority scheme (in terms of total delay changes), all changes in delay have been considered irrespective of whether or not they have been shown to be significant by statistical tests. The traditional method of obtaining net benefit is to multiply the average change in delay for each movement by the passenger flow in that movement and then to sum these passenger delay terms across all movements. The results, using this technique, for this study are given below.

Time Period	Total Change in Delay (s)
7:15-8:15 a.m.	+7 581
8:15-9:15 a.m.	−10 919
11:00 a.m.-12:00 n.	−1 458
1:30-2:30 p.m.	+8 743
3:45-4:45 p.m.	−3 739
4:45-5:45 p.m.	+36 529

It appears from this table that the effects are rather variable. In three of the periods delay has been reduced, but in the other three delay has been increased. Even when allowance is made for the extreme variability in results obtainable with field surveys, the priority scheme appears to have, if anything, slightly increased the total delay at the intersection over the course of a full day. This is because the relatively large decreases in delay that accrued to bus passengers have been more than offset by the small increases in delay suffered by the much larger number of automobile travelers.

Perceived Delay

The above argument has been based on the implicit assumption that small changes in delay should be weighted at the same value as large changes in delay. That is, the value of time (delay) savings is independent of the amount of time saved. There is, however, a growing body of literature in the travel demand field that questions this assumption [Thomas and Thompson (4), Hensher (5), and Gray and Bowen (6)]. Instead of assuming a constant value of time, they suggest that the value of time savings is itself a function of the amount of time saved. Thus the value of saving one unit of time is not half the value of saving two units of time. Similarly, the value of x people saving y units of time is not the same as one person saving x·y units of time.

This realization has important consequences for the evaluation of TSM schemes, especially bus-priority schemes. In these schemes large time savings to a small number of priority mode users are usually traded off against small time increases to a large number of nonpriority mode users. If large time changes are weighted more heavily (on the grounds that they are more easily perceived and usable), then the evaluation results will be more favorably inclined toward the consideration of large delay reductions or increases.

Various functional forms have been suggested for the relationship between value of time and the amount of time saved, some of which are shown in Figure 3. They include (a) a linear relationship, (b) a displaced linear relationship in which a minimum threshold amount of time saved (or lost) must be exceeded before time has any value, (c) a linear relationship with a maximum value of time, and (d) an ogive or sigmoid relationship (e.g., a probit curve) with a maximum value.

For illustration of the effects of assuming a variable value of time, and for simplicity of calculation, the linear relationship that has a maximum value of time that occurs for all time savings greater than 5 min will be adopted. Since all amounts of time saved or lost in this study are less than 5 min, this relationship reduces to a simple linear relationship. Thus,

$$v = v_m \times t/t_m \qquad (1)$$

where

v = value of time,
v_m = maximum value of time,
t = amount of time saved (or lost), and
t_m = minimum time for which v_m is assumed.

Hence,

$$TV(t) = (v_m \times t/t_m) \times t = (v_m/t_m)\, t^2 \qquad (2)$$

where $TV(t)$ = total value of amount of time t. Thus, by using a linear relationship between value of time saved and amount of time saved, which gives greater weight to larger amounts of time saved or lost, the overall effect of the priority system can be estimated. This is done by considering the squared values of the amount of time saved or lost. These values are shown in Table 2 and are summarized for all periods below.

Time Period	Total Change in Delay (s^2)
7:15-8:15 a.m.	−260 326
8:15-9:15 a.m.	−98 479
11:00 a.m.-12:00 n.	−28 622
1:30-2:30 p.m.	−15 383
3:45-4:45 p.m.	−171 518
4:45-5:45 p.m.	+234 201

This table demonstrates that when larger changes in delay are given more weight, it is relatively easier

Table 4. Effect of priority system on variability in delay suffered by various traffic movements.

Movement	Increase Variability	Reduce Variability		Total
		Number	Percent	
Priority buses	1	11	91	12
Nonpriority buses	5	6	55	11*
Complementary movements (3 and 6)	8	4	33	12
Movement 7	4	2	33	6
Conflicting movements (1, 2, 4, and 5)	19	5	21	24
Total	37	28	43	65

*One nonpriority bus movement contained only one bus and therefore had no variability in delay.

to justify the bus-priority scheme. When unweighted delay changes are used in the evaluation, the results are generally inconclusive. However, when delay changes are weighted by the magnitude of the change, then the bus-priority scheme can be justified on the basis of the net perceived change in delay.

Delay Variability and Budgeted Delay

Recent research in behavioral travel demand theory [e.g., Stopher and Meyburg (7)] has indicated that many factors affect travel demand besides the traditional variables of time and cost of a trip. Such additional variables include comfort, convenience, and reliability. One of the prime determinants of reliability is the ability to arrive at one's destination on time. This can be related easily to the distribution of travel time for a trip.

Consider a journey to work where the employee is permitted to arrive at work late once per pay period. Further late arrivals will result in deductions being made from his or her pay. If the employee aims to meet this standard, once every two weeks he or she can be late (i.e., 1 day in 10 or 10 percent of the time). Thus he or she must schedule the trip such that the 90th percentile of travel time distribution will be equal to the time between leaving home and starting work. Hence, he or she must budget for this 90th percentile time rather than for the 50th percentile time (the median ≃ mean). If the employee were to allow simply for the mean time, he or she would be late approximately 50 percent of the time.

Hence in the comparison of alternative modes, a function of mean travel time and variability of travel time should be considered. Similarly, in the evaluation of the level of service provided by a mode, this budgeted time should be considered rather than the mean time since it is this budgeted time that is effectively spent in using the mode. By considering the budgeted time, it is possible to obtain an improvement in the level of service without decreasing the average travel time (or delay). Thus a bus-priority scheme that does not result in a significant reduction in mean delay for buses may still be worthwhile if a considerable reduction in delay variability is achieved. In fact, it is possible to have better service even when mean delay increases, provided that the reduction in variability of delay is of sufficient magnitude. Thus the consideration of budgeted rather than mean delay presents more opportunities for the justification of bus-priority schemes.

The exact definition of budgeted time is, however, difficult to specify. In this study, it is defined as being equal to the sum of the mean and the standard deviation of travel time (or delay). It corresponds to an upper percentile point of the delay distribution. For a normal distribution, it would represent the 84th percentile point. For other distributions, the exact percentile point would depend on the skewness and kurtosis of the distribution. Although other definitions of budgeted time are possible, this simple sum is used in this study for purposes of illustration and ease of calculation.

The effect of the priority scheme on variability in bus delay has already been discussed. Consider now the effect on nonpriority vehicular traffic. Table 4 shows the effect of the priority scheme on the variability in delay for the 66 recorded intersection traffic movements. As in Table 3, the probability of receiving favorable treatment from the priority scheme is inversely proportional to the degree of conflict with the priority bus movement. Again, however, statistical testing of the changes in variance revealed no significant changes for nonpriority traffic. Once again, however, all changes in variability are included in the calculation of net benefit.

As before, both weighted and unweighted delay changes are calculated, except in this case budgeted delay is used instead of mean delay. The results are given below for the six time periods.

Time Period	Budgeted Time Change (s)	Perceived Budgeted Time Change (s)
7:15-8:15 a.m.	+21 951	-60 496
8:15-9:15 a.m.	-13 958	-76 468
11:00 a.m.-12:00 n.	-7 679	-205 669
1:30-2:30 p.m.	+14 180	+42 487
3:45-4:45 p.m.	-4 892	-233 204
4:45-5:45 p.m.	+43 231	-1 183 688

This use of budgeted delay appears to have had little effect on the overall results. Hence, as before, the unweighted budgeted delay results show an even split of positive and negative net benefits; however, the weighted delay results again show a five-to-one balance in favor of the bus-priority system. Overall, the inclusion of variability changes does not have as great an effect on the outcome of this evaluation as does the use of a variable, or perceived, value of time.

CONCLUSION

The evaluation of TSM schemes is, and will continue to be, an important topic of discussion in transportation planning. The current emphasis on improving the efficiency of the existing transportation system demands that TSM schemes be implemented if they can be shown to be economically, socially, and environmentally efficient. In the consideration of one type of TSM project, bus-priority schemes, this paper has suggested that a number of refinements can be made to improve the evaluation process. Specifically, two new variables are introduced: perceived delay and budgeted delay. Perceived delay accounts for the psychological finding that the relationship between stimulus and response is rarely linear. In terms of travel time delay, this is equivalent to the statement that the value of time savings is a function of the amount of time saved. Hence, large changes in delay are weighted more heavily than small changes in delay. In the evaluation of bus-priority schemes, where the basic trade-off is between large time savings to a small number of priority mode users and small time increases to a much larger number of nonpriority mode users, this realization is of considerable significance. Application of this principle to a case-study evaluation shows, as expected, that the results of the evaluation can be influenced considerably by the adoption of perceived delay as the appropriate measurement of performance.

The second major development is the concept of budgeted delay. This variable accounts for the amount of time a traveler budgets for a trip. It is a function of the mean travel time for a trip and the variability of travel time for a trip and corresponds to an upper percentile point on the travel time distribution. Reductions in budgeted time are a more accurate measure of the benefit of a bus-priority scheme than reductions in mean time. Use of budgeted time in a case-study evaluation produced no significant difference to the results, although this is not likely to be a general finding.

Finally, and most importantly, many bus-priority schemes that have been evaluated on the basis of net reductions in mean travel time may have been incorrectly labeled as infeasible. Reevaluation of these schemes on the basis of perceived, budgeted time changes would probably result in many of them being relabeled as feasible TSM schemes that can contribute to the more efficient operation of the existing transportation infrastructure.

ACKNOWLEDGMENT

The work described in this paper was performed as part of a research contract for the Road Safety and Traffic Authority and the Melbourne Metropolitan Tramways Board to develop and apply an evaluation methodology for bus-priority signalized intersections in Melbourne, Australia. Their assistance in the conduct of the study and the collection of data is most appreciated. The advice and assistance of W. Young of the Department of Civil Engineering at Monash University is also greatly appreciated.

REFERENCES

1. R. E. Patricelli. Definitions, Objectives and Implications of TSM. In Transportation System Management, TRB, Special Rept. 172, 1977, pp. 14-17.
2. A. J. Richardson and K. W. Ogden. Selective Vehicle Detection and Priority Treatment in Mixed Traffic Flow: Demonstration Project Evaluation Survey Results. Road Safety and Traffic Authority and Melbourne Metropolitan Tramways Board, Melbourne, 1978.
3. A. J. Richardson. Measurement of the Performance of Signalized Intersections. TRB, Transportation Research Record 699, 1979, pp. 49-58.
4. T. C. Thomas and G. I. Thompson. The Value of Time for Commuting Motorists as a Function of Their Income Level and Amount of Time Saved. HRB, Highway Research Record 314, 1970, pp. 1-14.
5. D. A. Hensher. Value of Commuter Travel Time Savings. Journal of Transport Economics and Policy, Vol. 10, No. 2, 1976.
6. D. M. Gray and W. S. Bowen. Towards an Integration of Macro Transport Modelling and Micro-Economics. Proc., 2nd Australian Transport Research Forum, Adelaide, 1976.
7. P. R. Stopher and A. H. Meyburg. Behavioral Travel-Demand Models. Lexington Books, D.C. Heath and Company, Lexington, MA, 1976.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Impact of Short-Term Service Changes on Urban Bus Transit Performance

Anil S. Bhandari, University of Dar es Salaam, Dar es Salaam, Tanzania
Kumares C. Sinha, Center for Public Policy and Public Administration,
Purdue University, West Lafayette, Indiana

This paper examines the impact on a fixed route of small changes in three operational policy variables: frequency, number of bus stops, and fare. Analytical expressions are developed that trace the impact of each variable on various other system variables, which leads to an assessment of changes in selected measures of efficiency and effectiveness. The application of the methodology is demonstrated by a case study of a selected bus route in a medium-sized Indiana city. Three specific options are evaluated in terms of alternative frequency, number of stops, and fare policies. Since none of the options was actually implemented, the paper reports only on a theoretical analysis of the changes that might be expected under each option. The results indicate that significant improvements are possible in most of the efficiency and effectiveness measures under all three options examined. The technique does not require an extensive amount of data or calibration effort; instead it relies on information generally available from the records of a transit company and reasonable assumptions where necessary.

Much effort is currently being directed toward gaining a better understanding of urban transit performance. Under public ownership, transit systems are being subsidized heavily by federal, state, and local funds. These subsidies are necessary if transit companies are to continue to provide service to the public even when they cannot recover their operating costs from the farebox. Under these circumstances, if service improvements are evaluated solely on the basis of cost recovery, few projects, if any, would be implemented. Previous studies of short-term changes in service have concentrated on ridership, costs, and revenue impacts; little emphasis was given to their impact on accepted measures of performance.

This paper presents a methodology for relating short-term service changes to changes in selected measures of performance. Particular reference is made to bus transportation in medium-sized urban areas. Specifically, an examination is made of the effect of changes in three major operational policy variables along a fixed bus route. These variables are (a) frequency of service, (b) spacing between stops, and (c) basic fare.

The emphasis is on the development of a systematic approach that traces the impact of each policy variable on various other system variables, which will lead to an assessment of the appropriate performance measures. The most important aspect is to establish reasonable impact relationships between the policy and the impact variables as well as relationships among the impact variables themselves.

A number of factors were considered of prime importance and common to the development of the specific relationships and the overall methodology. First, transit management and transportation planners should find the procedure simple and quick to apply to provide a reasonable assessment of the impacts. Second, the relationships developed should maintain a sound theoretical base, but they should not be unduly complex or require a great deal of modeling and calibration effort. Third, the procedure should not be too restrictive in the sense of being applicable only to unique situations. In other words, the methodology should be general and adapt readily to different environments. Last, use of the procedure should not be very costly in terms of data requirements. Most of the data required should be available from the usual records kept by the transit operators.

Figure 1. Linkages and ridership.

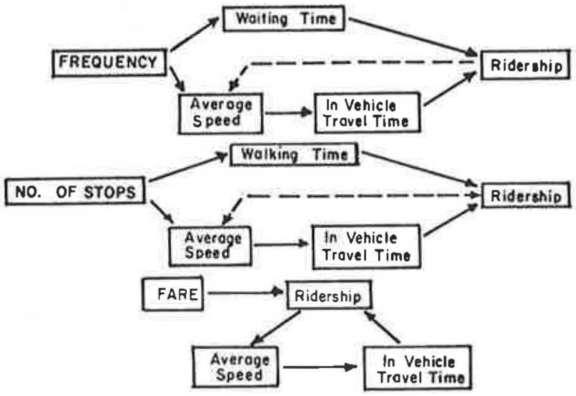


Figure 2. Linkages and system costs and revenues.

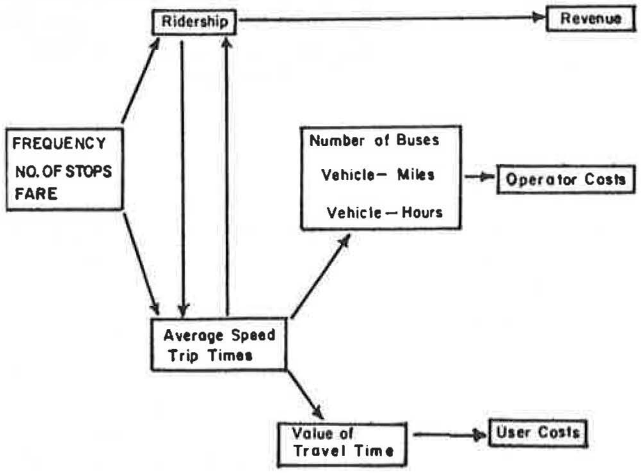
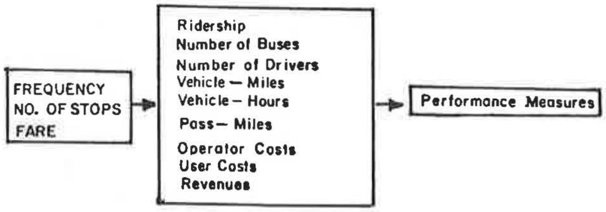


Figure 3. Linkages and performance measures.



IDENTIFICATION OF IMPACTS

On any given bus route, the entire spectrum of variables that can be affected directly or indirectly by changes in the operational policy variables may be grouped as follows:

1. Service variables—Average operating speed, vehicle travel time, walking time, and waiting time;
2. Output variables—Ridership, passenger miles, vehicle miles, vehicle hours, and revenue;
3. Resource variables—Number of buses, number of drivers, operator costs, and user costs; and
4. Performance measures—Cost efficiency (operator and total cost per vehicle hour, operator and total cost per vehicle mile, operator and total cost per passenger, and operator and total cost per passenger mile), revenue efficiency (revenue per dollar of operating cost and revenue per vehicle mile), driver utilization efficiency (vehicle miles per driver pay hour and passengers per driver pay hour), vehicle utilization efficiency (annual vehicle miles per vehicle and annual passengers per vehicle), user cost effectiveness (user cost per passenger and user cost per dollar of operating cost), ridership effectiveness (passengers per vehicle mile, passengers per vehicle hour, passengers per dollar of operating cost, and passenger miles per seat mile), and other measures (e.g., deficit per passenger).

The operator costs are the direct cost of bus operation computed as a function of the total vehicle hours and vehicle miles operated. Hourly costs include driver wages, fringe benefits, and advertising. Distance costs include depreciation, maintenance, parts, fuel, oil, tires, insurance, tickets and timetables, and right-of-way costs. The user costs consist of the value travelers place on their walking, waiting, and vehicle travel times.

The measures of performance selected here are those that are influenced most by changes in the policy variables and are felt to cover adequately major areas of interest. A more complete treatment of performance measures can be obtained by reference to other studies (1-4).

ASSESSMENT OF IMPACTS

The various linkages among the relevant variables are shown schematically in Figures 1, 2, and 3. The most important outcome is the change in ridership due to changes in the operational policy variables. This change occurs as a result of the inherent elastic nature of demand in response to changes in the level of service characteristics.

Figure 1 shows, for example, that an increase in frequency will decrease waiting time, increase the average speed, and decrease vehicle travel time, which will result in an increase in ridership. An increase in the number of stops decreases walking time but also decreases the operating speed, which will cause an increase in the vehicle travel time. The effect on ridership then depends on the relative elasticities and magnitudes of the change of waiting time and vehicle travel time.

In the case of a fare change, an increase in fare, for example, will decrease ridership as a direct result of the negative elasticity of demand with respect to fare. However, this decrease in ridership might improve the average operating speed and cause a decrease in the vehicle travel time, thereby inducing an increase in ridership. The net change in ridership may still be negative, depending, however, on the relative magnitudes of these opposing changes. This reverse effect of the change in ridership on the average bus speed is also present in the case of changes in frequency and number of stops, as shown by the dotted lines in Figure 1.

Figure 2 shows the linkages of the total system costs and revenues. Total costs are the sum of operator costs and user costs. The change in operator costs is related directly to the change in vehicle hours and vehicle miles of bus operation; however, change in user costs is a function of the change in the travel time components.

Eventually, interest lies in the effect these changes have on the performance of the system. This is measured through changes in the appropriate performance indicators obtained via changes in variables such as ridership, costs, revenues, vehicle miles, and vehicle hours, as shown in Figure 3.

Analytical expressions to represent the various linkages were developed as follows.

Average Operating Speed

The variables that are characteristic along a given bus route are defined below (SI units are not given for the variables of this model because its operation requires that they be in U.S. customary units.):

L = round trip route length in miles;
Y = number of stops per mile;
Q = average hourly demand (i.e., the number of passengers served along the entire route per hour);
M = average trip length per passenger in miles;
X = frequency of service in buses per hour;
S^* = running speed of bus in miles per hour;
S = average operating speed over the entire route in miles per hour;
ϵ = time spent per passenger in boarding or alighting from a bus, converted to hours; and
δ = time spent in a stopping and starting maneuver, converted to hours.

In addition, the following assumptions are made:

1. Origins and destinations are uniformly distributed along the route,
2. The probability distribution of the number of passengers that board a bus at a given stop follows a Poisson distribution, and
3. Passengers are equally likely to get off at any stop, and they make their decisions to do so independently of one another.

Mohring (5) showed that under these assumptions the total round-trip time may be obtained as

$$L/S = (L/S^*) + (2Q\epsilon/X) + \delta YL\,(1-e^{-2Q/XYL}) \qquad (1)$$

where

L/S = the round-trip time,
L/S^* = the running time (i.e., the time spent when the bus is in motion),
$2Q\epsilon/X$ = the time spent in loading and unloading passengers,
δYL = the time spent in starting and stopping maneuvers, and
$(1-e^{-2Q/XYL})$ = the probability that a given stop is made.

Dividing Equation 1 by L,

$$1/S = (1/S^*) + (2Q\epsilon/XL) + \delta Y\,(1-e^{-2Q/XYL}) \qquad (2)$$

which gives the desired expression for the average operating speed as a function of demand, frequency, number of stops, and the running speed of the bus.

In-Vehicle Travel Time (IVTT)

This is simply the average trip length divided by the average speed.

$$\text{IVTT} = 60M/S, \text{ in minutes} \qquad (3)$$

Walking Time (WKT)

In the absence of specific knowledge about the distribution of actual walking distances, we assume that the maximum walking distance will be one-half of the distance between stops; therefore, 1/4Y miles can be taken as the average walking distance. Since walking occurs at both ends of the trip, the total walking distance per trip is 1/2Y.

If w is the walking speed in miles per hour,

$$\text{WKT} = 30/wY, \text{ in minutes} \qquad (4)$$

Waiting Time (WTT)

For average waiting delays, the following relationships were used:

$$\text{WTT} = 30/X, \text{ for } X \geqslant 2, \text{ in minutes} \qquad (5a)$$

$$\text{WTT} = 8 + 14/X, \text{ for } X < 2, \text{ in minutes} \qquad (5b)$$

The assumption is that the average waiting time will be equal to one-half the headway for headways less than 30 min and vary linearly between 15 and 22 min for headways between 30 and 60 min. Headways greater than 1 h are not expected.

Ridership

If we assume that the demand function is of the product form with constant elasticities, the new ridership level (Q_1) after a small change (Δ) in the service variables can be obtained from

$$Q_1 = Q_0\{1 + \alpha[\Delta(\text{IVTT})/\text{IVTT}_0] + \beta[\Delta(\text{WKT} + \text{WTT})/(\text{WKT}_0 + \text{WTT}_0)] + \gamma[\Delta(\text{FARE})/(\text{FARE}_0)]\} \qquad (6)$$

where α, β, and γ are the demand elasticities with respect to vehicle travel time, excess travel time, and fare, respectively. Subscript zero refers to the level before the change in service variables.

Any change in the operational policy variables (namely, X, Y, and FARE) is analyzed by sequential solution of Equations 2-6. For greater accuracy, however, the change in X, Y, or FARE is divided into N smaller increments (positive or negative) and the equations are solved N times.

The remaining impact variables are obtained as follows: Let there be n distinct periods during which any of the variables such as ridership, fare, and frequency may be different, and let i denote the i^{th} such period where i = 1, 2, . . . n. The hourly impact variables in the

i^{th} period are then obtained as below:

Revenue

$$(\text{revenue per hour})_i = (\text{ridership per hour})_i \times (\text{FARE})_i \quad (7a)$$

or

$$REV/h_i = Q_i \cdot FARE_i \quad (7b)$$

Vehicle Miles

$$(\text{vehicle miles per hour})_i = (\text{frequency})_i \times (\text{round trip length}) \quad (8a)$$

or

$$VMPH_i = X_i \cdot L \quad (8b)$$

Vehicle Hours

$$(\text{vehicle hours per hour})_i = (\text{frequency})_i \times (\text{round trip time})_i + \text{layover} \quad (9a)$$

or

$$Vh/h_i = X_i \cdot (L/S_i)(1 + LOF) \quad (9b)$$

where, LOF = the layover time factor as a fraction of round trip time.

Passenger Miles

$$(\text{passenger miles per hour}) = (\text{ridership per hour})_i \times (\text{average trip length})_i \quad (10a)$$

or

$$PM/h_i = Q_i \cdot M_i \quad (10b)$$

To obtain the values on an annual basis, the hourly values are multiplied by the number of annual hours of the respective period and summed over all the n periods.

