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Bus Transportation Strategies

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Contents

Transit Operating Strategies and Levels of Service

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This paper discusses strategies of transit operation, differentiating between the all-day service function and the peak-hour operations of providing traffic and parking relief. A general mode split formula in which the disutility of the car is equated to the disutility of transit is used to evaluate the relevant factors in the individual choice of transit mode. Various types of networks are examined. For cities with low densities of development the timed transfer system is shown to give maximum destination opportunity. The concept of levels of service is discussed from the point of view of the passenger. It is recommended that levels of service be studied in greater depth so that these factors could also be considered.

The city of Edmonton started to use the concept of timed transfers in 1964 and has gradually expanded it. The system has to be viewed in relation to the functions of transit, particularly the service function, rather than from the point of view of providing peak-hour relief.

FUNCTIONS OF PUBLIC TRANSIT

There are four basic functions of public transit that should be considered:

1. To provide transportation to those who cannot use a car, who do not have access to a car, or who prefer transit;
2. To conserve energy based on an overall energy conservation strategy that a government may devise;
3. To provide peak traffic congestion relief, i.e., to divert transport demand to a less space demanding mode so as to avoid or postpone the construction of roadway facilities; and
4. To provide parking relief, particularly in areas of congestion and high land prices.

MODE SPLIT FORMULAS

The use of transit is dependent on individual decision making. The mode split formula developed in Paris, which equates the total disutility of a car trip to the total disutility of a transit trip, appears to give a good explanation of this decision-making process (3). Much has been written about predicting mode split. In general, the comparison has been with the car (1, 2). The result has been the development of paratransit, which provides services similar to those of a car, namely door to door and on demand. Care has to be taken to not reinvent the car or the chauffeured car. The latter, called taxis, already exists. There is beginning evidence that the taxi industry will follow the history of transit in the 1950s and 1960s with a cycle of higher prices and less service, leading to its eventual decline.

General Formula

In the modified Parisian equation, cost of car trip equals cost of transit trip, when

$$\text{Cost of car trip} = MC_c + (t_c/60)a_1I + C_{cp} + (t_{cp}/60)a_2I + (t_{cw}/60)a_3I \quad (1)$$

and

$$\text{Cost of transit trip} = C_T + (t_t/60)a_4I + (t_{tw}/60)a_5I + (t_w/60)a_6I + (t_{tt}/60)a_7I \quad (2)$$

where

M = kilometers traveled,
C_c = cost in dollars of car travel per kilometer,
t_c = travel time by car in minutes,
C_{cp} = cost in dollars of parking,
t_{cp} = time to find parking in minutes,
t_{cw} = time to walk from parking to final destination in minutes,
C_T = transit fare in dollars,
t_t = travel time by transit in minutes,
t_w = waiting time for transit in minutes,
t_{tw} = walking time to stop or station in minutes,
t_{tt} = transit transfer time in minutes between different routes, and
I = hourly income of individual.

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a_1 to a_7 are factors that evaluate time for travel, walking, waiting, and transferring in terms of hourly income. In Paris these factors were: for travel time 0.5, for transfer time 1.5, for walking time 0.875, for waiting time 1.5, and for parking time 0.25. These factors may be similar or different in Canada or the United States. More data and analysis are needed to obtain reliable factors that may even then vary among communities. For strategy purposes the formula explains the effect of various approaches. To improve the position of public transport any or all of the following could be attempted:

1. Increase the cost per kilometer for cars,
2. Increase the travel time of the car trip and reduce the travel time for transit (lane allocation, preferential signals),
3. Increase the cost of parking,
4. Reduce the availability of parking and thereby increase cost and walking distance,
5. Reduce or eliminate transit fares (the formula also explains that this factor is relatively minor),
6. Reduce waiting time at the bus stop,
7. Reduce the walking time for transit,
8. Reduce or eliminate transfer time, and
9. Decrease the hourly income (or the standard of living).