Number of Buses

The number of buses required during any period i is computed as follows:

$$(\text{number of buses})_i = (\text{frequency})_i \times (\text{round trip time})_i \quad (11a)$$

or

$$NBUS_i = X_i \cdot (L/S_i), \text{ rounded up to nearest whole number} \quad (11b)$$

Number of Drivers

The number of drivers required on any one day is largely a function of run cutting, labor rules, and the peak to off-peak service ratios. However, a reasonable estimate may be obtained by making certain simplifying assumptions. Assume, for example, a certain average ratio of the number of pay hours to platform hours relevant to a particular situation. Let this ratio be denoted as R. Assume also that a driver is paid for an average of N hours per day. Then, an estimate of the number of drivers required on any day can be obtained from

$$\text{Number of drivers} = (\text{vehicle hours per day} \times R)/N \quad (12a)$$

or

$$NDRVR = (Vh/D \cdot R)/N \quad (12b)$$

where Vh/D = total number of vehicle hours per day.

Operation Costs

The operating cost in the period i is obtained from

$$(\text{operating cost per hour})_i = a\,(\text{vehicle hours per hour})_i + b\,(\text{vehicle miles per hour})_i \quad (13a)$$

or

$$OC/h_i = a\ Vh/h_i + b\ VMPH_i \quad (13b)$$

where a and b are the unit costs of bus operation per vehicle hour and vehicle mile, respectively, for a bus of a particular size.

User Costs

This cost is taken as a function of the dollar value that users place on their travel time, obtained from

$$(UC/P)_i = V(IVTT)_i + \eta V(WKT + WTT)_i \quad (14)$$

where

$(UC/P)_i$ = the user cost per passenger in the period i,
V = dollar value of vehicle travel time, and
ηV = dollar value of excess time (η ranges generally from two to three).

Hence, the user cost per hour (UC/h) in the period i is obtained as

$$(UC/h)_i = (UC/P)_i \cdot Q \quad (15)$$

APPLICATION OF THE METHODOLOGY

The application of the methodology to a case study is illustrated here by an examination of a typical route selected from a transit system in a midwestern city that has a population of 600 000. First, a comparison is made of the results obtained by using the relationships developed above with those obtained from records of the transit operator. Then, an analysis is presented of specific policy alternatives in terms of their impact on performance.

Route Data and System Information

Most of the information required for the study was available from the transit corporation. The specific information is given below:

Route selected—English Avenue, route number 10;
Round trip length (L)—19.1 miles;
Number of stops (Y)—9.11/mile;
Number of periods (N)—4 (weekday peak and off-peak, Saturday peak and off-peak); and
Hours of service (weekdays and Saturdays)—peak, 7:00-9:00 a.m. and 3:30-6:00 p.m.; off-peak, 6:00-7:00 a.m., 9:00 a.m. -3:30 p.m., and 6:00-7:00 p.m.;
Running speed (S^*)—27.5 mph;
Average trip length (M)—0.56 mile;
Fare—$0.50, all periods;
Average loading and unloading time (ϵ) (computed from small-scale, on-board survey)—4.66 s/passenger;
Average stopping and starting time (δ) (computed from small-scale, on-board survey)—19.29 s/stop;
Assumed walking speed = 3 mph;
Assumed value of vehicle travel time (V)—$2.00/h;

Table 1. Summary of annual statistics for the base case generated by the model.

Variable	Weekday Peak	Weekday Off-Peak	Saturday Peak	Saturday Off-Peak	Peak Plus Off-Peak Weekday	Peak Plus Off-Peak Saturday	Annual Total
Headway (min)	20	45	45	45			
Number of buses	4	2	2	2	4	2	4
Layover factor	0.247	0.291	0.424	0.553			
Number of drivers per day					5	4	
Annual ridership	88 484	100 724	4 837	9 618	189 208	14 455	203 663
Annual passenger miles	49 551	56 405	2 709	5 386	105 956	8 095	114 051
Annual vehicle miles	65 752	55 198	6 704	11 256	120 950	17 960	138 910
Annual vehicle hours	4 590	4 335	468	884	8 925	1 352	10 277
Annual revenues ($)	44 242	50 362	2 418	4 809	94 604	7 227	101 831
Annual operator costs ($)	85 430	76 787	8 711	15 659	162 217	24 370	186 587
Annual user costs ($)	71 011	138 462	6 209	13 111	209 473	19 320	228 793
Annual total costs ($)	156 441	215 249	14 919	28 769	371 690	43 688	415 378
Annual deficit ($)	41 188	26 425	6 293	10 850	67 613	17 143	84 756

Note: Figures may not add exactly due to rounding errors.

Assumed value of waiting and walking time (ηV)—$4.00/h;
Bus size—47 seats;
Unit cost of bus operation—a = $10.5243/vehicle-h; b = $0.5646/vehicle mile;
Average ratio of pay hours to platform hours (R)—1.20;
Average pay hours per driver—9.25/day; and
Assumed demand elasticities—given below (6-8).

Variable	Weekday Peak	Saturday and Weekday Off-Peak
Vehicle travel time	-0.35	-0.45
Excess time (waiting and walking)	-0.70	-0.90
Fare	-0.20	-0.40

The layover factor (LOF) is computed from $1 + LOF = NBUS/(X \cdot L/S)$.

Headways, ridership, and hours of operation are as follows:

Measure	Time	Weekday	Saturday
Headways (60/x) (min)	Peak	20	40
	Off-Peak	45	45
Ridership (Q) (passengers/h)	Peak	77.11	20.67
	Off-peak	46.47	21.76
Annual hours of operation (based on 255 weekdays and 52 Saturdays/year)	Peak	1147.5	234
	Off-peak	2167.5	442

Comparison of Route Performance with System Average

First the model was used to obtain the annual output and resource variables in each of the four periods considered. The results are summarized in Table 1. The only route-specific data obtainable from the system records for comparison with those shown in Table 1 were annual weekday and Saturday vehicle miles and vehicle hours of operation. These values were found to differ by less than 10 percent, as given below.

Period	Annual Vehicle Miles	Annual Vehicle Hours
Weekday		
Actual	125 460	9873
Model	120 950	8925
Difference (%)	-3.6	-9.6
Saturday		
Actual	18 460	1381
Model	17 960	1352
Difference (%)	-2.8	-2.1

We were able to obtain data on most systemwide performance measures. A comparison of these with the route-specific values (obtained by using the model) is given in Table 2. The annual performance values obtained with the model are in close agreement with the system averages. The difference is less than 15 percent for all except the passengers per vehicle mile measure, which is about 33 percent below the system average. Comparison of weekday ridership counts on routes that have comparable service levels showed route 10 to have a much lower patronage per mile, which probably accounts for the lower route-specific passengers per vehicle mile value.

An important result to note in Table 1 is the relatively high layover factor in each period. Since this factor reflects the idle time between successive runs as a fraction of the total round trip, it seems that, if buses adhere strictly to headways as scheduled, they spend a large fraction of the time laying over between runs—25-30 percent on weekdays and 42-55 percent on Saturdays. Depending on individual labor contracts and scheduling constraints, layover times should not be greater than 5-10 percent of the round-trip time for greater performance efficiency.

Analysis of Specific Options

In order to demonstrate the possible use of the methodology by transit operators, a set of specific service improvement options was evaluated. These alternatives were formulated as shown below, along with the existing base case.

Alternative	Headways (min) Weekday Peak	Headways (min) Weekday Off-Peak	Headways (min) Saturday Peak	Headways (min) Saturday Off-Peak	Number of Stops	Fare (cents)
Base case	20	45	40	45	9.11	50
Option 1	17	36	30	30	9.11	50
Option 2	24	36	30	30	9.11	50
Option 3	24	36	30	30	12.00	50, peak; 40, off-peak and Saturday

Option 1 represents an improvement in the headways for all periods; the number of stops and fare are unchanged. Option 2 is the same as option 1, but headway is increased to 24 min in the weekday peak period. Option 3 is the same as Option 2, but the number of stops is increased to 12.0/mile and fare is reduced to 40 cents during the weekday off-peak period and all day Saturday.

The results obtained for each option are summarized in Table 3. Option 1 results in a considerable increase in annual ridership and vehicle miles operated, as well as corresponding increases in revenues and operating costs. Although the operating deficit increases by $6328, the deficit per passenger decreases from $0.416 to $0.398. Except for small increases in the operating cost and total cost per vehicle hour, the remaining cost-efficiency indicators are generally improved and the driver and vehicle utilizations are increased significantly. The option is also effective in reducing the user cost per passenger and user cost per dollar of operating cost.

The service cutback in the weekday peak period in option 2 causes ridership to decline relative to option 1, but it is still higher than the base-case ridership. The

Table 2. Comparison of route performance with system average.

Performance Indicator	Route Specific Data			System Average[a]
	Weekday	Saturday	Annual	
Efficiency				
Operating cost per vehicle hour ($)	18.18	18.03	18.16	20.51
Operating cost per vehicle mile ($)	1.34	1.36	1.34	1.60
Operating cost per passenger ($)	0.36	1.69	0.92	0.90
Operating cost per passenger mile ($)	1.53	3.01	1.64	1.62
Total cost per vehicle hour ($)	41.65	32.31	40.42	NA
Total cost per vehicle mile ($)	3.07	2.43	2.99	NA
Total cost per passenger ($)	1.96	3.02	2.04	NA
Total cost per passenger mile ($)	3.51	5.40	3.64	NA
Revenue per dollar operating cost ($)	0.58	0.30	0.55	0.55
Revenue per vehicle mile ($)	0.78	0.40	0.73	0.88
Vehicle miles per driver pay hour	10.26	9.34	10.13	NA
Passengers per driver pay hour	16.04	7.51	14.85	NA
Annual vehicle miles per vehicle	30 238	8980	34 728	36 771
Annual passengers per vehicle	47 302	7228	50 916	50 288
Effectiveness				
User cost per passenger ($)	1.11	1.34	1.12	NA
User cost per dollar operating cost ($)	1.29	0.79	1.23	NA
Passengers per vehicle mile	1.56	0.81	1.47	2.19
Passengers per vehicle hour	21.20	10.69	19.82	23.17
Passengers per dollar operating cost	1.17	0.59	1.09	1.11
Passenger miles per seat mile	0.019	0.010	0.017	0.021
Other				
Deficit per passenger ($)	0.36	1.19	0.42	0.41

[a] Numbers were obtained from a published report of the transit system.

Table 3. Comparison of alternatives.

Impact Variables	Base Case	Option 1	Option 2	Option 3
Output				
Annual ridership	203 663	228 568	208 147	221 025
Annual passenger miles	114 051	127 998	116 562	123 774
Annual vehicle miles	138 910	172 176	149 612	149 612
Annual vehicle hours	10 277	10 277	9 129	9 129
Annual revenues ($)	101 831	114 284	104 073	96 308
Resource				
Number of buses—weekday	4	4	3	3
Number of buses—Saturday	2	2	2	2
Number of drivers—weekday	5	5	4	4
Number of drivers—Saturday	4	4	4	4
Annual operator costs ($)	186 587	205 368	180 552	180 552
Annual user costs ($)	228 793	227 608	231 668	243 535
Annual total costs ($)	415 378	432 977	412 221	424 088
Efficiency				
Operating cost per vehicle hour ($)	18.156	19.983	19.778	19.778
Operating cost per vehicle mile ($)	1.343	1.193	1.207	1.207
Operating cost per passenger ($)	0.916	0.898	0.867	0.817
Operating cost per passenger mile ($)	1.636	1.604	1.549	1.459
Total cost per vehicle hour ($)	40.418	42.131	45.155	46.455
Total cost per vehicle mile ($)	2.990	2.515	2.755	2.835
Total cost per passenger ($)	2.040	1.894	1.980	1.919
Total cost per passenger mile ($)	3.642	3.383	3.536	3.426
Revenue per dollar operating cost ($)	0.546	0.556	0.576	0.533
Revenue per vehicle mile ($)	0.733	0.664	0.696	0.644
Vehicle miles per driver pay hour	10.126	12.551	13.171	13.171
Passengers per driver pay hour	14.847	16.632	18.324	19.458
Annual vehicle miles per vehicle	34 728	43 044	49 871	49 871
Annual passengers per vehicle	50 916	57 142	69 382	73 675
Effectiveness				
User cost per passenger ($)	1.123	0.996	1.113	1.102
User cost per dollar operating cost ($)	1.226	1.108	1.283	1.349
Passengers per vehicle mile	1.466	1.328	1.391	1.786
Passengers per vehicle hour	19.817	22.241	22.801	24.211
Passengers per dollar operating cost	1.092	1.113	1.153	1.224
Passenger miles per seat mile	0.017	0.016	0.017	0.018
Other				
Annual deficit ($)	84 756	91 084	76 479	84 244
Deficit per passenger ($)	0.416	0.398	0.367	0.381

most significant impact is a reduction of one in the number of buses and drivers required during weekdays. As a result annual operating costs are less, and the deficit is reduced to $76 479 compared to the base-case value of $84 756. There is also further improvement in the driver and vehicle utilization indicators and in the operating cost efficiencies, except for the cost per vehicle mile.

The main effect of simultaneous reductions in fare and spacing between stops in option 3 is to increase ridership relative to option 2. Operating costs remain the same due to no change in the number of buses; however, revenues decrease due to the reduction in fare. As a result, total deficit increases relative to option 2, but remains less than the base-case value. Option 3 is the most effective in terms of passengers per vehicle mile, passengers per vehicle hour, passengers per dollar of operating cost, and passenger miles per seat mile. Values of 19.458 passengers/driver-h and 73 675 passengers/vehicle are also the highest under this option.

In general, all three options offer significant improvements in most of the performance indicators. If a choice were to be made, it would have to be done with due regard to the relative importance of each performance measure and the magnitude of the trade-offs available.

CONCLUSION

A relatively simple and quick technique for analysis and assessment of the impacts of major operational policy variables has been presented in this paper. The technique involves identification of the impacts and use of simple mathematical relationships to measure them; particular emphasis is on performance. The applicability of the technique has been successfully demonstrated by a theoretical analysis of options for transit service improvement in a specific route of a case-study area.

The technique does not require an extensive amount of data collection effort; most of the information required is generally available from the records of a transit company. However, before it is applied, all of the assumptions made in the procedure must be considered and modified to suit a specific situation.

ACKNOWLEDGMENT

The paper was based on research work conducted under a research and training grant from the Urban Mass Transportation Administration. We are solely responsible for the results and opinions expressed in the paper.

REFERENCES

1. A. R. Tomazinis. Productivity, Efficiency and Quality in Urban Transportation Systems. D.C. Heath and Co., Lexington, MA, 1975.
2. G. J. Fielding and others. Applying Performance Indicators in Transit Management. Proc., 1st National Conference on Transit Performance, Urban Mass Transportation Administration, Norfolk, VA, Sept. 1977.
3. Public Technology, Inc. Transit System Productivity. Urban Mass Transportation Administration, March 1977.
4. D. Gerleman. Transit Performance, Productivity, and Efficiency. Urban Mass Transportation Administration, Draft Rept., 1977.
5. H. Mohring. Optimization and Scale Economies in Urban Bus Transportation. American Economic Review, Vol. 62, No. 4, Sept. 1972, pp. 591-604.
6. R. H. Pratt, N. J. Pedersen, and J. J. Mather. Traveller Responses to Transportation System Changes: A Handbook for Transportation Planners. Federal Highway Administration, Feb. 1977. NTIS: PB 265 830/0G1.
7. C. Yupo. Review and Compilation of Demand Forecasting Experiences: An Aggregation of Estimation Procedures. Pennsylvania Transportation Institute, Pennsylvania State University, University Park, June 1977.
8. Charles River Associates. An Evaluation of Free Transit Service. Aug. 1968. NTIS: PB 178 845.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Evaluation of Bus and Carpool Operations on the San Bernardino Freeway Express Busway

Lawrence Jesse Glazer and John Crain, Crain and Associates, Menlo Park, California

The San Bernardino Freeway Express Busway, which runs eastward from downtown Los Angeles, is the most complete busway in the nation. It includes park-and-ride and on-line stations, feeder bus lines, outlying park-and-pool lots, and a supplemental contraflow bus lane in the central business district. Beginning in October 1976, carpools of three or more were permitted on this previously bus-only facility. During the mixed-mode operations, the number of carpools on the busway and freeway more than doubled, increasing by at least 800. These carpools were new and not caused by diversion from parallel roadways. Bus ridership was not noticeably affected until after a major fare increase. During the peak 1 h, the busway lane carries twice the number of people as does one adjacent freeway lane, but traffic still moves at 88 km/h (55 mph). Surveys were conducted among bus riders, busway carpoolers, and freeway users (busway nonusers). Most carpoolers said they would not be carpooling if they could not use the busway. Attitudes of most busway nonusers were positive; the busway is not controversial. There were no major safety or enforcement problems. The type of separation between busway and freeway was found to strongly affect safety and enforcement require-

ments. The busway was generally found to be more cost effective than an additional freeway lane. The average savings in out-of-pocket costs, for busway-induced carpoolers and bus riders only, covered two-thirds of the annual (capital and operating) costs of the busway. Most of these conclusions would probably change, however, if congestion on the adjacent freeway was reduced or eliminated (for example, because of ramp metering or freeway widening).

The San Bernardino Freeway Express Busway is a 17.6-km (11-mile) exclusive roadway for high-occupancy vehicles (HOVs), which runs eastward from the Los Angeles central business district (CBD) (see Figure 1). The two unidirectional busway lanes are built in the median strip or alongside the freeway and are separated from the automobile traffic lanes by either concrete barriers or a buffer lane that has flexible posts. This $57-million facility is the most complete busway in the country, with its on-line stations, park-and-ride facilities, feeder bus lines, outlying park-and-pool lots, and a supplemental contraflow bus lane in the CBD.

From October 1976 through June 1978, carpools of three or more were permitted on this previously bus-only facility from 6:00 to 10:00 a.m. and 3:00 to 7:00 p.m. This mixed-mode phase was done in two stages; carpools were permitted on only the eastern portion of the busway during stage 1 and on the whole length of the busway during stage 2.

This paper summarizes an evaluation of the mixed-mode phase (1). A brief summary of previous (bus-only phase) findings is also included for background.

SUMMARY OF PREVIOUS FINDINGS

During bus-only operations bus ridership grew steadily during the first 29 months of operation, from 1000 to 14 500 daily passenger trips (2). The number of riders then stabilized until October 1976, when mixed-mode operations were added (see Figure 2). During bus-only operations, 50 percent of the bus riders formerly drove alone and 25 percent came from a carpool (3). Only 11 percent of those riders were transit captives; the remaining 89 percent had an automobile available to them (3). New riders added during that time had substantially higher incomes than prebusway riders (3). The transit market share in this corridor has stabilized near 25 percent (of those trips whose origin and destination are both served by a busway bus) (2). This mode share is comparable to that of other forms of rapid transit. The principal reasons cited for choosing to ride a busway bus were time and cost savings and freedom from traffic congestion (2).

CORRIDOR IMPACTS

In the half decade that the busway has been in operation, travel demand in the corridor has increased substantially. This has been caused by population growth in the eastern end of the corridor and also by latent demand becoming manifest as new capacity was added. Thus, although busway usage has increased dramatically, the freeway lanes are used at or near capacity for about 3 h out of each 4-h morning and evening period.

During mixed-mode operations, the number of carpools on the busway part of the freeway has more than doubled, causing an increase of at least 800 carpools. These carpools were newly formed and not created by diversion from parallel roadways. During this period vehicle and person volumes on other major east-west roadways in the corridor have increased slightly, speeds have decreased slightly, and accident rates have increased slightly. The main cause of these changes appears to be population growth, but since the busway does not extend the full length of the corridor, growth has just increased the preexisting congestion at both of its ends.

FACILITY USAGE

Carpool volumes showed a slow, steady growth (similar to the prior growth in bus patronage) from about 600 to over 1400 automobiles in each 4-h morning and evening period (see Figure 3). At the observed occupancy of 3.3 persons/carpool, this translates to about 4600 carpoolers daily. Reverse-direction carpool volumes on the busway are negligible because the adjacent freeway is normally uncongested. Carpool growth is still continuing.

Bus ridership was not noticeably affected by the introduction of carpools. After the major fare increase in July 1977, perhaps 1000 bus riders switched from buses to carpools and single-occupant automobiles. However, by the end of the evaluation period bus ridership appeared to have regained its previous levels. During each 4-h morning and evening period the busway carries about 1600 vehicles, which contain about 10 000 persons. Half of these people are in carpools and the other half are in buses.

Total person volume over each 4-h period now slightly exceeds the average volume on one adjacent freeway lane. Demand on the freeway lanes is at capacity for most of the 4-h period, but the busway shows a sharp 1-h peak, which may be an expression of desired commute times versus the capacity-constrained commute times on the freeway. During this 1-h peak, the busway carries about twice the person volume of one freeway lane. Even at this volume, the busway is operating at only two-thirds of the estimated 88-km/h (55-mph) capacity of 1200 vehicles/h.

OPERATIONAL PERFORMANCE

Bus running times have not been noticeably affected by the introduction of carpools and remain about 14 min for the 17.6-km (11-mile) length (including two station stops). Carpool travel time on the busway is 12 min at all times. Automobile travel times on the adjacent freeway lanes have actually grown worse during mixed-mode operations because of congestion caused by merges at the ends of the busway, increased demand, and construction on parallel surface streets.

Thus, busway carpoolers can save up to 18 min in the morning peak and up to 8 min in the evening peak periods. This time savings can be even greater during incidents on the freeway lanes. The reliability of busway travel times gives further, unquantified savings to busway commuters because they do not have to depart earlier to be sure of an on-time arrival at work. An additional time savings may result from the flexibility to travel at any desired time.

MODE SHIFTS

More than half of the busway carpoolers surveyed said that they would not carpool if the busway had not been opened to carpools. This means that 2600 people now carpool as a direct result of mixed-mode busway operations. More than one-third of the busway carpoolers formerly drove alone, one-fourth came from buses, and a smaller percentage came from another carpool. Two-thirds of all carpool partners are coworkers. The turnover rate among carpoolers is estimated to be about 25 percent/year.

Figure 1. San Bernardino Freeway Express Busway.

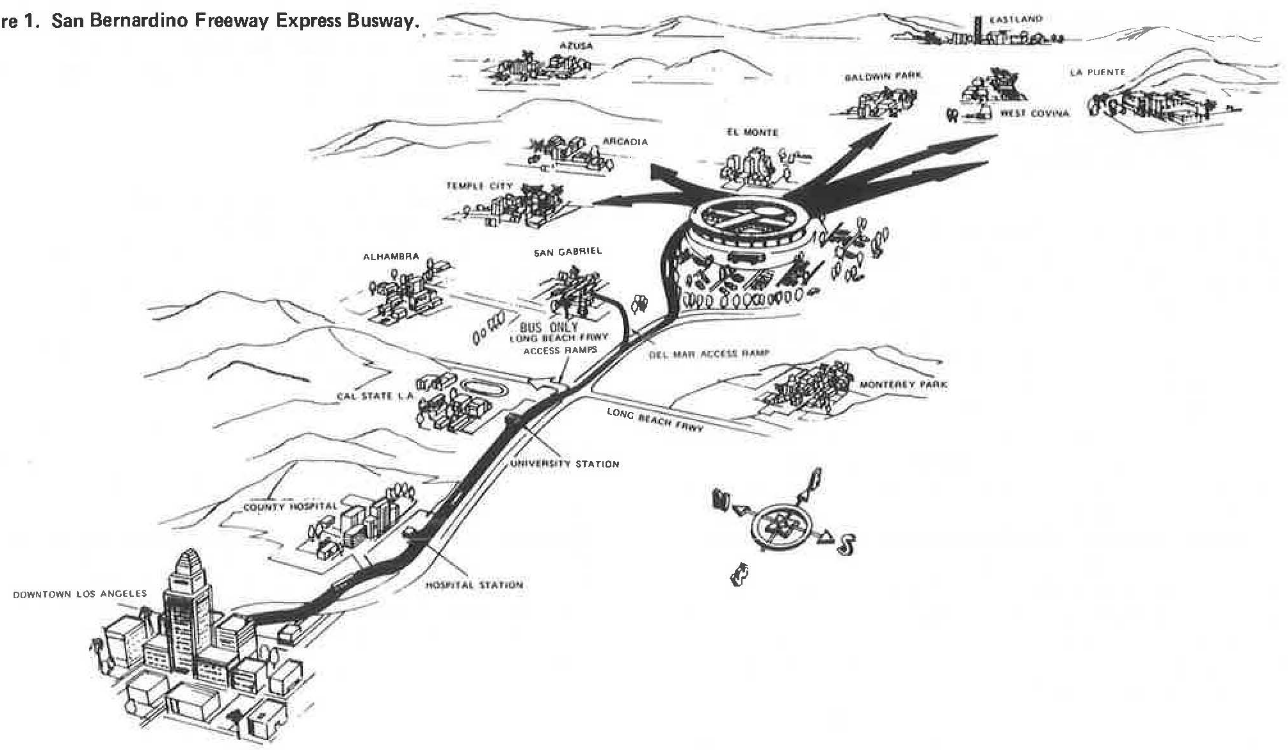


Figure 2. Busway patronage trends.

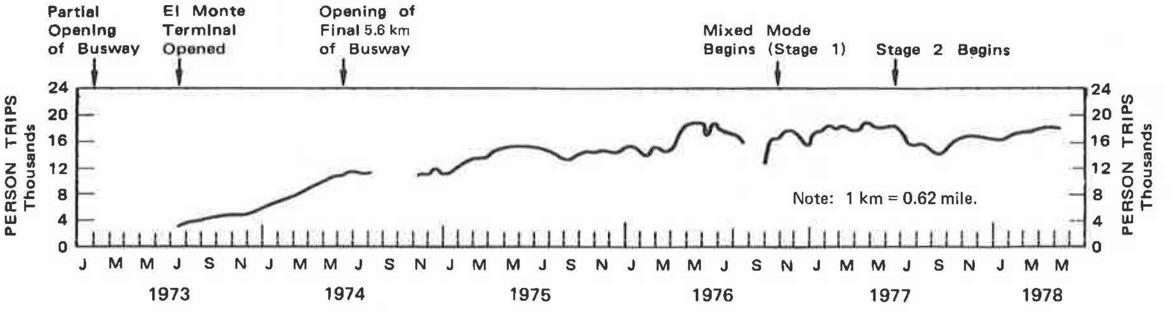
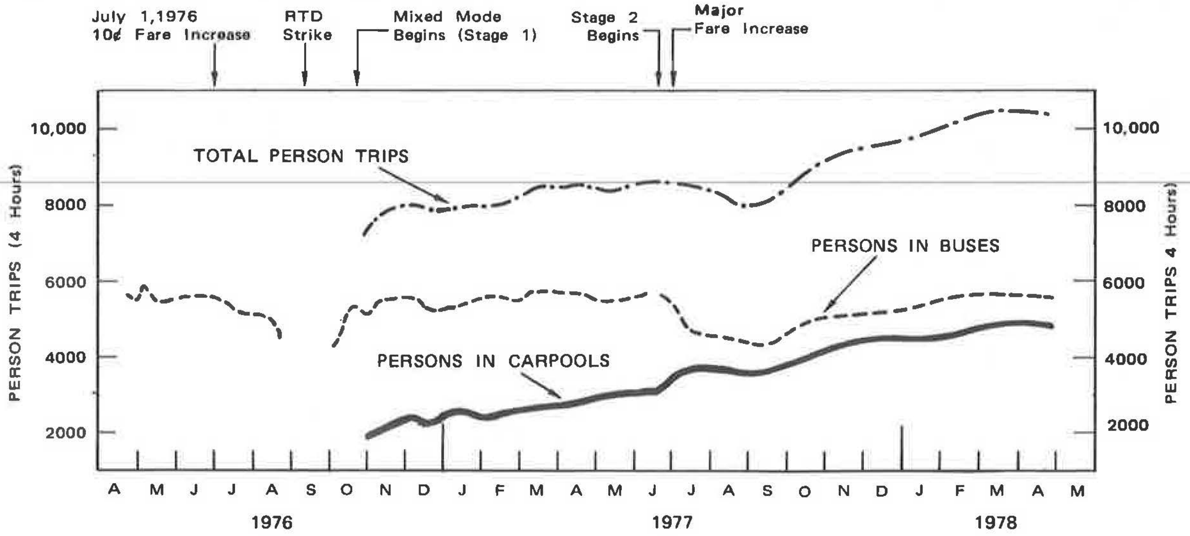


Figure 3. Busway person trips—morning period.



More than half of the carpoolers cited cost-related reasons for carpooling; time savings or convenience reasons were cited next most frequently. Parking costs are similar among carpoolers and solo automobile drivers. The major reasons cited by solo drivers for not carpooling were irregular work hours, the need for an automobile during the day, and convenience. Solo drivers' reasons for not riding a bus were time savings, convenience, and the need for an automobile. Carpoolers' perceptions of the time savings and pleasantness of carpooling were much more positive than those of solo drivers, but perceptions of carpool cost savings were similar. Most carpoolers agreed that they enjoy riding with other people; the solo drivers were neutral about that statement.

The large increase in bus fare in July 1977 caused roughly 200 bus riders to switch to carpools, but a greater number appear to have switched to a single-occupant vehicle. This is consistent with the findings about their prior mode of travel and automobile availability.

Figure 4. Western segment of busway.

Figure 5. Eastern segment of busway.

Figure 6. Access lane to busway.

ENVIRONMENTAL EFFECTS

The reduction in vehicle kilometers traveled just from those trips attracted to the busway during the 4-h morning and evening periods was 160 000 km/day (100 000 miles/day) during bus-only operations and 240 000 km/day (150 000 miles/day) during mixed-mode operations. The resulting reduction in air pollution emissions ranged from 10 to 20 percent and the energy savings from 7 to 10 percent of the 4-h, peak-direction totals on the busway-freeway lanes.

Although these savings were realized as a result of a major shift to HOVs, vehicular volumes on the freeway have also increased. This increased demand has offset some or all of the above savings. Other environmental impacts were inconsequential.

SAFETY AND ENFORCEMENT

The western segment of the busway is a physically separate roadway, accessible only at the end points (see Figure 4). The eastern segment of the busway is in the median of the freeway and is separated by a buffer shoulder with flexible posts (see Figure 5). Thus, it is possible to enter the busway at any point along the eastern segment, but it is illegal to do so except at the legal access points at the ends. Further, there are two lengthy access lanes to and from the busway where HOVs are separated from the freeway lanes by nothing more than a stripe on the pavement (see Figure 6). These differing configurations have a pronounced effect on safety and enforcement.

During bus-only operations, there were virtually no accidents, violations, or enforcement problems on any of the three parts of the busway. During mixed-mode operations, the same thing held true on the physically separated western segment. On the eastern segment, however, there was a low occupancy-violation rate (less than 10 percent) and a safety problem caused by illegal weaving across the buffer shoulder. This produced an overall accident rate that was about the same as for a typical freeway. About 500 enforcement contacts are made per month. For the unseparated access lanes this illegal weaving is an even larger problem that has caused accident rates to double and created enforcement problems.

A safety problem at the ends of the busway was caused by increased congestion. An enforcement problem during stage 1 was caused by unclear signing. This problem was resolved at the beginning of stage 2. In summary, a physical barrier between the HOV lane and adjacent traffic lanes is desirable for safety, and adequate room must be provided for emergencies and enforcement activities.

PUBLIC OPINION

Public opinion has remained strongly positive. Surveys were done of busway carpoolers, bus riders, noncarpoolers who use the freeway lanes, and households in the corridor. Most bus riders said that the busway

Table 1. Development of equivalent costs and revenues.

Item	Additional Freeway Lane ($)	Actual Busway ($)	Low-Cost Busway ($)	Low-Cost Reversible Busway ($)
Capital costs				
Rights-of-way				
East segment	3 400	8 600	8 600	8 600
West segment	2 000	4 400	2 400	2 400
Lane construction				
East segment	7 300	7 900	7 900	8 000
West segment	3 200	11 900	3 400	3 400
Railroad relocation				
East segment	1 700	4 700	4 700	4 500
West segment	0	1 500	0	0
Ramps and tunnels				
East segment	600	3 200	600	600
West segment	0	-[a]	-[a]	-[a]
Station construction				
El Monte	0	3 800	3 800	3 800
Hospital and college	0	1 100	0	0
Project planning, design, and implementation	3 000[b]	8 100	5 000[b]	5 100[b]
Bus purchases				
Initial purchase—100	0	4 700	4 700	4 700
Replacement in 1990—150	0	7 000	7 000	7 000
Total—1972 dollars	21 200	66 900	48 100	48 100
Total—1977 dollars[c]	29 400	94 900	67 400	67 400
Annual operating costs				
Roadways	84	150	175	110
Terminals	0	350	280	280
Buses	0	3 830	3 830	3 830
Enforcement	77	77	77	77
Total	161	4 407	4 362	4 297
Less annual revenues	-0	-1 500	-1 400	-1 400
Net annual operating costs—1977 dollars	161	2 907	2 962	2 897
Equivalent annual capital costs[d]	1 388	4 736	3 262	3 262
Total equivalent annual costs—1977 dollars	1 549	7 643	6 224	6 159

[a] Ramps included in lane construction.

[b] These are estimated costs in 1972. Cost in 1978 would be almost double.

[c] Inflated by using Federal Highway Administration Highway Construction Cost Index (5, p. 631).

[d] Annualized equivalent of capital costs, less residual value of right-of-way (estimated equal to the original cost, in constant 1977 dollars).

should be open to carpools and that carpools have not hurt bus service. Noncarpoolers on the freeway lanes said that the busway should be open to both buses and carpools and that the busway was a good investment of taxpayer's money. Press coverage of the busway has been infrequent but positive. The busway is not controversial.

COST-EFFECTIVENESS

To form a basis for an evaluation of cost-effectiveness, the goals of the busway project were identified as

1. Provide added corridor capacity,
2. Reduce environmental impacts of corridor travel,
3. Improve the level of service for corridor travelers,
4. Reduce the personal cost of travel,
5. Improve the safety of corridor travel, and
6. Provide for future contingencies (e.g., a future rail line).

Measures of effectiveness (MOEs) were identified for each of the goals, and data were gathered to measure the degree of attainment of each of the goals during bus-only and mixed-mode operations.

To provide a better basis for future decision making, several hypothetical alternatives as well as the existing busway were included in this analysis. These included an additional freeway lane, a low-cost busway to take full advantage of what we have learned from this busway demonstration experiment, and a low-cost, reversible-lane busway similar to the Shirley Highway busway near Washington, D.C. Cost estimates were then made for the existing busway and for the three alternative options (see Table 1).

By using the above cost estimates and MOEs, the cost-effectiveness of the four options, under bus-only and mixed-mode operations, was evaluated. Mixed-mode operations were found to be generally more cost effective than bus-only operation, mainly because the relatively fixed costs were spread among more users, all of whom gained some benefits. The only exception was with regard to safety.

The busway was superior to the additional freeway lane option in the reduction of user costs, improvement of level of service, reduction of environmental impacts, and provision for future contingencies. There was no difference with regard to safety, and the freeway was more cost effective for providing added capacity. The low-cost busway options were a little more cost effective than the existing busway.

The greatest monetary benefit of the busway is the savings in user costs that result from reduced vehicle use by those new carpoolers and bus riders attracted to the busway. These user cost savings (for busway-induced carpoolers and bus riders only) cover two-thirds of the annual (capital and operating) costs of the busway.

Most of the above conclusions, however, would probably change dramatically if operating conditions on the adjacent freeway were to change dramatically (e.g., because of ramp metering or freeway widening).

CONCLUSIONS AND IMPLICATIONS FOR FUTURE BUSWAYS

This demonstration project has shown that busways can be cost effective, noncontroversial, and attract substantial numbers of solo automobile drivers to buses and carpools.

Busways would be most cost effective in bus-only operations if sufficient demand existed to fully utilize available capacity. When sufficient bus ridership demand does not exist, or when its development is uncertain, carpools may be added to increase the cost-effectiveness of busways with only minor impacts on bus operations. When bus demand is uncertain, the busway design should permit carpools to be added, limited, or removed as circumstances change during the life of the busway.

Demand data from this project have shown that a properly designed busway can attract a mode share similar to that of a comparable rail facility, at substantially less cost. The collection and distribution function served by the same busway buses reduces or eliminates the transferring required for a typical rail trip. The ability to increase cost-effectiveness by the addition or deletion of carpools makes a busway more adaptable than rail to changing or uncertain future circumstances. Of course, if total demand grows beyond the busway capacity, conversion to a higher-capacity rail line is possible.

For maximum cost-effectiveness, each major aspect of the busway design should be examined to determine that its cost is justifiable in terms of the additional users that it will attract. To minimize adverse impact, busways should be physically separated from adjacent freeway traffic and should not begin or end at places where the freeway will be congested—where these features can be achieved in a cost-effective manner.

Finally, busways are most appropriate for congested freeway corridors. If congestion does not exist or is eliminated, much of the attractiveness, and effectiveness, of the busway would be lost.

REFERENCES

1. Crain and Associates. San Bernardino Freeway Express Busway: Evaluation of Mixed-Mode Operations. Southern California Assn. of Governments, Los Angeles, July 1978.
2. Crain and Associates. Third Year Report, Evaluation of Express Busway on San Bernardino Freeway. Southern California Assn. of Governments, Los Angeles, May 1976.
3. Crain and Associates. Second Year Report, San Bernardino Freeway Busway Evaluation. Southern California Assn. of Governments, Los Angeles, Sept. 1975.
4. Crain and Associates. First Year Report, San Bernardino Freeway Busway Evaluation. Southern California Assn. of Governments, Los Angeles, Feb. 1974.
5. Statistical Abstract of the United States 1977. Bureau of the Census, U.S. Department of Commerce, 1977. U.S. G.P.O. Stock No. 003-024-014 78-S.

Publication of this paper sponsored by the Committee on Bus Transit Systems.

Abridgment

Analysis of Bus Systems to Support Rail Rapid Transit

Gunter P. Sharp and Ronald L. Rardin, Georgia Institute of Technology, Atlanta
Howard G. Eisenstadt, Richard T. Shogren, and Charles C. Schimpeler, Schimpeler-Corradino Associates, Louisville

This abridgment describes an evaluation of alternative bus systems that will serve as line-haul and feeder service for the Metropolitan Dade County Stage 1 Rapid Transit System (Miami area). The weighted derivative (sensitivity) of transit ridership is defined and computed for all study-area zones, zone pairs, districts, and district pairs. Then a comprehensive transit system is determined for the study area to aid in the planning process. These two concepts are applied to a large urban area by using the urban transportation planning system (UTPS) and UTPS-compatible programs.

Transit planning by use of UTPS for large urban areas generally precludes the use of optimization techniques in the design of bus route systems. The large networks, long computer execution times, and impenetrability of the UTPS programs all combine to make optimum use of UTPS at the detailed planning level difficult. Previous studies of optimization concepts generally dealt with smaller networks that have fewer than 100 nodes (1-3). The concept of the weighted derivative is motivated by the desire to use a gradient-type interactive approach to make changes in the bus route system. Knowledge of the potential change in ridership due to changes in travel disutility can guide the planner in making changes to increase ridership at the least cost. Although the approach used did not iterate in the usual sense, the information provided gives new insight for the two route systems studied and helps explain why one is superior to the other.

The concept of a comprehensive transit system is not new, but its application in a UTPS setting is (4,5). Sometimes called an ubiquitous system, a comprehensive transit system is an abstract concept defined by the following service characteristics:

1. It covers the entire service area,

2. Each potential traveler has access to the system near trip origin and destination,
3. Headways are short,
4. Paths are not circuitous, and
5. There are few or no transfers.

In short, it is assumed that the numbers of vehicles and routes are unlimited. Transit fare and costs of competing automobile trips are assumed to be the same as for a design system. Such a system will attract the maximum potential ridership for any system by using the same vehicle types and speeds. The planner obtains an upper bound on ridership for evaluating various design systems. Detailed comparisons between a comprehensive and a design system on connectivity, ridership, travel times, and disutility can aid in modifying the latter. A comprehensive system can also aid in designing a new transit system (6). For Dade County the major use was to evaluate design systems.

APPROACH

The approach of the analysis is described by eight steps:

1. Develop initial alternative bus systems. For Dade County these are two—NET 6, a modified version of the existing system plus committed extensions and additions, and GRID 1, prepared by Dade County Office of Transit Administration. Both of these systems had already undergone considerable refinement before being subject to the present analysis.
2. Develop comprehensive transit system as a reference system. A 1985 highway network was used, and automobile speeds were factored down to appropriate bus speeds. Additional links were added to the resulting network to represent the 34-km (21-mile) long stage 1 rail line and a number of express busways.
3. Use UTPS program package to evaluate each system, generate paths, modal splits, and line assignments. Compatibility with UTPS was a requirement because virtually all previous planning had been performed with Federal Highway Administration (FHWA) and UTPS programs.
4. Generate reports of service indices and potential ridership changes for each alternative. The same program provided data on zone coverage, ridership, trip times, transfers, and the derivative of the modal split function. Most of the data were aggregated to district trip-end summaries and district-district tables.
5. Generate reports of resources needed: vehicles and vehicle distances and hours traveled on routes.
6. Examine reports to determine if further improvements or resource and patronage trade-offs can be made.
7. Use detailed output reports to make changes, then go back to step 3.
8. Stop. This decision was based on the time, manpower, and computer resources needed to perform another iteration versus the likelihood of achieving a significantly better bus system.

DESCRIPTION OF PROGRAMS

The program package consists of a sequence of UTPS programs (7); they are UNET, UPATH, UMODEL, ULOAD, and UFMTR. (These computer programs were designed for U.S. customary units only; therefore, values given are not in SI units.)

Comprehensive Transit System Development

Considerable effort was spent on the development of the comprehensive transit system. The first step assumes existence of a capacity-restrained highway assignment, which yields congested automobile speeds. FHWA program UNBLDHR is used to produce link cards from the historical record office (HRO) file (8). Highway link times are used to derive bus speeds by using the formula

$$T_b = T_a + L^2/(2ST_a) + 0.2L/S \qquad (1)$$

where

T_b = bus time on link (min),
T_a = automobile time on link (min),
L = length of link (miles), and
S = bus stop spacing on link (miles).

The second term expresses delay due to acceleration and deceleration of the bus and the third term reflects passenger boarding and alighting times. This formula is similar to one in McFadden and others (9). Bus spacing is a function of automobile speed:

$$S = (0.007)\,(\text{automobile speed}) + 0.12 \qquad (2)$$

Spacing is confined to the interval (0.17 mile, 0.33 mile), and the final bus speeds are confined to the interval (8 mph, 30 mph). Access to the comprehensive transit system is by walk connectors. These are the same as the centroid connectors to the 1985 highway net, except that walking speeds of 3.0 mph are assumed.

UMODEL Program

The key program in the analysis is a UMODEL routine with user-coded subroutines. The program reads zonal data, fare and toll matrices, parameters, and trip table data and then performs modal split for each interchange or zone pair, computes performance indices, and writes outputs. Person trip data used were for 1985, with four purposes defined: home-based work, home-based other, nonhome based, and school. Time and distance skims are for peak and off-peak. Also, trips are differentiated by origin zone location: beach area and nonbeach.

Modal Split

A logit model is used to predict transit choice (9):

$$\text{fraction transit} = 1/(1 + e^x) \qquad (3)$$

in which $x = sDD - aDA - b$

where

DD = disutility on design transit system (for comprehensive service, DC is substituted for DD),
DA = disutility for automobile trip, and
s, a, and b = constant coefficients for trip categories.

Disutility for a transit system (DD or DC) is obtained by

$$DD = \text{run time} + \text{fare disutility} + (\text{walk and wait time} \times 2.5) \qquad (4)$$

The automobile disutility (DA) is given by

$$DA = \text{run time} + \text{terminal time} + \text{parking cost disutility} + \text{automobile operating cost disutility} \quad (5)$$

Weighted Derivative

It is useful to know how sensitive system output is to changes in inputs. Previous work on mode choice (10) indicated that certain purpose-location-income group (PLI) combinations were far more sensitive to changes in transit service than others. Also, for a given PLI combination, the sensitivity to changes depends on the difference between transit and highway disutilities. This concept is expressed mathematically by the derivative of the modal split function, evaluated at the weighted disutility difference (x) for a design system under consideration:

$$DER = -e^x/(1 + e^x)^2 \quad (6)$$

The DER is multiplied by total person trips to show the change in transit ridership due to changes in x. This yields the weighted derivative (WTDER):

$$WTDER = DER \times \text{total person trips for zone pair} \quad (7)$$

The WTDERs are then aggregated to give district trip-end summaries and district-district tables.

These WTDERs must be interpreted with caution. At any aggregation level there is an assumption that a change in x for all person trips involved causes transit ridership to increase. Improvements in service to one or more zonal interchanges that cause the total district interchange to improve one disutility unit may not improve the transit ridership by the value WTDER. WTDER is computed with respect to x. For different PLI combinations, x exhibits different sensitivities for changes in DD or DA. For widely differing values of the coefficients, the WTDERs should not be aggregated. In summary, the WTDER values are another output of the program. Properly interpreted, they can aid the planner in making changes in the system.

Area-Adjusted Weighted Derivative

A problem in interpreting WTDER is that it is unrelated to the cost of changing the transit service. To adjust for the cost of improving transit service, by lower headways, closer line spacing, or faster bus speeds, one should modify WTDER based on these factors. Little work exists on such relationships—what has been reported suggests that some of the cost factors are related to the area of the district being served (11). Thus, it was decided to divide the WTDER for a district by the area of the district, giving the area-adjusted weighted derivative.

Program Time and Size

The program sequence was run on an IBM 360/65. Constraints that affect time and size include: number of tables input (24) and output (26), zones in the network (723), and nodes in the transit (2200) and highway (9000) network. A complete run takes about 250 central processing unit (CPU) min. Nearly half of that time is used by the UMODEL program, which also requires the largest amount of core, 616 000 bytes.

APPLICATION AND ANALYSIS

Summary details are given below for the bus lines in NET 6 and GRID 2, a revised version of GRID 1:

Variable	NET 6	GRID 2
Bus lines	137	103
Route miles	2 466	1 896
Vehicles	921	931
Vehicle miles	200 000	177 000
Vehicle hours	15 600	13 800

The most evident difference is in the higher route miles, vehicle miles, and vehicle hours for NET 6. One of the purposes of NET 6 is to provide service to an expanded area. This is also clear from an examination of the connected zones and interchanges.

Service to	NET 6 (%)	GRID 2 (%)
Peak zones	92	90
Interchanges		
Peak	82	80
Off-peak	77	80
Total person trips		
Peak	95	93
Off-peak	93	91
Average	94	92

NET 6 provides service to 2 percent more zones and interchanges during the peak than does GRID 2. During the off-peak, however, NET 6 coverage is reduced to 3 percent fewer interchanges than GRID 2.

Superior Performance of GRID 2

The GRID 2 system performs slightly better in terms of patronage and modal split.

Modal Split	NET 6 (%)	GRID 2 (%)	Comparable Service (%)
Peak	12	13	19
Off-peak	5	5	7
Total	6.5	7	10

GRID 2 attracts more peak rail patrons, but fewer during off-peak. Average disutility of travel time is 0.7 min less on GRID 2. As expected, transfers are higher for GRID 2 than for NET 6—1.4 and 0.7 versus 1.3 and 0.6 for peak and off-peak, respectively.

The major difference between the two systems is in productivity. Peak productivities are nearly the same, but the off-peak figures favor GRID 2—1.3 passengers/vehicle mile versus 1.1 passengers/vehicle mile and 18 passengers/vehicle-h versus 15 passengers/vehicle-h. NET 6 uses 22 percent more vehicles and 19 percent more vehicle miles during the off-peak and yet attracts only 1 percent more off-peak patrons. These differences are substantial: 131 more off-peak buses and 23 000 more off-peak vehicle miles (12).

Balance and Sensitivity

More detailed analysis shows that GRID 2 performs better for nonbeach work trips and low-income trips; however, NET 6 provides better service for beach zones. GRID 2 gives better service in the core area, and NET 6 serves the peripheral and beach areas better. The area-adjusted WTDERs indicate where cost-effective changes in transit service can be made. These WTDER values can be aggregated at higher levels to compare large areas against one another.