Obviously not all of these approaches are feasible, practical, or desirable. Most public transit improvement schemes have concentrated on reducing travel, waiting, walking, or transfer time. The demand-responsive schemes generally replace waiting at a stop with waiting at the place of origin, which eliminates walking time and may increase travel time (if the first one to be picked up) or reduce it (if the last one to be picked up).

Travel Time Reduction

The mode-split relationships developed in the past relied on travel time ratios or differences and used door-to-door times. The Paris equation assigns different weights to the various components of door-to-door time and shows that, while a reduction in travel time relative to the car is effective, a reduction in waiting or transfer time is more effective. Since the evaluation of time is subjective, it is most important that routes be direct and that traffic congestion be bypassed by traffic engineering measures such as exclusive lanes or priority signals.

Waiting Time Reduction

The general assumption has been to use half the frequency of service, up to a maximum of 10 min, as waiting time. Surveys in Edmonton however showed that there was often no time to interview passengers (4) on routes where the service interval was 30 min. In other words, as shown in Figure 1 (4), with good schedule information and absolute reliability in keeping to the schedule, the waiting time will be a minimum even when there is infrequent service (85 percentile, 6 min!). When the frequency of service is 10 min or less, passengers generally do not refer to timetables and the assumption of waiting time being half the frequency of service is probably correct. Schedule adherence and reliability are therefore of fundamental importance in low-density areas where the frequency of service is usually 15 or 30 min.

Walking Time Reduction

Walking time can be reduced for a fixed-route system by increasing the density of the network and by coordinating subdivision design (particularly in the provision of walkways) and bus routing design. As shown in Figure 2 (4), the maximum acceptable walking distance in Edmonton is 400 m (1300 ft).

Transfer Time Reduction

To reduce transfer time the route design and schedules must be coordinated. Edmonton has changed to the timed-transfer system and transit centers have been established. By having all routes meet at these centers at fixed intervals, multiple destination opportunity is provided. Transfers are guaranteed on a regular all-day basis. While a slight delay is introduced in waiting for transfers, the public appears to accept this delay as reasonable at a transit center.

TYPES OF NETWORKS

Historical

There are still a number of networks based on former streetcar networks or developed on a piecemeal basis.

Grid

A grid system as illustrated in Figure 3 has the advantage that passengers can go anywhere with only one transfer. However, it also requires frequent service and medium to high-density service areas. Frequent service may be justified in peak hours, but such service at midday (the base period) or at low patronage periods, late at night or Sundays and holidays, can be very costly. Based on acceptable walking distances, a grid requires a route spacing of 800 m (0.5 mile). With an average speed of 18 km/h (11 mph) on a perfect north-south/east-west 800-m (0.5-mile) grid, the frequency of service would have to be 5 min if waiting time is not to exceed 5 min. However, a 5-min frequency requires a traffic generation that many low-density residential areas cannot produce, even if everybody uses transit. The grid does not allow for different densities along different routes.

If the transfers are not multidirectional but unidirectional (e.g., to and from the CBD), then a lesser frequency of service can be designed. As in subdivision design the grid is too inflexible a system for many North American cities. The grid works only if densities are uniformly high and the subdivision design has an 800-m (0.5-mile) grid.

Radial

In a radial system, as illustrated in Figure 4, the main transit routes fan out from the center of a city like the spokes of a wheel. Such a system is usually complemented with several cross-town or circumferential routes. Many radial routes exist for historical reasons. A radial system depends greatly on a strong and healthy CBD, which results from good planning control. In Canadian cities the CBD still attracts about 30 percent of the work trips and is the largest single destination. The remaining 70 percent of the work trips are more dispersed (the density factor) and are therefore more difficult to serve by transit. The need for transverse or ring routes means that the transfer locations and times must be carefully designed. To make transfers possible the frequency of service has to be increased, for transit riding cannot be accomplished without a transit service opportunity.