Area-Adjusted WTDER for	NET 6		GRID 2	
	Peak	Off-peak	Peak	Off-peak
Central area	467	499	474	494
Periphery	114	168	150	236
Beach area	906	3290	888	3017

This comparison provides some numerical values about how much more difficult it is to gain riders in the peripheral areas. If transit disutility is reduced by 4 min throughout an area (4 times a typical s value of 0.25 = 1.0), the resulting increase in ridership will be about 467-499/mile^2 in the peak, and 114-236/mile^2 in the off-peak. The beach districts have the greatest area-adjusted WTDERs. NET 6 and GRID 2 are fairly comparable in the core and beach areas but differ markedly in the peripheral area.

CONCLUSIONS

Two concepts were applied in the transit planning process for a large urban area by using UTPS-compatible programs: the weighted derivative of transit ridership and a comprehensive transit system. Because design of bus route systems for Dade County had progressed considerably before application of these concepts, they did not lead to major changes in alternative transit systems. However, they did provide clear and meaningful new insight in explaining the superiority of one route system. In particular, it was judged that a grid bus system was able to achieve higher productivity because it concentrated service in the core districts, which have much greater weighted derivative values. Since the comprehensive system attracted about the same number of riders for both connected service areas, the difference between the two design systems is largely in emphasis on different areas. It is hoped that these concepts will be used to guide subsequent refinements of the grid system.

ACKNOWLEDGMENT

This work was performed while we were affiliated with Kaiser Transit Group, Miami, Florida. It was supported by a grant from the Urban Mass Transportation Administration. Valuable technical advice and complete cooperation were received from the Dade County Office of Transit Administration.

REFERENCES

1. M.H. Rapp, P. Mattenberger, S. Piguet, and A. Robert-Grandpierre. Interactive Graphics Systems for Transit Route Optimization. TRB, Transportation Research Record 559, 1976, pp. 73-88.
2. G.P. Sharp, P.S. Jones, and J.O. Bell. Application of a Route Structuring Algorithm to City Bus Lines. Georgia Institute of Technology, Atlanta, 1974.
3. L.J. LeBlanc. An Algorithm for the Discrete Network Design Problem. Transportation Science, Vol. 9, No. 3, 1975, pp. 183-199.
4. R.H. Pratt and G.W. Schultz. A Systems Approach to Subarea Transit Service Design. TRB, Transportation Research Record 419, 1972, pp. 37-47.
5. G.L. Thompson. Planning Considerations for Alternative Transit Route Structures. American Institute of Planners Journal, April 1977, pp. 158-168.
6. J.C. Rea. Designing Urban Transit Systems: An Approach to the Route-Technology Selection Problem. TRB, Transportation Research Record 417, 1972, pp. 48-59.
7. What is UTPS. Urban Mass Transportation Administration; Federal Highway Administration, Aug. 1977.
8. Computer Programs for Urban Transportation Planning: PLANPAC-BACKPAC General Information Manual. Federal Highway Administration, April 1977, GPO No. 050-001-00125-0.
9. R. McFadden and others. The Urban Travel Demand Forecasting Project: Model Estimation and Validation. Transportation Institute, University of California, Berkeley, June 1977.
10. Kaiser Transit Group. Mode Choice Model Patronage Forecasts. Metropolitan Dade County Transit Improvement Program, Miami, 1978.
11. G.C. Clarens and V.F. Hurdle. An Operating Strategy for a Commuter Bus System. Transportation Science, Vol. 9, No. 1, 1975, pp. 1-20.
12. Kaiser Transit Group. Grid Bus Analysis. Metropolitan Dade County Transit Improvement Program, Miami, 1978.

Discussion

S. Chandana Wirasinghe, Department of
Civil Engineering, University of
Calgary, Calgary, Alberta

The authors should be commended for their attempt to rationalize the design of a complex transit network. Several aspects of the paper, however, merit further discussion. Essentially, two transit networks proposed for Dade County, Florida, are compared with an ubiquitous network. The concept of an "area-adjusted weighted derivative of transit ridership" is also introduced.

A section of the paper is devoted to describing various idealized bus transit networks (such as grid and radial) that have been discussed at length elsewhere (5). Somewhat surprisingly and contrary to the title of the paper, feeder route systems and their orientation to fixed guideways (13, 14) are not discussed.

An ubiquitous transit network is rather attractive for the purpose of comparing such variables as total ridership. However, one should be careful because the system operating costs cannot be compared in a similar manner. Further, care should be taken in the definition of an ubiquitous system in a practical situation for purposes of comparison. For example, the sensitivity of the results to the arbitrary assumption of a 10-min headway between buses should be checked.

The highway link time formula given by Equation 1 is based on several assumptions that should be noted. The term $L^2/2ST_a$ is dependent on both the acceleration and deceleration of a bus being equal to 4 miles/min^2. The last term 12/S seems to be based on the heroic assumptions that the link lengths and the number of passengers that board and alight in each link are equal. The basis for the formulation of the bus stop spacing as a linear function of speed (given by Equation 2) is unclear. It has been shown elsewhere (15) that the spacing that minimizes the sum of the passenger time costs and bus operating costs (total cost) is proportional to the square root of the bus speed.

It is likely that the disutility of a transfer is composed of two parts: one related to the waiting time and one related to the intrinsic inconvenience. In other words, an intrinsic transfer disutility would exist even if the transfer time was zero. This fact should be reflected in the transit disutility function given by Equation 5, since up to three transfers are allowed in the transit networks being compared.

It is recognized in the paper that the "weighted derivative of transit ridership (WTDER)" is unrelated to the cost of altering the service and, hence, of little value. The proposed remedy—the division of the WTDER for a district by the district area to obtain an estimate of the sensitivity of the change with respect to cost—leaves much to be desired. The WTDER for a district (as I understand the paper) is the change in trip ends between all the zones in a district and all the zones in the study area inclusive of that district, when the (DD - DA) values are decreased by one unit. Thus, the division of WTDER by the district area to obtain the sensitivity with respect to operating cost is not helpful since the district area cannot be a surrogate for the cost of operating buses, let alone trains, between zones in the district and zones outside the district.

The "superiority of one route system" over another cannot be established without more explicit recognition of the operating cost of the systems. A good transit system is one perhaps where a balance is obtained between the level of service and the operating cost. Recent work in the area of optimal bus transit networks (16) has indicated that a grid is not likely to be better than an asymmetric network if the total cost is to be minimized.

Finally, the inclusion of sketches of the two networks (NET 6 and GRID 2) would have been helpful.

REFERENCES

13. V. F. Hurdle. Minimum Cost Locations for Parallel Public Transit Lines. Transportation Science, Vol. 7, No. 4, 1973.
14. S. C. Wirasinghe. Assignment of Buses in a Coordinated Rail and Bus Transit System. Proc., 7th International Symposium on Transportation and Traffic Theory (T. Sasaki and T. Yamaoka, eds.), Institute of Systems Science Research, Kyoto, Japan, Aug. 1977, pp. 673-696.
15. N. S. Ghoneim. Spacing and Location of Bus-Stops. Department of Civil Engineering, University of Calgary, Alberta, M.Sc. thesis, June 1978.
16. G. F. Newell. Some Issues Relating to the Optimal Design of Bus Routes. Transportation Science, Vol. 13, No. 1, 1979.

Author's Closure

Gunter P. Sharp

Wirasinghe's discussion contains a number of valid comments. Some points mentioned should be clarified.

The formula for bus link times (given by Equation 1) originally contained an error and should read

$$T_b = T_a + L^2/(2ST_a) + 0.2\ L/S \qquad (1)$$

The second term ($L^2/2ST_a$) does not imply bus acceleration and deceleration of 4 miles/min^2 but instead relates to the additional acceleration and deceleration time needed for bus rather than automobile. The third term (0.2 L/S), which previously contained the error, is based on 0.05 min/passenger and four passengers/stop.

Bus stop spacing was expressed as a linear function of speed because this was thought to provide a good, simple approximation of current and future practice by Dade County. Stop spacing is influenced heavily by the type of street and spacing of blocks.

The disutility of a tranfer was expressed in a manner consistent with previous mode split analysis for the system, so that comparisons could be made more easily between the one-step logit model and the hierarchical model used previously (10).

The division of the weighted derivative of transit ridership (WTDER) by the area of the district is intended to yield a measure of potential ridership increase per square mile. Such a measure is clearly helpful to the planner even if the relation between district area and bus operating cost is not well specified.

It is stated in the paper that the superiority of the GRID 2 system is based on productivity and sensitivity. Since both systems attract about the same total numbers of patrons, the higher productivity of GRID 2 translates into lower operating costs. Thus, operating costs are explicitly recognized.

The term grid is something of a misnomer for the GRID 2 system. A more detailed analysis of route types in each system gives this comparison.

Peak Vehicles by Route Type	NET 6 (%)	GRID 2 (%)
Routes oriented mainly east-west or north-south, local	42	60
Radially oriented routes, local	12	11
Routes of mixed type, local	28	11
Express routes of all types	18	18

The express routes are mainly radially oriented and of mixed type and are the same in both systems. The difference between the two systems is a matter of degree; either one might be classified as being an asymmetric network.

The route systems require eight or more figures for clear graphical representation; these were excluded because of page limits. The Grid Bus Analysis (12) contains a complete set.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Abridgment

Evaluation of the Greenwood Drive Fringe Parking Facility

M. J. Demetsky, R. N. Robertson, and Robert E. Jalette,
University of Virginia and Virginia Highway and Transportation Research Council, Charlottesville

Fringe parking (or park-and-ride) lots are designed to draw on the benefits of the private automobile and bus transit by using the automobile to collect passengers from low-density residential areas and then carry them along high-density transportation corridors by bus. Many fringe parking and express bus services have been successful; however, several lots, such as the Greenwood Drive lot in Portsmouth, Virginia, have not been fully utilized. One factor that may have contributed to the underutilization of such parking facilities is the lack of adequate planning procedures for use in preliminary feasibility studies and subsequent transit planning efforts for park-and-ride facilities and services.

To assist transit planners in developing park-and-ride facilities, Wester and Demetsky proposed a procedural method for express bus and fringe parking transit planning (1). This methodology is based on the analysis of population, service, and urban development characteristics of park-and-ride operations in Richmond and Virginia Beach (2, 3). In addition to determining the feasibility of the operation, the methodology also estimates the demand for the bus service.

This paper describes a study that was conducted to determine why the service from the Greenwood Drive lot failed to attract more riders than it did and to test the ability of the planning methodology to show why this fringe parking facility was not successful. In addition, the potential for more demand for the service is discussed.

HISTORY OF FACILITY

The Greenwood Drive park-and-ride lot was developed jointly by the Federal Highway Administration, the Virginia Department of Highways and Transportation, the Tidewater Transportation District Commission, and the city of Portsmouth. The lot, located at the interchange of I-264 and Greenwood Drive in southwest Portsmouth, was dedicated on May 17, 1976. Bus service connects the lot with downtown Norfolk, the central business district (CBD), and the naval bases at Sewell's Point. The lot provides 335 free parking spaces and includes a kiss-and-ride area, an enclosed passenger shelter, bicycle racks, lighting, landscaping, and easy access to both transit and private passenger vehicles.

The initial service consisted of six buses that departed from the lot during the morning and returned during the afternoon. Three buses traveled between the lot and the U. S. Naval Operations Base (NOB) and the U. S. Naval Air Station (NAS), and the others serviced the Norfolk CBD. Due to insufficient passenger demand, the service to the CBD was discontinued in April 1977. The remaining three buses also serve another free parking lot located at the Midcity Shopping Center and stop on demand at the Old Dominion University and Public Health Hospital and on Hampton Boulevard.

The use of the park-and-ride lot and the ridership on the bus service have been very low from the beginning—frequently only 15-20 vehicles are parked in the lot daily. Table 1 summarizes the bus patronage through October 1977. Approximately 30 persons trips/day were made in each direction between the Greenwood Drive lot and the NOB-NAS.

ANALYSIS

The procedural method for planning express bus and fringe parking transit was applied step-by-step to determine why demand for the bus service has been low.

An examination of the parking supply, roadway congestion, and travel costs revealed that conditions that have been shown to prevail where the majority of successful express bus and fringe parking services have been implemented do not exist in the Portsmouth-Norfolk area.

The area served by this service is made up of single-family houses and townhouses. The numbers of home-to-work trips to the Norfolk CBD and the NOB-NAS are given by census tract in Table 2.

Observations from an on-site survey and an analysis of the area around the Greenwood Drive lot revealed locational advantages that included proximity to an existing travel corridor at the interchange of an Interstate highway. Disadvantages of the lot site include a lack of signs to direct drivers to the site, low level of maintenance, and lack of security. Overall it was concluded that the status of the site could be improved, but no dominant negative characteristics were detected.

Demand Estimation

The demand for the Greenwood Drive fringe parking and express bus service was estimated by use of a model calibrated for a service that originated at the Princess Anne Plaza in neighboring Virginia Beach (2). This model was chosen because of the similarities between the two transit operations and the respective markets.

The traffic zones used in past studies of the area provided the basis for the demand analysis. A correspondence of the zones with the census tracts was established in order to apply the work-trip data given in Table 2 to the traffic zones.

The probability (P_b) of choosing the express bus was determined by the logistic model

$$P_b = e^{G(x)}/[1 + e^{G(x)}] \qquad (1)$$

where $G(x)$ = a linear function of explanatory variables and is given by $G(x) = 1.2444 - 3.2961X_1 + 2.8541X_2 + 2.0156X_3$;

$$X_1 = \text{number of household automobiles} \div \text{number of licensed drivers} \qquad (2)$$

$$X_2 = (T_a - T_b)/[(T_a + T_b)/2] \qquad (3)$$

Table 1. Ridership of Greenwood Drive park-and-ride bus service.

	Destination	
Week Beginning	NOB-NAS	CBD
May 17, 1976	18	8
June 14, 1976	33	17
July 19, 1976	63	24
August 16, 1976	63	31
September 13, 1976	58	31
October 18, 1976	61	29
November 15, 1976	69	29
December 13, 1976	77	19
January 17, 1977	57	21
February 14, 1977	63	19
March 14, 1977	65	18
April 11, 1977	58	Service terminated
May 16, 1977	63	
June 13, 1977	62	
July 18, 1977	61	
August 15, 1977	52	
September 12, 1977	66	
October 17, 1977	58	

Table 2. Greenwood Drive corridor market-area home-to-work trips.

		Home-to-Work Trips[a]	
Census Tract	Population	CBD	NOB-NAS
127.01	4568	29	228
127.02	5893	29	249
128.0	7541	46	126
213.01	1887	16	26
214.04	2531	39	64
215.01	3396	6	57

[a] The figures in this table were estimated from the 1970 census by assuming that all nonlocal government workers employed in Norfolk work at the NOB-NAS.

$$X_3 = (C_a - C_b)/[(C_a + C_b)/2] \tag{4}$$

where

T_a = travel time via automobile,
T_b = travel time via bus,
C_a = cost of using automobile, and
C_b = cost of using bus.

In order to estimate the demand for the express bus service the number of captive riders was subtracted from the zonal NOB-NAS and Norfolk CBD work trips. The rate of captive automobile riders was assumed to be the same as that for the area where the models were calibrated—47.7 percent. A summary of the ridership estimates by zone for the express bus service from the market area is given below.

Traffic Zone	Destination CBD	Destination NOB-NAS
389	1	1
390	3	4
391	1	1
393	1	5
398	1	4
400	0	1
406	0	1
407	1	2
408	0	0
487	8	59
495	7	16
505	8	63
Total	31	157

Demand Analysis

The NOB-NAS is unique in that a bus service that closely resembles that provided by the Greenwood Drive operation was available prior to the institution of the new service. Buses are privately owned and operated by employees of the NOB-NAS. Personnel interested in using this service contact an owner and arrange a pickup point. A current directory shows that nine 65-passenger buses operate in the same market area as the Greenwood Drive parking lot. The cost of this bus service ranges from 60 to 75 cents/trip. Therefore, the express bus service faces direct competition from the established subscription bus service. In order to determine the expected patronage for the Greenwood Drive lot service, the submodal split between the subscription buses and the Greenwood Drive express bus was estimated.

Since the travel time and cost of the established subscription bus service are similar to those of the new Greenwood Drive express bus service and the new service requires an additional access mode but the subscription bus provides door-to-door pickup, it was assumed that the majority (80 percent) of the current subscription bus passengers would continue to use that service.

These passengers were then subtracted from the total estimated demand in the market area for express bus service to get an accurate estimate of the number of people who would use the express bus service. The table below gives the final estimates of ridership for the Greenwood Drive express bus service.

Traffic Zone	Destination CBD	Destination NOB-NAS
389	1	1
390	3	3
391	1	1
393	1	1
398	1	1
400	0	0
406	0	0
407	1	1
408	0	0
487	8	23
495	7	9
505	8	17
Total	31	57

The final step of the procedure for planning fringe parking and express bus transit is to determine the number of automobiles that will be parked at the fringe parking lot. This was accomplished by using a submodal split model for each zone in the market area:

$$P_b = e^{G(x)}/[1 + e^{G(x)}] \tag{5}$$

$$G(x) = -5.7146X_1 + 3.4796 \tag{6}$$

The estimate of the number of automobiles parked was found by multiplying the probability of parking by the estimate of the express bus ridership. These results are given below.

Traffic Zone	Owner's Destination CBD	Owner's Destination NOB-NAS
389	1	1
390	2	2
391	1	1
393	1	1
398	1	1
400	0	0
406	0	0
407	0	0
408	0	0
487	5	15
495	2	2
505	5	12
Total	18	35

The estimated ridership for the express bus service (as given above) is approximately double that actually realized (Table 1). Much of the discrepancy between the actual and predicted values is attributed to the numerous assumptions required in order to account for the subscription bus service and the error to be expected by borrowing models. The demand analysis did indicate, however, that the service would experience levels of patronage much lower than those for which the lot and service were designed.

CONCLUSIONS

The application of the methodology to the planning of express bus and fringe parking transit to the Greenwood Drive service reveals that the low levels of patronage that have been experienced could have been expected. When the Greenwood Drive service was planned, the competing subscription bus service was not properly considered. Although the planning methodology was not designed to deal directly with such unique issues as competing bus service, we have shown that the comprehensive study approach could be adapted to special local problems, such as this competition. Accordingly, we conclude that the methodology improves the general capability for developing successful park-and-ride transit operations.

The following observations were made regarding the future potential of the Greenwood Drive lot service to attract riders:

1. The competing subscription bus service clearly dominates the market for transit to the NOB-NAS,
2. The site is somewhat isolated from the local neighborhoods,
3. The service should have been advertised continually and more directional signs should have been provided on local roads, and
4. The lot design is adequate, but better maintenance and security are desirable.

In view of the above findings plus other factors considered, it does not appear that demand for the service will grow in the near future. Only when the area to the south of the lot (Chesapeake and Suffolk) is developed will it be possible for the lot and service to be anywhere near successful.

REFERENCES

1. K.W. Wester and M.J. Demetsky. A Procedural Method for Express Bus-Fringe Parking Transit Planning. Virginia Highway and Transportation Research Council, Charlottesville, VHTRC 77-R23, Nov. 1976.
2. F.C. Kavak and M.J. Demetsky. Demand Estimation for Express Bus-Fringe Parking Services. Virginia Highway and Transportation Research Council, Charlottesville, VHTRC 75-R60, June 1975.
3. M.J. Demetsky and R.P. Cleveland. Planning Criteria for Express Bus-Fringe Parking Operations. Virginia Highway and Transportation Research Council, Charlottesville, VHTRC 75-R64, June 1975.
4. 1970 Census of Population and Housing Census Tracts, Norfolk-Portsmouth, Virginia, Standard Metropolitan Statistical Area. Bureau of Census, U.S. Department of Commerce, 1972.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Bus Route Analysis Model (BRAM) Summary Report

Robert Bengtson and Ken Markve, Upper Great Plains Transportation Institute,
North Dakota State University, Fargo

This describes the bus route analysis model (BRAM), a computer system that was developed to design bus routes. The computer program uses an iterative process to test various route configurations and to minimize the number of routes, the distance traveled, and the total travel time within constraints established by the parameters of maximum riding time and average speed of the bus. In the active mode BRAM designs bus routes by first dividing the district into a number of pie-shaped sectors, which are preselected by the planner, and then designing a route within each sector. Bus stops are first assigned to a sector by location and are then assigned to a route. A theoretical loop curve that represents an ideal route is used to form the routes. Bus stops are assigned to the route based on distance from the ideal curve and other constraints (such as bus capacity and student travel time). In order to test feasibility the routes are then subjected to a modeling procedure to determine travel time and travel distance. Through an iterative process various configurations of routes are tested until the best configuration is determined. BRAM is user oriented. A user's procedure manual describes the procedures for data collection and completion of coding forms, which are then keypunched. Support personnel input the data to the computer program and also establish the various parameters and constraints used. The printout is then sent back to the school district, where the routes are plotted and analyzed. The computer program also includes a management information system that can summarize daily statistics and print out monthly reports on the bus system. These reports provide information on the buses, routes, employees, and related costs. BRAM provides a design tool that can quickly investigate route alternatives for school buses or other fixed-route transit systems.

During the past several years research has been conducted at the Upper Great Plains Transportation Institute to develop a computer model to route school buses. The need for the conservation of energy is urgent in this age of increasing energy costs and dwindling resources. One area where costs can be reduced is in the transporting of students to and from school. The costs of transporting students are a particularly acute problem in North Dakota, where those school districts that responded to a questionnaire on usage of the computer indicated that there was an average of 1 student/7.8 km^2 (1 student/3 mile^2). After an extensive review of the literature (1-4) we decided that contemporary network analysis models would be too complicated for school district personnel to use. Structuring of the networks would be too expensive because many of the school bus routes in rural North Dakota are very long. Due to the severe weather and expected absences, routes change continually. The road system is everywhere—a road is available on most section and quarter-section lines.

DESCRIPTION OF THE RESEARCH

The objectives of the research were

1. To assess the state of the art of school transportation and the need for improved planning of school bus routes in North Dakota,
2. To assess the operating characteristics of a school bus system and to use these observations to develop a simulation model,
3. To develop a methodology for a computer program to design bus routes and manage a bus system, and
4. To develop a user's procedure manual so that school district personnel can use the bus route analysis model (BRAM).

The BRAM computer system designs bus routes and then models these routes to test student travel times and the distances traveled by the buses. The computer program uses an iterative process to test various route configurations in order to minimize the number of routes, distances traveled, and total travel time within constraints established by such parameters as maximum bus riding time and the average speed of the bus. In North Dakota a student cannot spend more than 1 h on a bus.

BRAM designs bus routes by first dividing the district into a number of pie-shaped sectors, which are preselected by the planner, and then routes are cut within each sector. Bus stops are first assigned to a sector by location and are then assigned to a route. A theoretical loop curve that represents an ideal route is used to form the routes. Bus stops are assigned to the route based on distance from the ideal curve and other constraints (such as bus capacity and maximum student travel time). The routes are then subjected to a modeling procedure to determine travel time and distance in order to test feasibility. Through an iterative process various configurations of routes are tested until the best configuration is found.

Figure 1. Near optimum route.

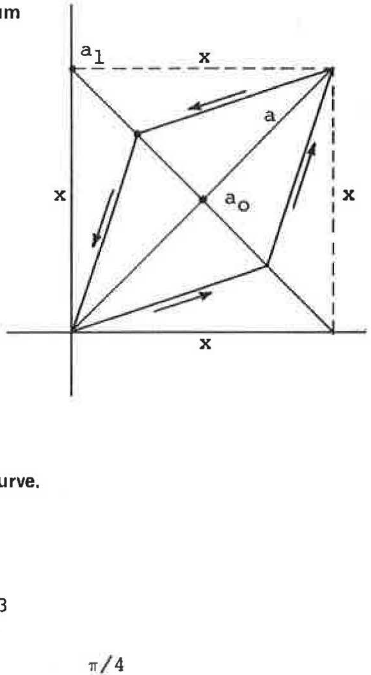
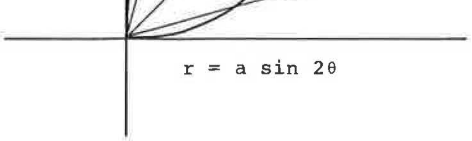


Figure 2. Rose-petal curve.



The data required by the computer program can be supplied by the school district personnel. A user's procedure manual describes the processes of data collection and completion of coding forms, which are then keypunched. Support personnel put the data into the computer program and also establish the various parameters and constraints used in the program. The printout is sent back to the school district, where the routes are plotted and analyzed.

The computer program also includes a management information system (1) that can summarize daily statistics and print out monthly reports on the bus system. These reports provide statistics on the buses, students, employees, and related costs. This system can provide monthly, year-to-date, or yearly totals so that costs can be watched closely and information provided on bus replacement or route revision.

TECHNIQUES

A false coordinate system is established on the southwest corner of each school district in order to express each student-boarding point as a positive (X, Y) coordinate. The centroid of the student population can then be established. The ideal location of the school would be this centroid; however, factors such as population density and land use trends need to be considered in the location of the school. The school district is divided into sectors. The total number of sectors is the total students divided by bus capacity. Usually three computer runs are made: (a) The first run uses two fewer than the current number of buses, (b) the second run uses one fewer than the current number of buses, and (c) the third run uses the same number of buses as are currently used.

The first route modeled is in quadrant 1. The bus is backed out of the school to the closest passenger point. In the initial research each additional passenger was picked up until either travel time or bus capacity was exceeded. This resulted in a zigzag pattern that had many crossovers. Another attempt was made to pick up passengers by use of all possible combinations. This would give more iterations than the computer could handle. For example, for a route that has 24 stops, the resultant combinations are approximately 2.3×10^{23}.

Other attempts were made. The longest route (a rectangle in which the farthest student is at the opposite diagonal of the rectangle) was tried, then the shortest route on the diagonal was tried. It was also a failure. A near-optimum kite-shaped pattern shown in Figure 1 was also attempted. This produced results but the computation time was awkward and excessive.

A continuous curve was needed to direct the bus along the route. Mathematical integration of a uniform density of students to a point is difficult. A search of a set of math tables (5) indicated sets of curves, called rose-petal curves, for which the formula illustrated in Figure 2 is

$$a = \sin n\,\theta \qquad (1)$$

where n, an even integer, results in 2n leaves and n, an odd integer, results in n leaves. A formula for any number of sectors can thus be derived. The distance from the farthest student to the origin is represented by a. Even though this is longer than the kite-shaped route (2.42a versus 2.32a), the conversion from polar to Cartesian coordinates is simple and better routes

Figure 3. Summary of BRAM methodology.

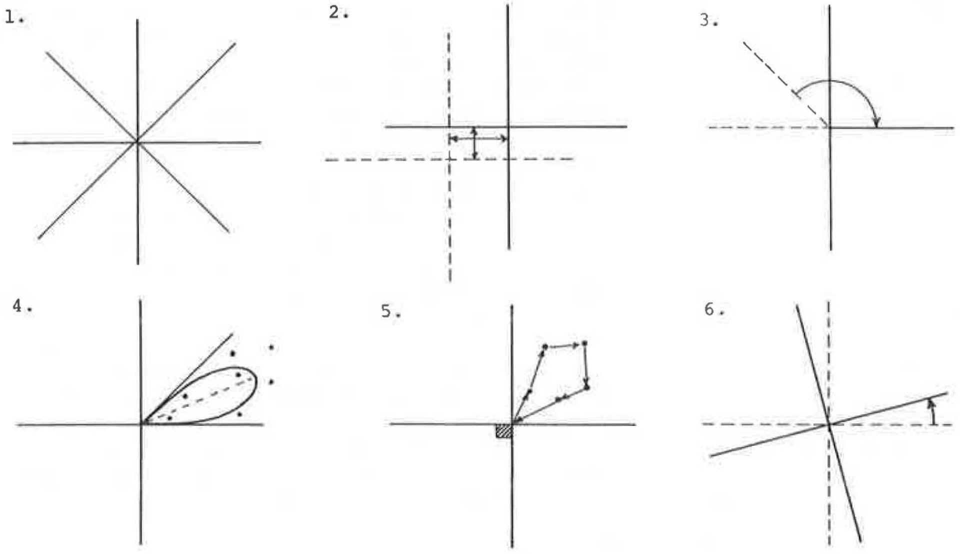
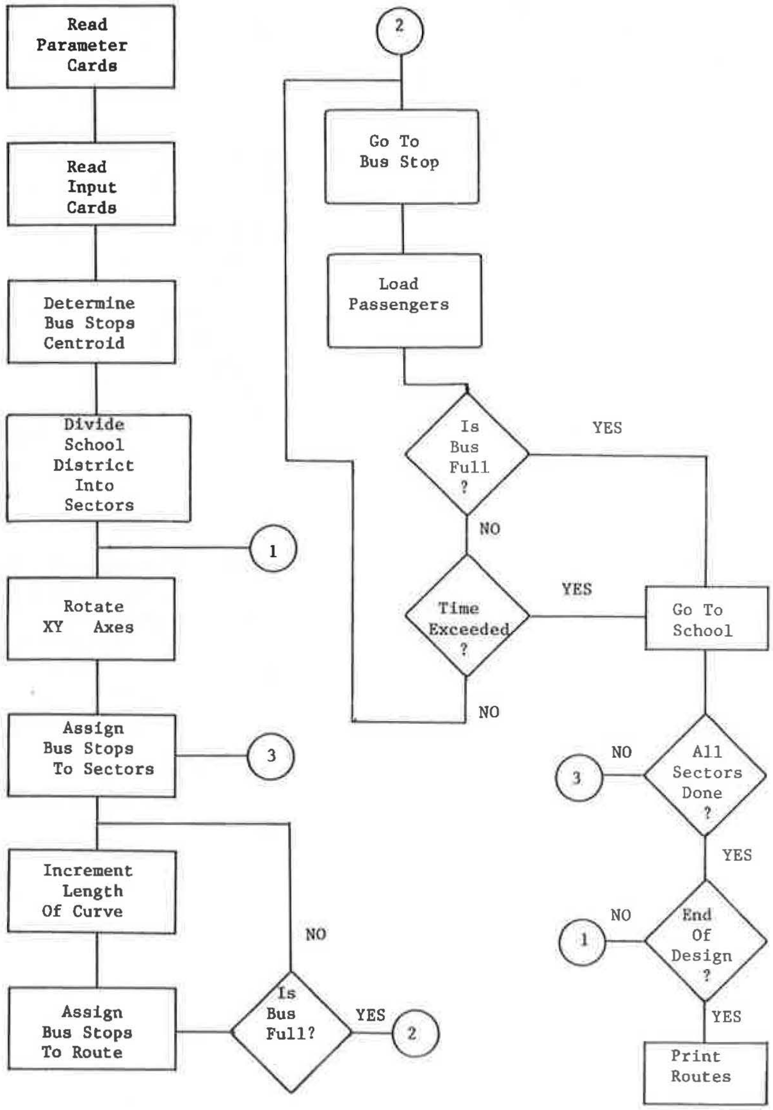


Figure 4. Internal macroflowchart.



are obtained through improved computation.

Thus, the bus is backed out on the curve in a counterclockwise direction and students in the path of the curve [3.2 and 4.8 km (2 and 3 miles) are used] are picked up. The pickups are stored and, at the completion of the program, a printout is given of the information that follows (1 km = 0.62 mile):

```
Bus route number 1
Bus number 1
Dead haul to first bus stop = 10.0 km
Route distance = 76.8 km
Total distance = 87.7 km
Number of students loaded = 33 (bus capacity = 48)
Total elapsed time = 68.4 min
Bus stop sequence (order of pickup) 14, 11, 9, 8,
   7, 3, 5, 4, 2, 1, 6, 30
```

After one iteration in each quadrant, the axis is rotated 5° for successive iterations. Total travel distance is computed, and the route selected for printout is based on the lowest travel distance.

A summary of the program steps is given below and described in Figure 3 and by the internal macroflowchart of Figure 4.

1. The school district is divided into sectors by dividing total students by bus capacity;
2. The centroid of bus stops is determined and translated to XY axes;
3. The sector is rotated to the first quadrant;
4. A stop is assigned to a route by using the design curve;
5. The route is simulated by loading passengers and determining travel time (the above procedure is repeated for each of the remaining sectors);
6. The next iteration is prepared by rotating XY axes and repeating steps 1-5 to create a new configuration of routes; and
7. After all iterations are complete, the best configuration of routes is printed.

RESULTS

This computer program has been used for 15 school districts and, in general, has produced a 20 percent reduction in fleet size and also a 14 percent reduction in travel distances over the manual systems that are currently used by school districts to establish bus routes. A sample of the cost savings is shown in Table 1.

Table 1. Potential savings to school districts resulting from application of BRAM.

School District	Operating Cost Savings per Year ($)	Travel Distance Savings per Year (km)	Fuel Savings per Year (L)	Equipment Savings
Butte	7 860	14 190	15 900	2[a]
Drayton	2 520	8 110	3 810	1[b]
Emerado	3 300	2 610	5 900	1[b]
Finley	12 240	16 220	7 630	1 bus
Gackle	5 220	16 800	7 910	2[a]
Langdon	9 530	22 530	9 650	1 bus
Linton	22 300	59 680	28 090	2 buses
Mayville-Portland	4 320	13 900	6 550	1 bus
Page	8 585	16 340	11 130	1 bus
Park River	2 880	9 270	4 350	1 bus
Rhame	3 920	1 450	9 270	2[a]
West Fargo	17 900	8 110	3 820	2 buses
Wishek	14 300	31 540	13 490	2 buses

Notes: 1 km = 0.62 mile; 1 L = 0.26 gal.
Potential savings are calculated based on a comparison of the present busing system to the optimum busing system arrived at through use of BRAM.

[a] Replace two large buses with two minibuses.

[b] Replace one large bus with one minibus.

A grant from the state energy office was used to fund the development of the routes for 13 districts. Currently, the engineering experiment station is working with districts on a cost-plus-fee basis. A typical cost per district for computer time, travel, and personnel is about $1000. This can be reduced if district personnel code the student locations and decipher the printout. Only one-fourth of the school districts contacted in North Dakota indicated that they would be interested in using this model. However, if all school districts used this model, North Dakota would save about $2 million in costs for buses and gasoline. The research also points out that some school buses have excess capacity because school children (especially high school students) drive to and from school. School districts shaped in oblong or egg-shaped patterns are not conducive to route development. A better geometry would be square-shaped patterns. BRAM has other spinoff effects. In the Wishek district, for example, improvement of 3.2 km (2 miles) of county road will provide substantial route savings.

Limitations of the Model

The model has several limitations, which are currently being studied in the continuing research effort. First of all, the model cannot show any savings for school districts that have three buses or less. These systems are too small to model effectively. If a school district has multiple schools that are separated by some distance, the model will not work. This can be resolved by running the program the same number of times as there are individual school sites or transfer points. In this case the last school or transfer point modeled merely becomes a bus stop for the next modeling run. This, of course, is expensive.

The model has not been tried and may not work where large physical constraints (such as badlands or lakes) are present. Current research will attempt to divide the sectors into square-shaped cells and mask those cells with geophysical constraints. Then routes can be directed around the masked cells. The decision on when to use a short route (0.5 h) or a long route (1 h) is not clear and the investigation and analysis are continuing in these areas.

Some of the districts in western North Dakota that have few roads, routes longer than 1 h, and many physical constraints may not be candidates for the modeling effort. Special studies and manual methods may be needed in these areas because model development might exceed the cost of a special study.

Future Research

During the course of the research the idea of using school buses for other purposes was developed. These purposes include

1. Package delivery in small urban and rural areas,
2. Mail delivery,
3. Library book delivery,
4. Senior citizen subscription ride services,
5. Mobile health services, and
6. Rural public transportation systems.

Research will also be conducted on the design of a multipurpose rural vehicle that could handle all of the above services.

The feasibility of using BRAM for the following will be tested:

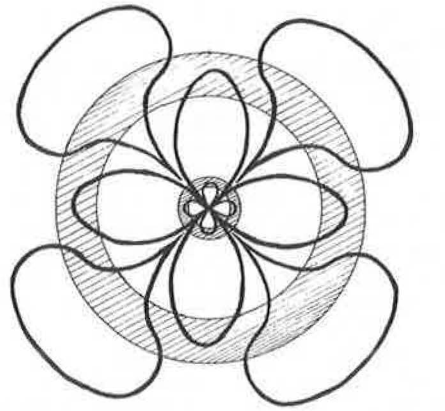


Figure 5. Bus route configuration.

1. Solid waste optimization collection systems (SWOCS)—The routing of garbage trucks is a similar problem but the delivery point is not at the centroid of the pickups.
2. Small urban fixed-route transit planning—This is a similar problem, but the coordinates change for each run on a route.
3. Small urban floating-point transit planning—Requests have been made to investigate routing of vanpools and senior citizen demand-responsive systems.

Other low-density routing problems will be investigated.

In some of the remote or very low-density areas the revival of the country school should be considered. There is a breakpoint at which the cost of operation of these schools approaches the cost of transportation. The psychological factors involved in riding a bus 2 h/day needs to be considered. In 12 years of school, a student could spend as much as 0.5 year on a bus. The four-day school week and study-at-home packages need to be considered. The use of vans to collect distant passengers could reduce riding time. Also, near and far loops need to be investigated.

The major disadvantage of the loop-shaped route is excessive riding time for the first students on the bus, who travel away from their destination half of the time. This route is, therefore, not suitable for long routes but is satisfactory for short- and medium-length routes. Outlying stops should be serviced by more direct routes. In order to keep travel time under 1 h, the riding distance should be no more than 48-56 km (30-35 miles). By using the design curve (rose petal) with a length of 56 km, the radius of a cell around the central school location can be determined. Loop-shaped routes can be used within a radius of 19 km (12 miles). This is represented in Figure 5. The small circle represents the area in which double-tripping is feasible (a bus unloads after servicing a medium-length route and then immediately services a short route on the outskirts of a town). The radius is approximately 3 km (2 miles). The West Fargo school district uses several short routes of this type. The large circle represents the area in which loop routes of a medium length can be used. Stops in the area beyond the larger circle must be serviced by more direct routes of a general configuration, shown in Figure 5.

CONCLUSION

The development of this model has shown that an expensive network analysis is not needed to route school buses. The coordinates from the computer printout can be easily plotted on an overlay by school district personnel, and decisions on which routes to take are then based on local knowledge in the school district. This leaves the decision on final bus routes and schedules where it should be—at the local level.

REFERENCES

1. K. Markve. Alexandria-Pineville Transit Update. Planning Commission, Pineville, LA, June 1975.
2. P. R. Pickens and J. M. Tyler. Transportation Planning for Urban School Systems. Transportation Engineering Journal, Vol. 100, No. TE 2, May 1974.
3. L. W. Schruben. How to Reorganize Your Delivery Routes. American Dairy Review, April 1972.
4. L. W. Schruben and V. L. Nelson. An Analysis of School Bus Routes. Unified School District 383, Manhattan, Kansas; Agricultural Experiment Station, Kansas State University, Manhattan, Kansas, July 1973.
5. Standard Mathematical Tables. Chemical Rubber Publishing Company, Cleveland, OH, 1959.

Publication of this paper sponsored by Committee on Bus Transit Systems.

Estimating the Effects of Alternative Levels of Service on Rural Transit Ridership

Wayne R. Ugolik and Robert G. Knighton, Planning and Research Bureau, New York State Department of Transportation, Albany

This paper deals with the need to assess public response to alternative levels of service and travel flexibility on proposed rural transportation systems. A public opinion survey was conducted in rural Otsego County, New York, among 254 households, 30 of which had no telephones. The survey presented three public transportation options (fixed route, dial-a-bus, and mobility club) and asked questions about possible use of such

services at different fare and service levels. The survey questionnaire was designed to minimize noncommitment bias and responses were separated on the basis of automobile availability to minimize the need for adjustment for noncommitment. Adjustment for noncommitment was necessary for the group that had an automobile available. This adjustment was based on the proportion of transit trips made by the automobile-available group on the existing dial-a-bus system (as determined by an on-board survey), which operates in Oneonta, the county's largest city. Estimates of potential ridership were made for each transit option at different fare levels, service levels, and travel-flexibility levels. Although it is not suggested that the demand estimates developed for Otsego County are transferable to other areas, the relative changes in demand resulting from changing fare, service, and travel-flexibility levels should be generally useful.

Providing for the mobility needs of rural residents is a growing national concern. In fact, a 1974 public opinion poll in New York State (1) identified the lack of adequate public transportation as the number one community problem in rural areas.

Estimates of potential usage are essential to planning and implementing any rural transportation system. Previous methods for estimating demand for such service have varied from extremely simple trip rate schemes to fairly sophisticated models (2-7). These methods contribute to the establishment of estimates of demand, but they do not provide a method for assessing public response to innovative approaches to public transportation that might be appropriate in rural areas. In particular, some understanding of how restrictions on service availability might affect ridership is necessary in order to analyze and develop alternative fare levels, service levels, and travel-flexibility policies. This study was intended to provide insight into these matters.

The research involves the design of a questionnaire, its administration in a telephone and personal interview survey, and an analysis of the data obtained. The survey was conducted in Otsego County, a rural county in central New York. The county has a population of 56 000, 16 000 of whom live in the city of Oneonta, where a dial-a-bus service has been in operation since 1974. The remaining 40 000 live in rural areas and small vilages; the largest is Cooperstown, which has a population of 2400 and is famous as the "home of baseball".

The analysis resulted in estimates of potential demand, outside the city of Oneonta, for various proposed transportation services (dial-a-bus, fixed-route bus, and mobility club) at different fare and service levels.

DATA AND METHOD

A sample of 224 households outside the city of Oneonta was selected at random from telephone directories, and one person per household was interviewed. The sample was proportioned among census minor civil divisions in order to ensure representation of all areas of the county. A snowball method was used, whereby persons interviewed were asked if they knew of households that did not have telephones. An additional 30 households were then personally interviewed so that the needs of persons who do not have telephones could be assessed. Thus, the survey resulted in 254 completed questionnaires.

Initial analysis of the sample indicated an over-representation of women and older men. Therefore, the sample responses were weighted on the basis of six age and gender categories to align the sample with census statistics (see table below; note that P = the population proportion and p = the sample proportion). The demand estimates were based on the weighted survey results by summing weights rather than units.

Age	Women	Men
16-34	P = 0.165 p = 0.185 n = 47 w = P/p = 0.892	P = 0.150 p = 0.067 n = 17 w = P/p = 2.238
35-54	P = 0.171 p = 0.209 n = 53 w = P/p = 0.820	P = 0.162 p = 0.086 n = 22 w = P/p = 1.88
55+	P = 0.185 p = 0.275 n = 70 w = P/p = 0.673	P = 0.160 p = 0.177 n = 45 w = P/p = 0.904

The survey was conducted during the second week of April 1978. The survey questionnaire (8) was designed to investigate the effects that various service limitations and fare levels would have on the demand for different transportation services. Each respondent was asked questions specific to the last time he or she needed to go somewhere (one round trip). Of particular interest was a question referring to "automobile availability" for that trip. Each of three transportation services (dial-a-bus, fixed-route bus, and mobility club) (9) were described and the respondents were asked whether or not they would have used such transportation service for that trip. The questions were asked sequentially and required simple yes or no answers. After an indication of "yes I would have used that option", answers to questions such as "would you have used that option if. . ." were solicited for various levels of different types of service constraints in increasing order of their limitation to service (such as increasing fares, increasing wait time, and requiring advance reservation time). The weighted positive responses were doubled (assuming a round trip), averaged to reflect trips per day, cross-tabulated by type of service restriction, and expanded to the entire population (16 years of age and over) within the county, but outside the city of Oneonta, to yield an estimated number of one-way trips per day at various service levels. These estimates were then adjusted for noncommitment bias.

Estimates obtained directly from data of this kind are distorted by noncommitment. A 1974 study (4) showed that noncommitment responses sometimes need to be reduced more than 90 percent in order to obtain reasonable estimates of demand. That is, many persons indicate in surveys that they would use a transportation service when in reality, if the service were made available, they would not. This is particularly true for respondents who have an automobile available for their use. Persons who have an automobile who think that they might use public transportation are still more apt to use their automobiles rather than public transportation. This is especially true because obstacles to using public transportation such as waiting time, required advance reservation time, and immediate out-of-pocket cost make an available automobile a much more attractive option. However, persons who do not have an automobile to use are apt to use public transportation if it is available and if its use appeals to them.

In fact, most riders on existing systems do not have an automobile to use. A recent on-board survey conducted on the Oneonta dial-a-bus system (10) showed that 85 percent of the riders had no other means of transportation. Here a rough concept of need enters the picture: The person without an automobile to use needs public transportation more than the person who has an automobile available. One might expect then that persons who do not have an automobile to use are more committed to the use of public transportation. Moreover, the majority of persons reached in a telephone survey have an automobile for their use. Indeed, 89 percent of those surveyed in this study indicated

Table 1. Initial noncommitment response rates (raw data).

Transportation Service	Would Use				Would Not Use			
	Automobile Available	No Automobile Available	Total	Percent	Automobile Available	No Automobile Available	Total	Percent
Dial-a-bus	94	14	108	42.5	132	14	146	57.5
Fixed-route bus	86	16	102	40.2	140	12	152	59.8
Mobility club	101	8	109	43.0	125	20	145	57.0

that they had an automobile available to use for the last trip they made. Thus, the bulk of the overestimation of demand, which results from the direct use of noncommitment raw data responses, derives from the automobile-available respondents. Therefore, the no-automobile-available and automobile-available respondents were analyzed separately. The distortion that is introduced by noncommitment is indicated by Table 1. Certainly, an expectation that over 40 percent of the population would use public transportation is unreasonable.

By asking each respondent to answer all questions with regard to one specific trip that he or she actually made, the questionnaire was designed to bring the respondent from some vague idea of general transit use to a more realistic conception of actual travel restrictions that might be encountered in using public transportation. We assumed that such a real-world frame of reference would reduce noncommitment bias, particularly among those who need public transportation. In particular, since persons without automobiles are much more apt to use public transportation, we assumed that noncommitment bias among the no-automobile-available respondents was eliminated by the design of the questionnaire. This assumption was supported by the raw data. Of the entire sample of 254 respondents, 28 did not have automobiles available for their trips. Of these, only 12 indicated that they would have used a dial-a-bus at a $0.50 fare; 8 said they would have paid $0.75; 5 said they would have used it at a $1.00 fare; only 3 indicated that they would have paid $1.50. From an empirical standpoint, these numbers appear realistic.

A certain element of demand was expected to be generated by persons who have an automobile available. However, these respondents should generate only a fraction of the total demand. But, the number of automobile-available respondents who indicated in the survey that they would have used public transportation for their trips was more than five times that of the no-automobile-available group. This apparent paradox is due to the high degree of noncommitment among the automobile-available respondents. In order to obtain more accurate estimates of demand within this group, a noncommitment adjustment procedure was developed. The technique was based on the procedure developed by Hartgen and Keck (4). But, rather than using a presupposed trip rate to forecast demand, we assumed that, at a prescribed fare and service, availability level, the automobile-available group would generate a specific share of the total demand.

NONCOMMITMENT ADJUSTMENT METHODOLOGY

Data from the recent on-board survey conducted on the Oneonta dial-a-bus system (10) were used to determine that the average fare for the system is about $0.40 and the required advance reservation time is about 0.5 h. At this fare and service-availability level, 85 percent of the ridership had no other means of transportation. Therefore, about 15 percent of the demand is generated by persons who have an automobile available for their use. We therefore assumed that, at this same fare and advance reservation level, 15 percent of the total demand for a dial-a-bus outside the city of Oneonta would come from individuals who have an automobile available for their use.

The dial-a-bus noncommitment responses of the automobile-available group (weighted by age and gender category) were then expanded to the entire population over age 16 who live outside the city of Oneonta and were cross-tabulated by fare level and call-in-advance level. We determined that at a $0.40 fare and a 0.5-h call in advance, 2722 daily one-way trips would be generated by the automobile-available noncommitment responses. Similarly, we determined that at this same fare and service level, 440 daily one-way trips would be generated by the no-automobile-available responses.