The Timed-Transfer System

The timed-transfer system (Figure 5) is often developed from a radial system. A number of transit centers, each with its own feeder bus system, are established, and the CBD and transit centers interconnect to form a network (Figure 6). The basic midday schedule is generally based on 30-min intervals but could be 60 or 120 min in suburban or more rural areas. Maximum destination opportunity is provided by timing all routes to meet at the transit center at the same number of minutes past the hour each hour (Figure 7). To minimize transfer time, the system works best with off-street transfer stations, which can best be located at shopping centers or community centers, or alternatively at commuter rail, rapid transit, or light rail transit stations. The regular basic schedule should be maintained in the peak hours, with additional service as needed. Feeder buses can then become express buses to other major destinations. The route modifications for Southwest Edmonton provide an example of how such a system evolved (Figure 8). It is relatively easy to add service on those links that generate a greater load.

In Edmonton the peak-hour service frequency is

Figure 1. Waiting time at bus stop.

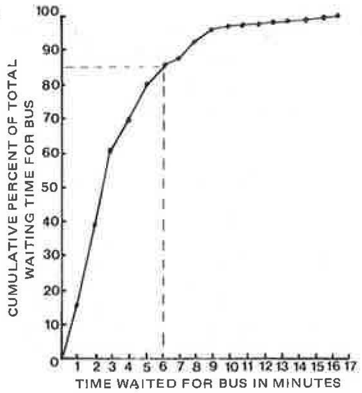


Figure 2. Walking distance from home to bus stop.

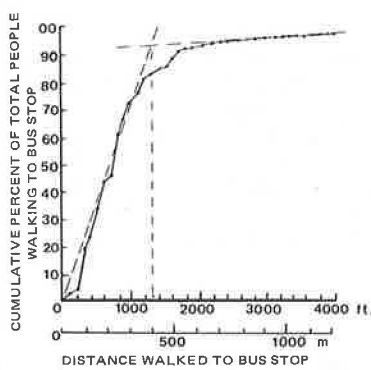


Figure 3. Grid system.

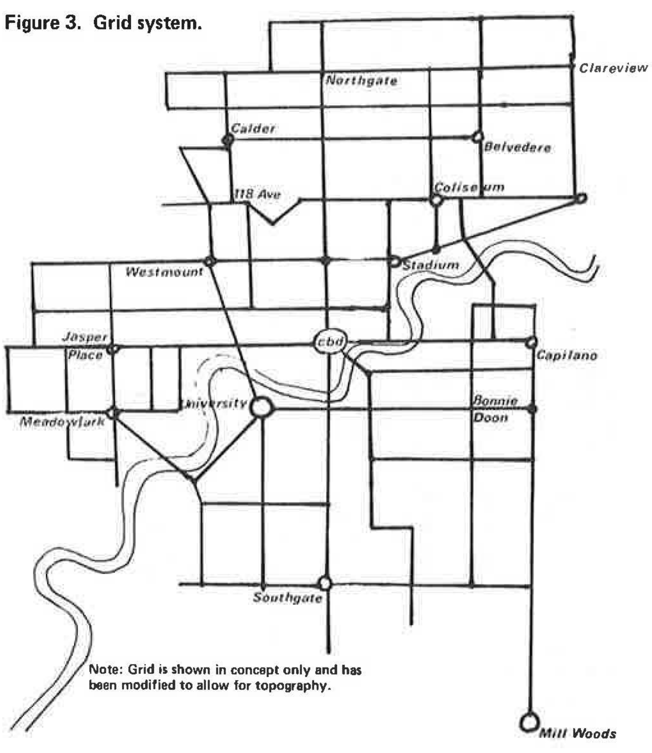


Figure 4. Radial system.