The assumptions that the 440 trips generated by the no-automobile group are committed trips, and that this number is 85 percent of the total number of daily one-way trips, led to the estimate that about 518 daily one-way trips would be made on a dial-a-bus that operates outside the city of Oneonta at a $0.40 fare level and 0.5-h advance reservation. This meant that the noncommitment response for the automobile-available group was 34.897 times what it should be [$34.897 = 2722/(518-440)$]. Therefore, the noncommitment adjustment factor for the automobile-available group is 0.0287 ($0.0287 \approx 1/34.897$). We assumed that the same degree of noncommitment applied at each fare and service level. This assumption is based on the premise that a respondent's answers to questions about increasing fare levels and service restrictions merely help to quantify preference for or against the service, but commitment to use the service remains constant through the levels of fares and service that he or she finds acceptable.

Therefore, in order to estimate the demand for dial-a-bus service under a particular set of service restrictions, the total number of trips generated by the expanded and weighted responses of the no-automobile-available group were summed with 2.87 percent of the total number of trips generated by the expanded, weighted, noncommitment responses of the automobile-available group.

Moreover, because both a mobility club and a fixed-route bus serve the same function as a dial-a-bus (they differ mainly in the level of service), and since each of the persons surveyed was questioned about each transportation option, we also assumed that the same degree of noncommitment applied to the fixed-route and mobility-club options. Thus, the estimate of demand for an option at a particular fare and service level was determined in exactly the same way as that for a dial-a-bus; 0.0287 was used as the adjustment factor for the automobile-available response group.

RESULTS

Dial-a-Bus

The specific factors that limit dial-a-bus service that

Table 2. Dial-a-bus demand estimates.

Fare ($)	Automobile Availability	No Flexibility	0.5-h Flexibility	1-h Flexibility	2-h Flexibility
<0.50	No	436	406	236	178
	Yes	53	50	31	15
	Total	489	456	267	193
0.50	No	436	406	236	178
	Yes	52	49	30	14
	Total	488	455	266	192
0.75	No	298	268	148	148
	Yes	42	39	24	10
	Total	340	307	172	158
1.00	No	202	172	148	148
	Yes	34	32	21	9
	Total	236	204	169	157
1.50	No	124	124	124	124
	Yes	21	18	12	7
	Total	145	142	136	131

Table 3. Mobility-club demand estimates.

Fare ($)	Automobile Availability	No Flexibility	0.5-h Flexibility	1-h Flexibility	2-h Flexibility
<0.50	No	250	232	134	102
	Yes	57	54	33	16
	Total	307	286	167	118
0.50	No	250	232	134	102
	Yes	56	52	32	15
	Total	306	284	166	117
0.75	No	170	152	84	84
	Yes	45	42	26	11
	Total	215	194	110	95
1.00	No	116	98	84	84
	Yes	37	34	22	10
	Total	153	132	106	94
1.50	No	70	70	70	70
	Yes	22	19	13	8
	Total	92	89	83	78

were considered are (a) fare level, (b) required call in advance for reservation, and (c) flex-time. The flex-time factor is an innovative concept that requires the potential user to be flexible in his or her desired pickup time to the extent that he or she would still use the dial-a-bus service if notified in advance by a dispatcher (presumably soon after making a reservation and specifying a pickup time) that the dial-a-bus might make a pickup as much as 0.5-2 earlier than planned. This added flexibility on the part of the user would make scheduling pickups easier and could aid in increasing vehicle occupancy, thereby requiring fewer vehicles to meet the demand. This would help in the practical implementation of such service. Naturally, as the respondents were asked to be more flexible (increase flex-time from 0.5-2 h) the demand was seen to decrease, yet many respondents appeared to feel comfortable with a 0.5-h flex-time requirement. Demand decreased noticeably from the 0.5-h flex-time requirement to the 1-h flex-time requirement, particularly at the low fare levels. Table 2 gives the demand estimates for the dial-a-bus option for various fare and flex-time levels under the specific limitation of a one-day call in advance for a trip reservation. We thought that this advance reservation time was reasonable from the standpoint of the practical implementation of a demand-responsive service, and in fact it was reasonably well received by the survey respondents. Such tables exist for other call-in-advance levels but will not be presented here.

Mobility Club

The mobility club is a grass-roots approach to rural transportation that has many of the same service characteristics as a dial-a-bus (e.g., door-to-door service) except that the mode of travel is usually a privately owned passenger automobile (9). Thus, potential users would be expected to call to make a reservation, specify a pickup time, and pay for the service. We, therefore, assumed that the relative changes in demand that result from decreases in levels of service for a mobility club would be the same as that for a dial-a-bus service. Survey respondents were, therefore, not asked questions about their perceived use of a mobility club under various fare, flex-time, and advance reservation requirements. Rather, the estimates of demand for dial-a-bus service were adjusted to reflect the different composition (on the basis of automobile availability) of respondents who initially indicated that they would have used a mobility club. Table 1 indicates that the mobility club option was 1.07 times as popular as the dial-a-bus option among the automobile-available respondents ($1.07 \approx 101/94$) but only 0.57 times as popular among the no-automobile-available respondents ($0.57 \approx 8/14$); therefore, each dial-a-bus estimate for the automobile-available group was multiplied by 1.07 to obtain the corresponding estimate of mobility-club demand, and each dial-a-bus estimate for the no-automobile-available group was multiplied by 0.57 to obtain the corresponding estimate of mobility-club demand. Table 3 gives the resulting demand estimates for a mobility club at various fare and flex-time levels under the specific limitation on potential users of a one-day call in advance for a trip reservation. Tables 2 and 3 indicate that the dial-a-bus option would reach more persons who need transportation—i.e., those who do not have an automobile to use.

Table 4. Fixed-route bus demand estimates.

Fare ($)	Automobile Availability	Walk 1 Block to Bus Stop	Walk 0.40 km to Bus Stop	Walk 0.80 km to Bus Stop
<0.50	No	124	68	68
	Yes	28	25	17
	Total	152	93	85
0.50	No	124	68	68
	Yes	28	25	17
	Total	152	93	85
0.75	No	124	68	68
	Yes	27	24	16
	Total	151	92	84
1.00	No	94	68	68
	Yes	23	21	13
	Total	117	89	81
1.50	No	92	68	68
	Yes	15	13	9
	Total	107	81	77

Note: 1 km = 0.62 mile.

Fixed-Route Bus

From the standpoint of practical implementation, the fixed-route bus option is the least likely to provide adequate service at a reasonable cost to residents of a sparsely populated area. This option was considered primarily so that later analysis might be done to see if such service could be made available along specific routes. The specific factors that limit fixed-route service that were considered are (a) fare level (b) distance to bus stop, and (c) bus headway. After reasonable service limitations were proposed, the fixed-route bus option proved to be the least popular option. Table 4 indicates the estimates of demand under the specific constraint of 4-h bus headways.

NO-PHONE RESPONSES

The implementation of some form of demand-responsive system appears to be the most realistic approach for a rural transportation service to reach the most people. This paper has considered two: dial-a-bus and mobility club; however, these systems require that the user telephone a request for service. Thus, an investigation of the needs of persons who do not have telephones is of interest. The fundamental question is, Do these perople need public transportation more than persons who have telephones? That is, are they more apt to be unable to use automobiles? If so, such demand-responsive systems will not be readily available to the people in greatest need of them.

Three important observations were made from the analysis of the responses of the 30 persons who were interviewed in person. Only five indicated no household automobile, but three of these did have an automobile available for their own use; only three persons that had a household automobile did not have an automobile available to use. In total, 83 percent of the no-phone respondents did have an automobile to use (this compares with 89 percent for the entire sample). Moreover, only two of the no-automobile-available persons who did not have a telephone indicated that they would use dial-a-bus; neither would pay more than a $0.50 fare and only one responded to the 0.5-h flex-time requirement. Thus, the need among people without a telephone does not appear to be appreciably greater than that of persons who have a household telephone.

SUMMARY AND CONCLUSIONS

This paper presents a procedure for assessing the simultaneous effects of fare and service levels on potential demand for proposed rural transportation systems—dial-a-bus, fixed-route bus, and mobility club. The method is based on a survey that uses a questionnaire designed to reduce noncommitment bias. This is done by asking respondents to answer all questions in a yes or no format with reference to an actual trip previously made.

Respondents to our survey were classified on the basis of automobile availability. It was empirically determined that noncommitment bias among the no-automobile-available respondents was eliminated by the questionnaire design. However, adjustment for noncommitment bias was necessary for the automobile-available group. The noncommitment adjustment methodology was based on an assumed share of the total ridership that should realistically be expected to be generated at a specific real fare and service level by persons who have an automobile. The results showed that the highest demand would be for a dial-a-bus service, regardless of the fare or service level.

The survey also included a subsample of 30 households that do not have telephones, which were selected by a snowball method. It was found that, based on automobile availability, this group of households did not have a greater need for public transportation than those households that have telephones. However, the method of selecting these housholds may have introduced bias in the subsample. Therefore, further research into the relation between automobile availability and telephone availability is needed in order to more fully understand the transportation needs of persons in rural areas who do not have telephones.

Estimates of demand based on surveys are often high estimates due to noncommitment bias. In the research reported here a reasonably easy adjustment for this bias was made. But, the resulting estimates were based on the assumption that the levels and types of services described can actually be implemented. Actual use of a public transportation service may fall short of these estimates if the promised level of service is not provided.

The concept of flex-time was introduced in the study as a method to serve the public more realistically and in the hope that its implementation could increase vehicle productivity. The idea was well received by the survey respondents. Research is currently being conducted to determine how well demand-responsive systems might actually perform under the various flex-time and service levels described in the questionnaire. The objective is to determine ways to serve the estimated potential demand with a reasonable number of vehicles at a realistic cost level.

ACKNOWLEDGMENT

We express our heartfelt appreciation to David L. Weiss for his assistance in developing the survey question form and the sampling scheme and for his constant interest in the project. Special thanks are due to William Grab of the Otsego County Planning Board for his help in carrying out the survey and to the more than 25 county volunteers who did the actual telephoning. Very special thanks go to Wilma Marhafer for her patient and expert typing and, particularly, for organizing the tables. Any errors in fact or opinion are solely our responsibility.

REFERENCES

1. D. L. Weiss. Citizen Opinions on Public Transportation Roles, Service, and Financing. TRB, Transportation Research Record 590, 1976, pp. 5-8.
2. Methods for Measuring Rural Public Transportation Needs and Demand. Technical Council Committee 6F-10, Institute of Traffic Engineers, Transportation Engineering, May 1978, pp. 39-46.
3. J. E. Burkhardt and A. M. Lago; Ecosometrics Inc. Methods of Predicting Rural Transit Demand. Pennsylvania Department of Transportation, Harrisburg, 1976.
4. D. T. Hartgen and C. A. Keck. Forecasting Dial-A-Bus Ridership in Small Urban Areas. TRB, Transportation Research Record 563, 1976, pp. 53-62.
5. R. G. Knighton. Forecasting Fare-Sensitive Dial-A-Bus Demand Without Surveys. Planning Research Unit, New York State Department of Transportation, Albany, July 1976.
6. P. S. Liou. A Technical Review of a Ridership Forecasting Method: Dial-A-Bus in Small Urban Areas. Planning Research Unit, New York State Department of Transportation, Albany, Prelim. Res. Rept. 73, Feb. 1975.
7. E. S. Neumann and B. F. Byrne. A Poisson Model of Rural Transit Ridership. TRB, Transportation Research Record 661, 1978, pp. 21-27.
8. W. R. Ugolik and R. G. Knighton. Estimating the Effects of Alternate Service Levels on Rural Transit Ridership. Planning Research Unit, New York State Department of Transportation, Albany, Prelim. Res. Rept. 144, Aug. 1978.
9. R. Yukubousky and D. Fichter. Mobility Club: A Grass-Roots Small-Town Transport Concept. TRB, Transportation Research Record 559, 1976, pp. 89-100.
10. A. Pollock. City of Oneonta Dial-A-Bus On-Board Survey. Development Division, New York State Department of Transportation, Albany, Aug. 1978.

Publication of this paper sponsored by Committee on Rural Public Transportation.

Abridgment

Analysis of Volunteer Driver Systems in Rural Public Transportation

Robert L. Smith, Jr., Department of Civil and Environmental Engineering, University of Wisconsin, Madison

Rural public transportation systems that rely on volunteer drivers who use their own automobiles have been proposed and analyzed theoretically by transportation planners (1-3). Yukubousky and Fichter developed the concept of a volunteer driver system called the mobility club (1). More recently Weaver and Lundberg proposed a friends-and-neighbors rural transportation system supplemented by a conventional van service in North Dakota (2) as a demonstration project under Section 147 of the Federal-Aid Highway Act of 1973. A volunteer driver system has also been developed for the Chester County, Pennsylvania, Section 147 demonstration project (3). Human service agencies have already gained considerable experience in operating volunteer driver systems. Recent inventories of specialized transportation providers in Wisconsin and Texas showed that a significant proportion of the total service was being provided by volunteer driver systems (4, 5). The purpose of this study is to evaluate the potential for continuing, and even expanding, volunteer driver systems in rural areas. Case studies of volunteer driver systems in two Wisconsin counties are used to test the hypothesis that volunteer driver systems can be a cost-effective, feasible means of providing high-quality, specialized transportation service in rural areas. In addition, the role of volunteer driver systems in relation to paid driver systems that use vans or buses is examined in terms of an optimum mix of service types. Finally, the implications for public policy in the implementation of the rural public transportation operating assistance program (Section 18 of the Surface Transportation Assistance Act of 1978) are examined.

GROWTH OF VOLUNTEER DRIVER SYSTEMS

The growth of social welfare programs designed to meet the needs of low-income and handicapped people in recent years has made human resource personnel more aware that programs to provide medical care, nutrition, and other basic human services require transportation to bring the people to the services. Thus, human resource agencies have taken a leading role in the development of transportation systems in rural areas. Volunteer driver programs in which the volunteers use their own vehicles and usually are reimbursed for the expense of operating their vehicles [generally about 9.3-13.6 cents/km (15-22 cents/mile)] provide a low-cost means for human service agencies to meet the transportation needs of their clients.

A volunteer driver system has many advantages. The capital, maintenance, and operating costs of a van or bus system are avoided. Often the existing staff has had experience with volunteer programs so that additional personnel are not required, at least initially. Part-time, paraprofessional staff can be added incrementally as the number of volunteer drivers increases. Sometimes volunteers can also be recruited to aid in scheduling trips. Funds for reimbursement for the distance driven have been available from a variety of sources, including Titles XIX and XX of the Social Security Act of 1935, as amended; local support; and, in Wisconsin and other states, seed-money grants under Title III of the Older Americans Act of 1965, as amended.

Table 1. Service measures for volunteer driver and van systems.

	Volunteer Driver		Van Systems	
Service Measures	Dane County	Grant County	Dane County[a]	Grant County
Persons eligible for service (age 65+)	7746	6130	4351	7746
Trips per month	1310	230	1890	1450
Annual trips per capita	1.2-2.8	0.038	5.2	2.2
Vehicle kilometers per month	15 680	11 520	3700	6080
Number of drivers	158	90	-	-
Vehicle kilometers per trip	12.0	21.3 82.6[b]	2.0	4.2
Trips per vehicle hour	1.4	-	5.0	4.4
Cost per trip—travel cost ($)	1.11	2.08 7.68[b]	1.68	1.11
Total trip cost—including administrative costs ($)	1.72	4.24 9.84[b]	1.81	1.20

Note: 1 km = 0.62 mile.

[a] Rural area only.

[b] Trips to destinations outside of Grant County.

In many rural areas the growth of volunteer driver systems has been restrained by the lack of a continuing source of operating assistance; however, volunteer driver systems are not affected by abrupt changes in funding as much as are van or bus systems that have paid drivers. Also, the volunteer systems can be more easily funded from a variety of sources because of the ease of allocating and recording the funds spent.

Potential problems faced by volunteer driver systems include recruitment and retention of volunteers, reliability, safety, and insurance. In order to maintain an adequate roster of volunteer drivers, the professional staff must devote a substantial amount of time to the recruitment, training, and retention of volunteers. The turnover rate among volunteers often is high; however, the rate can be reduced by a regular program of public recognition of the volunteers' contributions.

The reliability of services provided by volunteers was not found to be a problem in the two Wisconsin systems that were studied in depth. As long as volunteers are only called on to provide the amount and kind of transportation service they agreed to initially, a high level of performance can be expected. A screening process should be used to select volunteers who will be safe, competent drivers. In addition, the users of the system quickly recognize the less-than-competent drivers and refuse to ride with them. If the volunteer driver system is part of a larger volunteer program, the less-competent drivers can be shifted to some other area of the program.

Insurance has been a continuing problem because the lack of claims experience for volunteer driver programs represents an unknown risk. Insurance companies, in some cases, react by canceling the insurance policy or raising the rates. Excess personal liability coverage purchased by the agency responsible for the volunteer program to cover the volunteer has been difficult or even impossible to obtain. The Wisconsin Commissioner of Insurance has advised counties that have volunteer driver programs that the primary question that affects insurance rates is "whether the volunteer driver is 'driving for profit'. In that circumstance, the driver would be considered as operating a 'livery' and would not be covered under his or her private passenger automobile policy" (6). The commissioner recommended paying only the actual expenses of these drivers based on a set rate per kilometer driven by the volunteer. Furthermore, in Wisconsin insurance rates for volunteer drivers should not change solely because the person is a volunteer driver.

EXAMPLES OF VOLUNTEER DRIVER SYSTEMS

In order to provide insight into the role that volunteer driver systems can play in providing specialized transportation service in rural areas, systems in two Wisconsin counties are analyzed and compared with van or small-bus systems. The Dane County system is one of the few systems in Wisconsin that is operated under the Retired Senior Volunteer Program (RSVP) of ACTION, the federal domestic volunteer program. The RSVP program is administered by a full-time coordinator, who spends most of her time in recruiting and volunteer recognition activities. Medical trips receive first priority, but about 40 percent of the trips are for nonmedical purposes, such as shopping, eating at the nutrition program meal site, and personal business. In contrast, the Grant County system is administered by the county department of social services. A social worker spends about 50 percent of his or her time on program support. Nearly all of the trips are for medical purposes. Many of the trips are to medical facilities in Madison, which is more than 125 km (80 miles) away.

Service measures for the two volunteer driver systems are presented in Table 1. Both systems generate a large number of vehicle kilometers of travel each month. Because of the long average trip lengths of the Grant County system, the number of trips served in Grant County is much smaller than in Dane County. The differences in average trip costs for the two systems also reflect the differences in average trip lengths. The total cost per trip for a volunteer driver system includes the cost of administrative and volunteer support services. As shown in Table 1, the overhead costs increase the cost of a volunteer driver trip substantially. The increase is particularly high in Grant County because so few trips are provided.

VAN AND BUS SYSTEMS IN DANE AND GRANT COUNTIES

In contrast to the highly individualized, direct door-to-door service provided by volunteer drivers, van or small-bus systems provide group service. Individuals are still picked up at their homes, but, in general, several other individuals are also picked up on the same trip and taken to the same destination, typically the nearest Title VII nutrition program meal site. In rural Dane County almost 60 percent of the trips are nutrition program trips, 30 percent are shopping trips, and 8 percent are social or recreation trips. Only 2 percent are medical trips. In Grant County the trip purpose distribution is even more heavily oriented to the Title VII nutrition program.

The grouping of passengers makes more efficient use of the driver's time. Since the driver's wages are the major expense in operating a van or small-bus system, grouping of trips reduces the cost per trip substantially. A simple model for computing the total cost per trip for van or bus systems (including capital costs) is

$$\text{total cost per trip} = [(\text{driver wage per hour} + \text{vehicle operating cost per hour}) \div \text{trips per hour}] + \text{administrative cost/total trips} \quad (1)$$

in which all nonadministrative costs associated with vehicle operation are included in the hourly vehicle operating cost. A more complex cost model for rural transportation systems has been developed by Ceglowski (7), but the simplified model is adequate for comparison with the costs of volunteer driver systems.

For the Dane County van system, the parameters for the cost model are (a) hourly wage of $4.80, (b) vehicle operating cost of $3.60/h ($0.22/km × 16 km/h), and (c) administrative costs of $1000/month. If these parameters are assumed to be fixed in the short run, then the total cost per trip becomes a function of the productivity of the system (trips per vehicle hour) and the total number of trips served. Based on a productivity of 5.0 and 7650 trips/month (urban and rural), the total cost per trip in Dane County is $1.81 (see Table 1). The total cost per trip in Grant County is even lower because the hourly wage is about $3.00. Administrative costs are low because the drivers schedule passengers, handle vehicle maintenance, and submit monthly reports on system use.

The costs per trip for the Dane and Grant County systems are substantially lower than the costs reported for low-density systems operated as part of the Section 147 demonstration program (8). Average total costs per trip for two groups of low-density systems ranged from $3.13 to $4.19. Much higher costs can be expected if groups of passengers are transported to the same service in a relatively high-wage area, as shown by costs of $7.62/trip in Barnstable County, Massachusetts (9), and $6.53/trip in Washtenaw County, Michigan (10).

VOLUNTEER DRIVER VERSUS VAN SYSTEMS

The services provided by the volunteer driver and the van or small-bus systems are complementary. A van system cannot provide the high-quality door-to-door service appropriate for medical trips at the same low cost as does the volunteer driver system. In some cases the elderly need assistance throughout their stay at their destination. The cost of using paid drivers to provide such assistance would be prohibitive. A volunteer driver system, however, cannot provide the high volume of trips that can be served efficiently by a van service, which emphasizes group rides. The supply of volunteer drivers is limited. Thus, only the highest-priority trips can, in general, be served by the volunteers. The supply of volunteers can be increased somewhat by a vigorous recruitment and volunteer recognition program, as is the case in Dane County; however, a point of diminishing returns is probably reached very quickly.

A direct comparison of the costs per trip for the volunteer driver versus the van systems (as shown in Table 1 for Dane and Grant Counties) is misleading. The relevant cost comparison is the cost of providing the volunteer driver trips versus the cost of providing a van system. By using Equation 1, the cost for Dane County, assuming a vehicle productivity of 2.0 trips/h, an operating cost of $8.40/h, and a 10 percent overhead rate, would be $4.62/trip. This is over 2½ times the current volunteer driver system cost.

The main impediments to the development of a mix of volunteer driver and van transportation systems in other rural areas are the lack of stable funding and, in some states, possible insurance problems. In Wisconsin the funding problem is less acute because a modest level of operating assistance is now available through grants by the state of Wisconsin to counties for elderly and handicapped transportation. Thus, in Wisconsin the experience of Dane County should be readily transferable to other counties. In fact, initial analysis of the county programs submitted for funding under the state's Elderly and Handicapped Transportation Assistance Program (Wisconsin Statute 85.08, Section 5) shows that a number of counties already have both volunteer driver and van systems in operation.

IMPLICATIONS FOR FEDERAL OPERATING ASSISTANCE

As demonstrated by the case studies of the systems in Dane and Grant Counties, substantial benefits can be obtained from volunteer driver systems. Benefits are obtained not only from the lower costs per trip but also from the increased social interaction of both the tripmakers and the drivers. Thus, federal operating assistance under Section 18 of the Surface Transportation Assistance Act of 1978 should be made available for volunteer driver systems. In general, a van or small-bus system would provide the basic service, but the volunteer driver system would meet the specialized needs of the elderly, handicapped, and others for medical and other high-priority trips. Maximum flexibility should be given to local and regional agencies in deciding what mix of specialized transportation services is most appropriate for each local situation.

CONCLUSIONS

The two case studies of volunteer driver systems show that volunteer driver systems can provide high-quality, cost-effective transportation for the elderly in rural areas. Volunteer driver systems can provide lower costs per trip than all but the most productive van systems. Only a high-cost, taxi-like van system can approach the high-quality, door-through-door service of the volunteer driver system. Even then the volunteer driver system provides superior service because of the potential for personal assistance to passengers at their destination.

The feasibility of volunteer driver programs has been demonstrated over an extended period of time (six years in Grant County and three years in Dane County). With professional direction, potential problems of volunteer recruitment and retention, volunteer reliability, and driver safety can be minimized. Insurance may be a problem in some states, but in Wisconsin the insurance commissioner has stated that volunteer drivers should not have their rates increased or insurance canceled solely because of their volunteer driver status.

Volunteer driver systems should not be expected to provide for all of the public transportation needs in rural areas, but volunteer systems can provide high-priority trips (such as medical trips) at a high degree of efficiency. Van systems should be used for trip purposes for which extensive grouping of rides is possible.

Research is needed on how volunteer driver systems can best be integrated into a total rural public transportation system. For example, the potential for a volunteer driver system to serve as a feeder system for a regular fixed-route system needs to be examined.

ACKNOWLEDGMENT

The information and background material required for this study were provided through the cooperation of a number of people. Special thanks are extended to Christine Beatty of the Dane County RSVP Driver Escort Program; John Pfotenhauer and Charles Hurlbut of Independent Living, Inc.; Colleen Barnett of the Grant County Department of Social Services, and Richard Audetat of the Grant County Commission on Aging. The views expressed in this paper are mine, and I am responsible for the facts and accuracy of the data presented.

REFERENCES

1. R. Yukubousky and D. Fichter. Mobility Club: A Grass-Roots Rural and Small Town Transport Concept. New York State Department of Transportation, Albany, Prelim. Res. Rept. 69, Aug. 1974.
2. V. C. Weaver and B. D. Lundberg. Rural Public Transportation: North Dakota Case Study. TRB, Transportation Research Record 638, 1977, pp. 44-46.
3. D. J. McKelvey and R. S. Watt. Innovative Approaches to Rural Transportation. TRB, Transportation Research Record 661, 1978, pp. 1-6.
4. Transportation for the Elderly and Handicapped in Wisconsin: Report 1—Analysis of Specialized Transportation Services. Division of Planning, Wisconsin Department of Transportation, Madison, July 1976.
5. R. Briggs. Characteristics of Local Passenger Transportation Providers in Texas. Department of Community Affairs, University of Texas, Res. Rept. 45, Austin, Jan. 1977.
6. Memo from the Wisconsin Commissioner of Insurance to All Counties with Volunteer Driver Programs. Madison, March 14, 1978.
7. K. P. Ceglowski, A. M. Lago, and J. E. Burkhardt. Rural Transportation Costs. TRB, Transportation Research Record 661, 1978, pp. 7-14.
8. First Quarter 1978 Evaluation Data. Rural Highway Public Transportation Demonstration Program, Federal Highway Administration, Aug. 1978.
9. R. P. Warren and J. Collura. Second Progress Report on Barnstable County Rural Public Transportation Demonstration Program. Barnstable County Public Transportation Program, Barnstable, MA, Feb. 1978.
10. R. Perez and K. Guenther. Six Month Report on AATA Out-County Dial-A-Ride Service. Ann Arbor Transportation Authority Board, Ann Arbor, MI, Memo, Feb. 25, 1977.

Publication of this paper sponsored by Committee on Rural Public Transportation.

Abridgment

Forecasting Experiments for Rural Transit Policymakers

Yorgos J. Stephanedes, Department of Civil and Mineral Engineering,
University of Minnesota, Minneapolis
Thomas J. Adler, Thayer School of Engineering, Dartmouth College,
Hanover, New Hampshire

Four major groups are involved in the development of transit service in an area: (a) users, (b) management, (c) planning and funding agencies, and (d) the community. This paper addresses problems faced by transit managers and funding agencies. Such problems have been identified through the interaction of state and federal officials and during a review of rural transit systems in northern New England performed during the first part of 1978 (1). The authorization of more than $24 million for FY 1976 by Section 147 of the Federal-Aid Highway Act of 1973 and $420 million by Section 303e and Section 313a of the Federal Public Transportation Act of 1978 for FYs 1979-1982, will encourage the growth (in size and number) of rural transit systems. With this growth, the number of problems will increase.

Some of the first problems that transit managers face are in the initial application for funding and making plans based on socioeconomic and demographic characteristics of the service area. During the same period, federal subsidies for rural transit projects may be allocated to applicants based on the relative merit of alternative proposals. The benefit/cost standards that a local community applies to the expenditure of federal or state subsidies can be somewhat different from those used for local subsidies; since the former are considered to be marginally free, the accrual of any form of benefit is a net gain to the community. In most cases this means that the effectiveness of the expenditures of federal subsidies depends heavily on an operator's internal evaluation of his or her service or on the external evaluation of the allocating agency.

These problems are further complicated by the urgency with which funding agencies expect to see results in order to decide about funding continuation and budget approval. Because of this urgency, state and federal officials often use single average values to describe system performance in order to make decisions about the long-term feasibility of rural transit operations. Such values are then compared against each other at the national level and decisions made about whether a system's performance is acceptable or not. The danger of such decision making is illustrated by Figure 1. During its 19th month of operation the transit system in Bennington, Vermont, exhibits acceptable behavior. The same system if reviewed at the end of the 7th month would seem unacceptable. The figure shows that about 19 months were needed for the Bennington system to reach equilibrium behavior (i.e., a range of performance values that do not change appreciably with time). The magnitude of this overall system delay depends on four individual delays, each of which is from 4 months to one year long (2). These delays have been identified during our work on case studies of rural transit systems in northern New England:

1. Vehicle acquisition delay,
2. Schedule change delay,
3. Subsidy award delay, and
4. Ridership information delay.

GENERAL RESEARCH APPROACH

This research consisted of three sequential sets of activities. The first was an evaluation of the rural transit systems in northern New England (primarily New Hampshire and Vermont). The evaluation and comparisons served as a base of information from which the more generalized analyses proceeded.

In the second part, the effects of characteristics of (a) the service area, (b) management policies, and (c) funding policies on different measures of productivity and efficiency were tested. One of the findings was that an overall delay of at least one year occurs before the system exhibits steady-state behavior. For example, this delay was about 19 months for the Bennington system, as evidenced by the behavior of its ridership over time. Another finding was the existence of a seasonal variation in system performance, which was particularly evident from the moving average of a performance measure (e.g., the 4-month moving average of the Bennington load factor, which exhibits a seasonal variation during a period of 6 months) (see Figure 2).

Figure 1. Bus ridership in Bennington, Vermont.

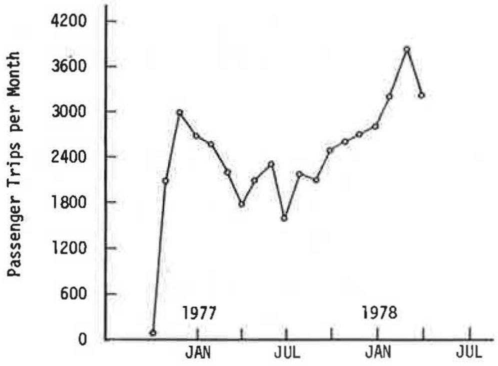
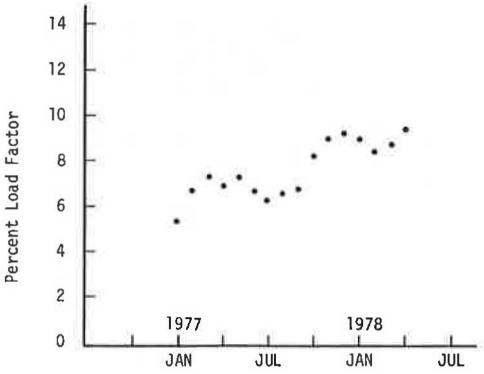


Figure 2. Bennington load factor (four-month moving average).



The third part of the analysis was a detailed study, by use of a computer simulation, of the effects of different policies or environmental changes (e.g., energy shortages) on rural transit productivity and efficiency (both in the short and long term). Examples of the types of policies that were tested are (a) different federal or local subsidy policies, (b) fuel price increases, and (c) different operating and design strategies (e.g., fleet size, vehicle utilization, and service area). The set of nonlinear differential equations developed to simulate the rural transportation system across time incorporates (a) logit travel demand models (3, 4) previously shown to be transferable to areas of differing characteristics, modified and calibrated in rural Goffstown, New Hampshire, and (b) supply and resource functions developed empirically in rural northern New England. More information on the model structure and a comparison with other existing models can be found in Stephanedes (5) and in other forthcoming papers.

EXPERIMENTS THAT USE THE RURAL TRANSIT MODEL

The results of simulation experiments reflect the implications of structural assumptions used in formulating the model. [Area and service characteristics that were input to the model are detailed in Stephanedes (2).] For example, this particular model assumes that managers and funding agencies behave in a particular manner in response to changes in ridership. In most cases, these representations should be different, depending on the specific transit system being analyzed. The same basic structure, as represented by the existence of certain delays (e.g., in vehicle acquisition) and of interrelationships (e.g., between ridership changes and service levels), should, however, apply to all rural transit systems. Thus, the results of experiments described here should be interpreted as having numerical values that apply to the specific prototype system, whose managers and funding agencies behave as assumed, but the direction of changes applies more generally to other rural transit systems.

Should High-Quality Service Be Offered Early in System Life?

An example was used of headways that were assigned a lower upper limit (30 min; base value = 1 h), and lower initial headways (24 min; base value = 30 min). These decisions were combined with an aggressive managerial policy that had a low desirable load factor (0.3; base value = 0.5). Even though load factors remained slightly below full capacity, headways became half of the base value, passenger trips tripled, and noncapital net cost per kilometer decreased by 30 percent [from about $0.54 ($0.75/mile)] within a five-year period. The choice of service quality to be offered remains to be made by the transit manager, who could be aided in this task by the use of a simulation approach.

Should Capital or Operating Subsidies Be Reduced?

When capital subsidies are reduced to 50 percent of what is applied for and initial capital equipment are doubled, service quality declines slowly, as does ridership (by 60 percent) and noncapital net cost (by 35 percent). The prototypical system in our example went into the zone of unacceptable service (headways above 1 h) after seven years of operation. Given that service quality and ridership start to decline only toward the end of the fourth year, this policy may be tried in combination with incentives to increase the local share of transportation costs while the transit system still enjoys a good reputation with the community.

Reduction of operating subsidies causes service quality to quickly deteriorate. Within two years headways fall (from about 25 min) to the lowest acceptable level, ridership decreases by 90 percent (from about 320 passengers/week), and costs more than double. Similar results were obtained by doubling initial capital and by varying subsidy decreases between 20 and 50 percent.

If Operating Subsidies Are Reduced, Should New Systems Be Preferred?

After the transit system had been in operation one to two years, operating subsidies were reduced by 20-50 percent. Results did not differ appreciably from the case where operating subsidies started at a reduced level. Unless old systems have picked up the necessary local funding support, they are as likely to suffer at reduced subsidy levels as are new systems.

How Much Should Be Spent for Advertising and How Much for Streamlining the Transit Funding and Schedule Change Process?

Rider information delays are particularly high for rural systems. Because of low demand, capital acquisition delays are also appreciably higher than should be expected. Because the rural transportation programs are new, a large amount of paperwork is necessary during the funding application process. The same holds for procedures to approve schedule changes, especially when they are in conflict with interests of established interstate carriers. The question that arises is, What will be gained if these delays are reduced?

When information delay alone was reduced by 50 percent, the behavior of the system did not change appreciably, except for the total net cost at the end of five years, which was reduced by 5 percent. When all other delays were reduced by 50 percent, noncapital net cost increased by 100 percent and buses ran 20 percent less full than in the base run—probably a result of excess capacity, because ridership was still slow in responding. Reduced delays by 50 percent across the board, however, increased the noncapital net cost by 50 percent but caused a 60 percent increase in ridership; thus the noncapital net cost per vehicle kilometer was reduced by 15 percent.

What Is the Effect of Fare Increases and Promotional Policies on the System Behavior?

Fare increases have negative effects on ridership, and such effects are smallest when changes are instituted late in the life of a system (i.e., at least after the first six months of operation). Data from the two Section 147 systems in Vermont confirm this observation.

Promotional policies (e.g., free rides) have negligible effects on ridership, unless they last for a long period (i.e., six months). Data from the Stagecoach system in Bethel, Vermont, confirm this observation.

CONCLUSIONS

A simulation technique is used in the analysis of the effects of different policies on the development of a rural transit system. Results from policy experiments agree with the observed behavior of rural transit systems in northern New England. The technique is useful primarily as a quick-turnaround policy-analysis tool. A complete simulation run consumes less than 10 s of central processing unit time on a Honeywell 66/40.

The technique has potential applications for policy analysis at two levels: (a) at the managerial level to provide help in project planning and operation and (b) at the fund allocation level to help in decisions about funding approval, funding allocations, and funding renewal. The inclusion of a large set of policy-relevant variables as endogenous in the rural structure allows for the testing of policies that vary with time, and requires relatively limited initial data input. No intermediate data are necessary.

Four major delays in rural transit are identified. Specific ways of reducing the effects of delays are proposed and applied to experimental cases. The effects such improvements have on transit behavior are not obvious and may vary, depending on the particular way such improvements are instituted.

Further research will identify, through implementation case studies, ways in which transit managers and others can use the model to increase the effectiveness of rural transit programs. Inclusion of more variables as endogenous to the transit structure will make it possible to ask policy questions of a much broader spectrum.

ACKNOWLEDGMENT

This work is partially supported by the U.S. Department of Transportation, Program of University Research.

REFERENCES

1. C. Connell, T. J. Adler, Y. J. Stephanedes, and S. R. Sterns. A Review of Rural Transit Systems in Northern New England. Thayer School of Engineering, Dartmouth College, Hanover, NH, DOT/OS/80006, 1978.
2. Y. Stephanedes. Performance Indicators and Policy Evaluation in Rural Transit. Thayer School of Engineering, Dartmouth College, Hanover, NH, Ph.D. thesis, Nov. 1978.
3. M. Ben-Akiva and T. Atherton. Transferability and Updating of Disaggregate Travel Demand Model. Center for Transportation Studies, Massachusetts Institute of Technology, Cambridge, MA, Rept. 76-2, 1976.
4. T. J. Adler and M. Ben-Akiva. Joint-Choice Model for Frequency, Destination, and Travel Mode for Shopping Trips. TRB, Transportation Research Record 569, 1976, pp. 136-150.
5. Y. Stephanedes. A Feedback Dynamic Model for Transportation Systems. Proc., 2nd International Symposium on Large Engineering Systems (Univ. of Waterloo) Sandford Education Press, 1978.

Publication of this paper sponsored by Committee on Rural Public Transportation.

Abridgment

Maintenance Planning for Small Transit Systems

M.M. Bakr, Division of Engineering Science, University of Wisconsin-Parkside, Kenosha
Henry Glueckstein, Jr., Weyerhaeuser Company, Marshfield, Wisconsin

Vehicle maintenance in most transit systems follows a fixed routine of daily inspection and service, which includes fueling, cleaning, and washing. Bus operators are often required to check various systems on the bus before they leave the storage garage and to report any malfunction or suspicion of problems. Additional inspection and service is also undertaken at various intervals by mechanics, who then correct the problems discovered. As the interval between inspections increases, the inspection covers a greater number of systems and component units (1).

TRANSIT BUS MAINTENANCE FACILITY

A complete maintenance facility for a transit bus consists of a storage garage; a service area for daily fueling, cleaning, and inspection; a periodic inspection area; a bus repair area; and a component unit repair and rebuild facility. The component repair and rebuild facility is often subdivided according to the types of systems (for example, electrical systems are often housed together). Special areas are also devoted to engine and engine components and transmission and brake rebuilding. In addition, a body shop and an interior repair work area are often included in the bus maintenance facility (2).

Transit Bus Maintenance for Small Systems

Large transit systems can justify the costs of a complete maintenance facility, but smaller systems do not have the same advantage. Most small systems, because of the low volume of repairs, acquire segments of the maintenance facility but depend on outside sources to handle the majority of their maintenance work needs. The size of the property (as reflected in the number of buses it operates) dictates the size and shape of the maintenance facility. The smaller the size of the fleet, the smaller and more limited the maintenance facility and the more the system will depend on outside sources for maintenance. This study focuses on the small systems, which are often neglected in discussions of transit maintenance.

Small Transit Systems Under Study

This study, conducted in 1976, focuses attention on two small transit systems in the state of Wisconsin—the Bell Urban System (BUS), which serves the Racine area, and the Sheboygan Transit System, which serves the city of Sheboygan and some of the surrounding communities. The study deals with the current maintenance facilities and procedures, as well as with expected future needs.

A review of available maintenance reporting and planning systems such as the Service, Inventory, and Maintenance System (SIMS) (3) and BUS (4) reveals that such systems could not be supported efficiently in small transit systems.

FEATURES DESIRED IN THE MAINTENANCE PLANNING SYSTEM

Maintenance work, particularly that of a less frequent nature, requires evaluation of the necessary tasks and the proper allocation of these tasks to sources inside and outside the transit maintenance facility. The allocation process should capitalize on the attributes of the available internal and external resources.

Several areas should be looked into in the evaluation of possible outside vendor services. Balancing service time, repair quality, and cost of repair are among the factors to consider when work is contracted to outside vendors.

Adequate communication is necessary between the system and outside vendors. The vendor should be informed of the particular problems on the bus and may also be provided with a short history of previous work completed on the bus. The vendor, in turn, should provide the transit system with the necessary information to update the bus file. When information is uniformly dispensed and received, the transit system can control the maintenance process and associated costs.

Accurate quality-control records can reduce the transit property cost and improve both in-house and vendor maintenance services through auditing and controlling the quality of these services. If records of various maintenance costs and projected expected maintenance requirements are maintained, transit management can evaluate the need for expansion of their maintenance facilities by the addition of a particular service or facility.

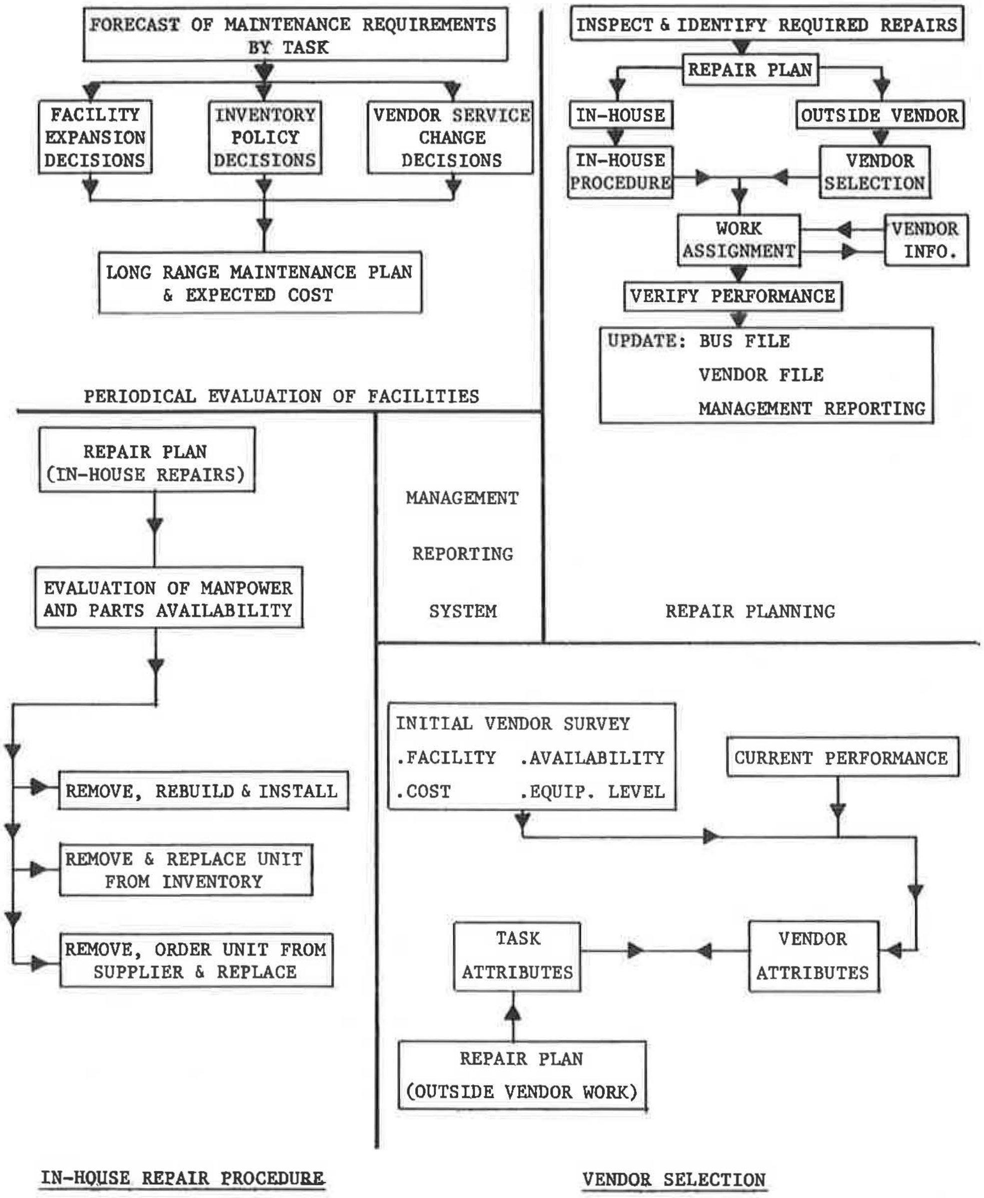
Maintenance cost can be reported in various degrees of detail according to management needs. Costs reported by vehicle are used for replacement decisions; costs of emergency repairs are useful to the evaluation of a preventive maintenance policy. Costs reported by various maintenance activities are helpful in pinpointing productivity and performance quality problems. In addition to the previous reports, small transit management would be interested in the cost of outside services, performance of the vendor, and the cost of spare parts inventory.

Figure 1 shows the main components of the desired system for maintenance planning. The proposed system could be applied in a manual fashion or by the use of a small computer, in which case it may be integrated in the total management information system.

REFERENCES

1. M.M. Bakr and S.L. Kretschmer. Scheduling of Transit Bus Maintenance. Proc., ASCE, Transportation Engineering Journal, Vol. 103, No. TE1, Jan. 1977.

Figure 1. Components of a system for maintenance planning.



2. H.J. Glueckstein. Maintenance Facilities Planning: Milwaukee County Transit System Main Shop Analysis. Mimeograph, May 1976.
3. R.L. Scott. SIMS Implementation Handbook. Urban Mass Transportation Administration, Rept. UMTA-VA-06-0004-75-1, Dec. 1974.
4. D. Robey and M.M. Bakr. Factors Influencing the Adoption of Management Innovations at the CTA. May 1977. NTIS: PB 266 154.

Publication of this paper sponsored by Committee on Maintenance Equipment.

Overview of Accessible Bus Services

Robert Casey, Transportation Systems Center, U.S. Department of Transportation,
Cambridge, Massachusetts

By December 1978, the number of transit authorities that operated fixed-route, wheelchair-accessible bus services totaled five. This paper is intended to disseminate information about these initial efforts. The majority of the operational data and results are from the experience of the St. Louis metropolitan area with accessible bus service, which was operated by the Bi-State Development Agency. Very few persons who use wheelchairs have used the fixed-route accessible bus services to date. Ridership has averaged only a few trips per day. However, the reliability of the services has been poor and some wheelchair boardings have been denied due to unavailability or malfunctioning of lift equipment. Consequently, judgment of the effectiveness of accessible bus services based on this early experience is premature. Accessible bus operations can have a substantial economic impact. In addition to the capital cost of the lift equipment, operating costs have increased due to the heavy lift maintenance and repair workload and, to some extent, to the changes in operational procedures that partial accessibility may necessitate. Due to the low number of riders who are wheelchair users, the overall mobility of this population group would seem to be little changed.

An increasing number of cities, counties, and metropolitan areas are planning fixed-route accessible bus services. The impetus varies, but principal causes have been proposed regulations to implement Section 504 of the Rehabilitation Act of 1973, U.S. Department of Transportation guidelines, local group pressure, or actual or threatened lawsuits. By the end of 1978, five transit authorities had fixed-route accessible bus programs in operation. The amount of data available from these regular fixed-route accessible bus services is limited. Some information is available from San Diego, San Mateo, Santa Clara, and Detroit, but the majority of the operational and user data presented in this paper are drawn from the St. Louis experience. Six more transit authorities are ready to initiate accessible bus services as soon as problems with the buses, the lifts, or legal issues are overcome.