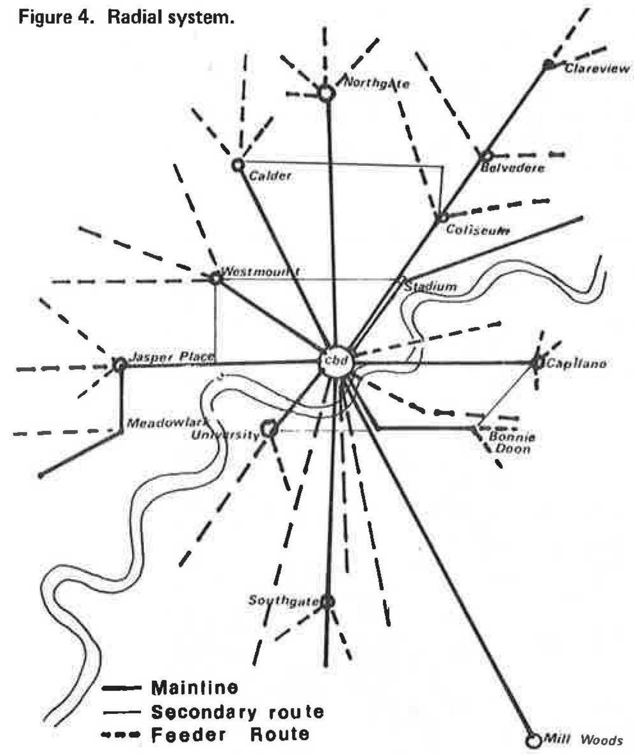
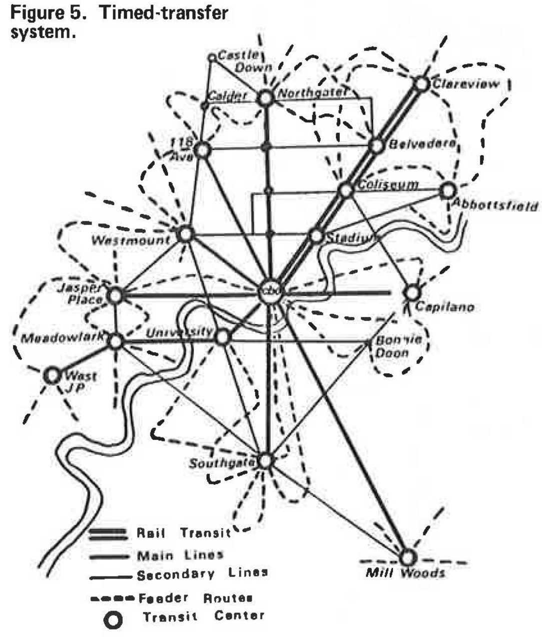


Figure 5. Timed-transfer system.



generally 10 or 15 min on the feeder routes with a 30-min express route maintained at midday. As long as the peak service fits with the critical transfer time at the centers, there is complete flexibility (i.e., 15, 10, $7^{1}/_{2}$, 6, and 5-min frequencies work, but 20, 12, or similar odd service frequencies do not fit). Because several feeder routes may arrive simultaneously at a center, it may be necessary to send platoons of buses (express continuations of feeder routes) to a major destination rather than increase the frequency of service.

The basic consideration in establishing a transit network is to provide access to transit within an acceptable walking distance. The length of the route is determined by the distance between transit centers or more precisely by the time taken to cover that distance, which is (15n-2) min, where n is an integer. Sometimes the frequency of service has been increased between centers so as to provide the linkage. Sometimes the route has been deformed so as to fit the travel time between centers. The feeder bus to a center can make a collection trip that is determined by the schedule module and requires, for a 30-min module, (28n-3) min, where n is an integer. Greater efficiency is achieved by taking a feeder route from one center and feeding it also to another center; one-way loops are therefore to be avoided.

In Edmonton the transit centers are also used as the starting points for routes to industrial areas. At present these services are provided only in peak hours, and the possibility of a demand-responsive basic daytime service is being investigated.