The principal target population for accessible bus service is the wheelchair-using traveler. In St. Louis and in some of the other sites discussed, use of the lift by persons not in wheelchairs will not be permitted due to the perception by the transit authority of a potential safety hazard, such as a person standing on the lift being struck by the door frame as the lift rises to the bus floor level. This paper, therefore, concentrates on the utilization of accessible bus services by wheelchair users and the operational and economic impacts of providing these services.

ACCESSIBLE BUS SERVICES

San Diego

On February 6, 1976, the San Diego Transit Corporation implemented a pilot program to demonstrate the need for wheelchair-accessible transit buses (1). Permission was received from the Urban Mass Transportation Administration (UMTA) to shift funds within an existing capital grant in order to retrofit five buses with wheelchair lifts. Additional lift-equipped buses are currently on order, but service implementation with these added buses will not occur for some time.

Four of the buses provide approximately hourly service on two heavily patronized routes. The fifth bus is a spare. The lift buses run over 36.5 line-km (22.7 line-miles) or about 3 percent of the total system. Nineteen runs are made in each direction on both routes. Both routes pass through the San Diego central business district (CBD).

San Mateo, California

In August 1978, the San Mateo County Transit District initiated accessible bus service on two routes. Only 15 of the 24 accessible buses are scheduled to provide service, but the majority of the other 9 are needed and used to provide regular route service; consequently, the spare ratio is low. Altogether, the district operates 223 buses on 67 routes.

Accessible bus headways are scheduled to be 30 min on the main-line route from Palo Alto to the Daly City Bay Area Rapid Transit (BART) station. A 1-h accessible bus headway is scheduled on the Coastal Highway 1 route to the Daly City BART station. Approximately every other bus on both of these routes is an accessible bus.

St. Louis

On August 15, 1977, the Bi-State Transit System, operated by the Bi-State Development Agency, instituted a pilot program of accessible fixed-route transit services, which runs 60 wheelchair-lift-equipped transit buses on 10 routes (2). After three months, on November 28, the service was expanded to 157 buses, which serve 17 regular and 5 express routes. The entire Bi-State Transit System is composed of approximately 1100 vehicles that operate on 100 local routes and 50 express routes.

Accessible bus coverage varied by route and time of day; during peak periods it ranged from 27 percent on the route that has the least coverage to 86 percent on the route that has the highest coverage and from 51 to 100 percent during midday. The 22 routes were assigned 126 buses, and 31 buses were kept as spares. This is a spare ratio of nearly 25 percent, compared to the normal range of 8-12 percent for standard nonaccessible buses. However, due to extensive downtime, actual coverage often fell far short of the scheduled coverage. The continual failure to provide the accessible bus coverage advertised in the published schedules caused Bi-State to cut back the scheduled accessible bus service to a level they felt confident could be provided. This action changed the schedule to only 40 accessible buses on 12 routes, beginning in September 1978. The reduction in service was carefully chosen so that existing riders would be accommodated to the maximum extent possible. As a result, ridership remained virtually the same after the cutback.

Detroit

Two transit authorities in the Detroit metropolitan area have purchased accessible buses. The Southeastern Michigan Transportation Authority has 16 accessible buses, which are operated in a single corridor. They initiated accessible bus service on October 9, 1978.

The city of Detroit Department of Transportation has received 41 accessible buses. These buses are to be used in the same corridor as the transportation authority's accessible buses in order to test the impact of fully accessible bus service in one portion of the region. The buses are currently in service, but not as accessible buses due to litigation initiated by the union that represents the drivers. The date of initiation of accessible service with these buses is, therefore, uncertain. The state of Michigan has mandated that all new buses purchased will be fully accessible.

Santa Clara County, California

The Santa Clara County Transportation Agency has operated one fixed-route accessible bus service for more than two years. This route is operated with three lift-equipped small buses. However, the reliability of the equipment is such that the number of runs that are actually accessible are probably only 30 percent.

Since the transportation agency has increased emphasis on accessibility, 52 standard buses with lifts have been delivered. They will also soon advertise for bids on 50 advanced-design buses with lifts and for 81 lifts to retrofit other recently purchased buses. The 52 lift-equipped buses are expected to begin service in 1979.

Current plans for the 52 new buses call for making 3 or 4 of the 44 routes on the system completely accessible. Other routes will be made fully accessible as the retrofits or the advanced design lift-equipped buses become available.

The transportation agency board has established a policy of complete system accessibility. The current activities will make the fleet about 85 percent accessible.

Milwaukee

The Milwaukee County Transit Board has purchased 100 accessible buses. These buses have been delivered but are undergoing lift modifications in order to improve their performance. Of the 100 buses, 88 will be assigned to 11 of the 35 system routes (3). The remaining 12 accessible buses will be used as spares—a spare ratio of 14 percent.

The deployment of these 88 accessible buses will make 11 routes completely accessible during the base service period and approximately 50 percent accessible during the peak period. These routes will be fully accessible on Saturdays and Sundays. Deployment of the accessible buses is expected in early 1979. The next bus order will purchase 180 more accessible buses.

Washington, D.C.

The Washington Metropolitan Area Transit Authority has ordered 130 standard-sized accessible buses. Implementation of accessible fixed-route service is expected in the spring of 1979.

The staff of the transit authority has recommended that only 80 of these buses be scheduled in the first phase of the service, which would reserve 46 percent of the buses for relief of those that experience mechanical difficulties. Under these recommendations 44 routes would receive service hourly throughout the day. In addition, 20 new small accessible buses will be used in the downtown circulation service. The purchase of 131 lifts to retrofit other recently purchased buses has been authorized.

Palm Beach County, Florida

The Palm Beach County Transportation Authority has an UMTA service and methods demonstration program grant to demonstrate a fully accessible, small urban area transit fleet. Service is expected to begin by March or April 1979, using the first of the 30 retrofitted accessible buses (4). A second stage will be implemented on receipt of the 15 small accessible buses currently out for bids. At that time the entire fleet will be accessible.

The transportation authority operates 19 routes. Routes will be made fully accessible as vehicles become available. A priority scheme has been developed for route accessibility. Some routes will, therefore, have no accessible service until the new buses are delivered.

Los Angeles

On October 22, 1974, the Southern California Rapid Transit District adopted a policy that all buses purchased in the future be able to accommodate handicapped persons, including those confined to wheelchairs. On October 13, 1976, a contract was awarded for 200 wheelchair-accessible, standard-sized transit coaches.

The district operates 195 regular service routes plus 10 subscription lines and 9 park-and-ride express services within four counties of the Southern California area, covering more than 5905 km^2 (2280 $miles^2$). The district currently operates approximately 2000 scheduled buses, excluding spares, on this complement of lines. The proposed placement of 171 accessible buses is nearly 9 percent of the scheduled buses that operate on 10 percent of the district's routes. The 29 spare accessible buses represent a spare ratio of approximately 17 percent.

Initially, 23 routes were selected for implementation of the accessible buses. Accessible bus headways on these routes will average about 30 min during the day and 45 min at night. The date when the accessible routes will commence operation with the lift mechanism has been postponed due to the failure of the manufacturer to deliver accessible buses that are accepted as operationally satisfactory. The anticipated maintenance requirements are such that the operating division for 15 of the routes will be reassigned to maximize the efficiency of lift maintenance activities.

Rhode Island

The Rhode Island Public Transit Authority has received 19 accessible advanced-design buses, which are undergoing preimplementation testing. Service may start as early as January 1979.

Fifteen of the accessible buses will be scheduled on five of the authority's routes, which leaves four buses in reserve—for a spare ratio of 27 percent. Accessible bus headways on the five routes range from a low of 30 min to a high of 90 min. The entire system consists of 58 routes and 222 buses.

ACCESSIBLE BUS TRAVEL DEMAND

Data on the use of accessible buses by wheelchair users are limited, since only five accessible fixed-route services are in operation as of December 1978, and St. Louis is the only one that has both a substantial amount of service and a lengthy period of operation. However, actual ridership is somewhat uncertain even there. Comparison of travel diary information of wheelchair users with dispatcher records indicates that only about half of the accessible bus trips by wheelchair users were recorded. Also, in many instances a wheelchair user has tried to board a bus but could not due to an inoperable lift or the lack of an accessible bus. Some of these trips were foregone while others were made on a subsequent accessible bus. The number of foregone trips cannot be ascertained from the data available, however.

During January and February of 1978, estimated wheelchair ridership on the Bi-State system averaged 2.5 one-way trips/day. (Some trips are indeed one-way by bus as the return trip is made by another mode.) The winter was exceptionally snowy in St. Louis and outdoor travel by wheelchair was often difficult or impossible. As the weather improved, estimated ridership increased to 4 trips/day in March and to 8 trips/day in April, the highest monthly average achieved (250 wheelchair passengers). Since April, however, ridership has decreased to an estimated average of 5 one-way trips/day. This trip level amounts to only one wheelchair passenger for every 320 scheduled accessible bus trips. Of note is that a few fairly regular riders account for a large majority of the wheelchair-user transit trips.

The San Diego Transit wheelchair ridership level has been low (commensurate with the level of service offered). As of November 1978, ridership averaged 5 one-way trips/week. The Southeastern Michigan Transportation Authority service, in operation for only two months, carries about 18 passengers/week. In San Mateo, where any handicapped person can use the lift, lift usage during October was about 18/week. The percentage of these boardings that were made by persons in wheelchairs is not known.

A survey of 62 wheelchair users in St. Louis sheds some light on reasons for nonuse of the accessible buses. The most important reasons were the inability to go out without help, the availability of another mode, and the difficulty of getting to the bus stop. Reasons rated least important were the dislike of being out in public, the crowdedness of the buses, an unsafe feeling on the lifts of buses, and the unreliability of the lifts and the scheduled accessible bus service. Other reasons listed as moderately important included: the accessible bus routes not serving their trip origins or destinations, the transit trip time being much greater than by automobile, the difficulty in obtaining schedule information, severe weather conditions, and the fear of having difficulty in getting on and off the bus.

Some transit authorities have placed restrictions on driver assistance to wheelchair passengers. This may be a factor that tends to depress ridership. The lifts currently being installed are somewhat difficult to board due to the initial incline of the ramp. Without the assistance of another person, some wheelchair users would not be able to get on the bus. If the driver cannot help, an attendant or companion would be required for the trip. The availability of a companion thus would have a bearing on whether or not a trip is made.

The current wheelchair-accessible bus services offered are unlikely to have significant immediate effect on the mobility of wheelchair users. The limitations in the origins and destinations served and the obstacles in getting to and from the buses virtually ensure that there will be no great change in wheelchair-user travel.

The St. Louis survey and another survey conducted in Portland, Oregon, indicate accessible demand-responsive services would have much more widespread appeal to wheelchair users than do fixed-route accessible services due to their door-to-door nature. Nevertheless, many transit authorities are implementing fixed-route services due to local pressures, expected Section 504 requirements, or a perception that fixed-route accessible service will be cheaper for them than special or separate services.

OPERATIONS AND MAINTENANCE

The decision to provide a fully or partially accessible bus system has had a major effect on its maintenance operation. Most transit authorities that have received lift-equipped buses have experienced severe problems in the initial testing of the lift equipment. In most instances the problems have delayed the initiation of accessible bus service for several months. Many corrective measures have been tried by the transit authorities and the lift manufacturers, but all of the problems have not yet been solved.

A major difficulty for the operational systems has been keeping enough accessible buses available to provide the service published in the schedules. San Diego (at least at the beginning), San Mateo, Santa Clara, and St. Louis have been unable to provide the full service advertised. San Mateo Transit, for example, operates five of its accessible vehicles out of its South San Francisco operations base and the lifts on only three of them are operable on an average day.

Much more is known about vehicle availability in St. Louis. During 1978, a daily average of 66 of the 157 accessible Bi-State buses were unavailable for service. Since only 31 spares were planned for, this left a shortage of 35 buses. Bi-State developed a priority system to cover the most important routes when shortages occurred. The lift is also placed in a particularly vulnerable spot (the right front) and the lower outside longitudinal support member has to be cut so that the lift can be installed. This increases the potential for damage to the bus and lift due to minor bumps or hitting curbs. These buses also are used more than the other buses due to their constant use in both peak and off-peak periods. Consequently, they require more frequent maintenance and repair than do other comparable vehicles. As a result, a larger number of spare lift buses are required for schedule adherence than are normally required for the rest of the fleet. St. Louis allowed for 25 percent spares, which turned out to be insufficient. However, it is too early to say with assurance what the spare ratio should be. Of note is that the unavailability of lift buses was not always due to a difficulty with the lift. Other causes accounted for 21 percent of the bus unavailability.

The burden of maintaining the lifts has caused an increase in the maintenance staff in St. Louis. Bi-State had originally planned to hire one additional mechanic for each 40 accessible buses. However, due to the large lift maintenance workload, Bi-State needed to hire two mechanics more than had been planned. Given current experience, extra mechanics will be needed at all properties that implement any significant amount of accessible bus service.

So many St. Louis lift buses broke down on the road that two more road supervisors were hired to handle the lift problems and the wheelchair passengers stranded on the buses. The supervisors normally not only help the stranded wheelchair passengers off the bus but also take them where they are going.

Unless fleet accessibility is total, system operations may be further affected. Special garage requirements for ease of operation and maintenance, extra deadheading from the garages, and a restriction on through-routing are possible consequences for systems that are less than 100 percent accessible. In some instances these elements may result in extra costs but otherwise may not cause serious operational problems. However, the impact on system operations is very much site specific. San Mateo, for example, due to the routes selected for accessible bus service, expects very little change in system operations except for a heavier maintenance work load.

Los Angeles transit officials have decided to operate their accessible buses from a few garages rather than have them spread out among all the garages in the system. This permits concentration of mechanics who are specially trained for lift maintenance and repair at a few locations and also facilitates the deployment of substitute or standby buses and drivers when problems arise. It also results in extra deadheading for the buses, however, as they will not all be located at the most efficient storage facility.

The reduction in through-routing occurs when an accessible bus completes its run but the route to which it would normally be connected is not scheduled for an accessible vehicle. It could be through-routed and the lift not used if there were an excess of lift vehicles, but this will probably not be the case for the partially accessible systems described in this paper. When through-routing is reduced, greater bus service hours generally result. This complication does not exist for fully accessible systems.

Some transit authorities expected that the implementation of accessible bus service would require the modification of schedules to accommodate longer running times due to wheelchair passenger boarding and alighting. Bi-State, in fact, did modify the schedules on a few routes for this reason. However, the low ridership by wheelchair users indicates that such modification might not have been necessary.

Some transit operators have voiced concern about the loss of seating capacity on the accessible buses. However, only the Southeastern Michigan Transportation Authority has added buses to make up for the seating capacity lost due to the wheelchair-tiedown positions. The additional standing room available on the accessible buses will permit total capacity to remain about the same even though seating capacity on each bus will be reduced by four to eight seats.

COSTS

An inescapable cost of lift bus service is the cost of the lift and the bus modifications to accommodate it. Costs to date have been as follows:

	Cost ($)	
Place	Retrofit	New Order
St. Louis		5 000—first order 6 315—second order
San Diego	9800	
Palm Beach	8160	
Milwaukee		6 000
Los Angeles		8 000—first order 14 000—second order
Washington		7 000
Detroit		8 000

In addition to the above capital costs, accessible bus service will cost more than regular bus service to operate. Some elements of the added operational costs are easy to determine, others are not. The actual cost due to schedule changes, reassignment of buses, and reduction in through-routing could be obtained through a special effort, but most transit properties will not bother. Often accessible bus service is instituted along with other schedule changes, which precludes easy calculation of the cost impacts of the accessible buses alone. On the other hand, the cost of extra mechanics and maintenance, driver training, promotion and advertising, accident claims (if any), and extra drivers' pay (if any) should be readily discernible.

Scattered information or estimates from the various sites point to at least some of the potential extra operating costs. Bi-State estimated that accessible bus operations resulted in 519 extra driver hours/week due to schedule changes, reduction in through-routing, and deadheading drivers to and from the routes so that the accessible buses would not have to come in to the garages. The cost of these added driver hours totaled $213 180 for 12.5 months of service. Bi-State also found it necessary to hire six extra mechanics and two extra road supervisors as a consequence of the accessible bus service.

In Los Angeles, the cost of reassignment of buses to different garages was estimated to be $70 000/year. San Diego Transit calculated the cost of inspection and maintenance of the lift equipment at $16 900, or $3380/bus during FY 1978. The cost of inspection and maintenance of the Bi-State lifts (including replacement parts) totaled $244 800 for the first 12.5 months of service, or about $1500/bus annually.

The cost of Bi-State's driver training (1 h) was calculated to be $16 320. This is a very low cost for this effort. At the other extreme is Washington, D.C., where the program is budgeted for $150 000, $105 000 of this just for the cost of the drivers' time (3 h) to participate. Bi-State estimated the cost of administrative staff time related to accessible bus planning and operations at $68 180.

Bi-State spent $35 000 on advertising to make the public aware of the accessible bus services, which were implemented in two stages. Palm Beach County has a $70 000 advertising and promotion budget, which also includes outreach and training of potential users. Accident claims due to the lift cost Bi-State $11 000 during the first nine months of 1978.

In order to present the cost of accessible bus service in an organized manner, a hypothetical estimate of the added capital and initial annual operating cost for a partially accessible fleet of 200 buses (25 percent of the total fleet) might be as follows: The cost of the capital item—lifts (including installation and assuming that buses would be bought anyway) = $8000 × 200 = $1 600 000. Operational costs would be

Item	Cost ($)
Reduction in through-routing and other operational changes	200 000
Driver training	100 000
Extra mechanics—8	160 000
Extra supervisors—3	75 000
Administrative staff	15 000
Accident claims	10 000
Advertising	25 000
Total	585 000

The basic service costs would recur annually. However, in subsequent years the amount of driver training would be cut to a much lower level and less advertising would undoubtedly be necessary. If reliability is improved, fewer mechanics and supervisors may be necessary. Counteracting these real or potential cost reductions are an added cost for replacement parts (previously covered under warranty) and possible added costs for drivers' wages (for helping wheelchair passengers or merely for operating the accessible buses). The cost of operation of the 200 accessible buses would be a minimum of $350 000/year and could be substantially more, particularly if lift reliability is not markedly improved.

The cost of operating accessible bus service will obviously be affected by the number of accessible buses used. The strategy or route configuration for deployment of accessible buses can also have a significant bearing on the cost of the service. San Mateo for example, which operates 24 accessible buses (12 percent of the fleet) on 2 of its 60 routes, will have little added operational cost except for maintenance. They will incur costs associated with driver training and advertising but the marginal cost for accessible bus service will be small.

Alternative demand-responsive services have been discussed as an alternative to fixed-route services for the handicapped. Determination of the level of demand-responsive service that might be the equivalent of fixed-route service is not easy. The number of trips carried by the accessible buses in St. Louis, for example, could be handled by one demand-responsive, lift-equipped van at less than 10 percent of the operating cost and less than 2 percent of the base capital cost. On the other hand, a $350 000 budget would run the 15-bus Portland, Oregon, LIFT service for about eight months. The LIFT service carried 1341 wheelchair trips during the month of June. It can be argued that these are not equivalent services and that neither ridership nor cost are appropriate measures by which to judge equivalence. As yet no guidelines have been published as to what would constitute equivalent service if an alternative to fixed-route bus service were to be provided.

OTHER EFFECTS

Bus Riders

For those able to use the lift buses, travel cost will be lower. Riding a bus at a $0.15 fare is cheaper than driving an automobile or taking a taxi or a medicab. The cost is also lower than being driven by a friend or relative if the convenience and travel cost to the other person is considered.

The impact on transit travel time of nonhandicapped bus riders will be minimal until wheelchair ridership builds up. Lift operation for two or more passengers during a single bus run would definitely affect other riders and bus operations. Regular use in this amount has not occurred to date.

Regardless of the usage of the life there will be a loss of seating capacity on the accessible buses. If two wheelchair-tiedown positions are installed in the buses, as is most often the case, eight permanent seats will have to be removed. If the wheelchair positions are not occupied, fold-down seats, which most transit operators will install, will accommodate four persons. Seating capacity is, consequently, reduced by four to eight seats, depending on whether either or both of the wheelchair positions are occupied. When the tiedown positions are not being used by wheelchair passengers, total capacity will not be reduced since there will be added standing room. This would be a change in the level of service, however, for those forced to stand.

Other Service Providers

The usage of the present services is such that there would be minimal effects on private operators such as taxis or medicab type services. This could change, however, if wheelchair ridership on the accessible buses increases substantially.

Labor

Labor unions have not so far negotiated extra pay for the operation of lift buses. Whether this will hold true for the future is unknown.

Safety

Accessible bus operations have resulted in 12 accident claims in St. Louis. The importance of driver training and the verification of driver competence in the operation of the lift cannot be stressed strongly enough.

FINDINGS

Available information on the travel patterns of wheelchair users and their capabilities and the provision of lift-equipped fixed-route bus services reveals several interesting points. The most significant of these are

1. Initial ridership on accessible bus services has averaged only a few trips per day.
2. It is not known how much service unreliability has contributed to low ridership among wheelchair users, but the St. Louis survey indicates that this was one of the least important reasons for not using the accessible bus service. The availability of another mode of travel, the difficulty of going out at all without assistance, and the difficulty of getting to a bus stop were listed as the most important reasons.
3. Keeping the accessible buses available for service has been the most serious problem encountered in the provision of fixed-route accessible bus services to date. Spare-bus ratios higher that those normally required for regular buses appear to be necessary.
4. Lift maintenance and repair have been responsible for substantial costs above those experienced for the operation of regular buses without lifts. Changes in operational procedures, particularly for partially accessible systems, have also caused considerable added expense.
5. The fixed-route accessible bus service appears to have caused very little overall change in wheelchair user mobility, regular bus riders' level of service, or use of other transportation services by wheelchair users. However, no data are available at this time to support these hypotheses.
6. Some injuries have been sustained due to the operation of accessible buses. Some of these were caused by lift malfunctions and some were due to negligent operation of the lift by drivers. Since the human element will always be present, accidents will probably never be completely eliminated.

CONCLUSIONS

Ridership on fixed-route accessible buses by wheelchair users has been low, but judgment of the effectiveness of this concept from early results is premature. It will take time to change the travel patterns of a large number of wheelchair users. Furthermore, these travel changes will be somewhat inhibited until the reliability of the service is improved. The cost of providing this service will not be insignificant, however.

A major drawback to the provision of accessible bus services to date has been the amount of bus downtime, due primarily to malfunctions of the lift equipment. It appears that lift technology has not advanced to the point that reliable service can be maintained without a very large number of spare accessible buses (compared to spare requirements for regular buses). Some transit authorities have indicated that they are holding off on purchases of accessible buses until lift reliability is proven.

ACKNOWLEDGMENT

I wish to thank the planning and operating officials of the transit authorities mentioned in this paper for their cooperation in providing information on their fixed-route accessible bus services. I am particularly indebted to the staff of Applied Resource Integration, Limited, who

supplied much of the information and results on the Bi-State accessible bus project.

REFERENCES

1. R. Casey. San Diego Wheelchair Accessible Bus Study. Transportation Systems Center, Cambridge MA; Urban Mass Transportation Administration, UMTA-MA-06-0049-77-8, Sept. 1977.
2. Applied Resource Integration, Ltd. Evaluation of St. Louis Accessible Fixed Route Bus Operations Pilot Program—Draft Task 4 Report on Project Planning, Implementation, and Operations. Transportation Systems Center, Cambridge, MA; Urban Mass Transportation Administration, July 1978.
3. A Regional Transportation Plan for the Transportation Handicapped in Southeastern Wisconsin, 1978-1982. Southeastern Wisconsin Regional Planning Commission, Detroit, April 1978.
4. Multisystems, Inc. Evaluation Plan for the Palm Beach County Fully Accessible Bus Fleet Demonstration Project. Transportation Systems Center, Cambridge, MA; Urban Mass Transportation Administration, Sept. 1978.

Publication of this paper sponsored by Committee on Transportation for the Transportation Disadvantaged.