PATRONAGE STATISTICS

The timed-transfer system in Edmonton, together with a market analysis, has increased patronage over the years both absolutely and relatively. Patronage trends are given below and are also shown in Figure 9.

Year	Population	Passengers	Rides per Capita
1951	159 600	35 800 000	224
1956	226 000	34 400 000	152
1961	281 000	28 100 000	100
1966	376 900	32 000 000	85
1971	434 800	40 000 000	92
1972	440 900	41 000 000	93
1973	443 100	42 500 000	96
1974	443 300	45 200 000	102
1975	451 600	51 200 000	113

The market analysis consists of studying origin-destination data for work trips obtained from the civic census (5). The census gives, at 3 to 5-year intervals, all work trips by mode and morning destination time. Knowing the market a system has, plus the potential market that can be served, allows for better routing systems. The market analysis is then supplemented by public hearings, first an orientation meeting to identify needs, and then a meeting to discuss alternatives.

Figure 6. Part of transit map, showing timing points.

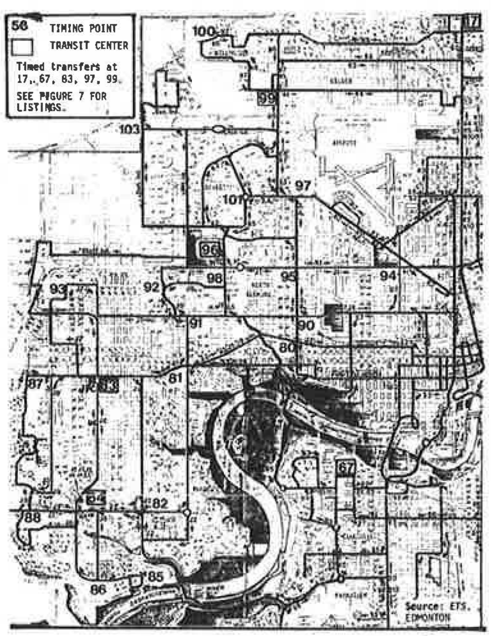


Figure 7. Part of transit schedule, showing timings.

	LOCATION			MINUTES PAST HOUR
(97)	124 St./118 Ave. Route	#3	S.B.	03,13,23,33,43,53
			W.B.	01,11,21,31,41,51
		N6	W.B.	00,30
		N7	W.B.	15,45
			E.B.	14,44
		R3	W.B.	27,57
		R4	E.B.	13,43
(98)	135 St./111 Ave. Route	J1	E.B.	24,54
			W.B.	19,49
		N1	E.B.	07,37
			N.B.	16,46
		U5	N.B.	24,54
			S.B.	27,57
(99)	127 St./129 Ave. Route	N4	E.B.	06,36
		N5	N.B.	06,36
		N6	S.B.	21,51
			W.B.	06,36
		N7	S.B.	06,36
			N.B.	21,51
		R4	S.B.	06,36
		R3	N.B.	06,36
		U5	Ter.	
			S.B.	08,38
		Dom. Ind. ●	Ter.	6:37 every 30 min. to 8:37 A.M. 3:34 every 30 min. to 5:34 P.M.

Figure 8. Route changes in Southwest Edmonton based on timed transfers.

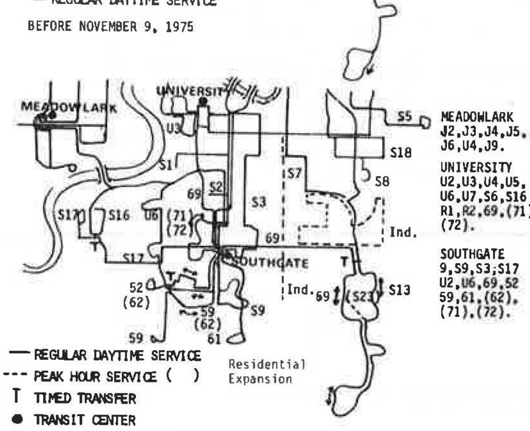
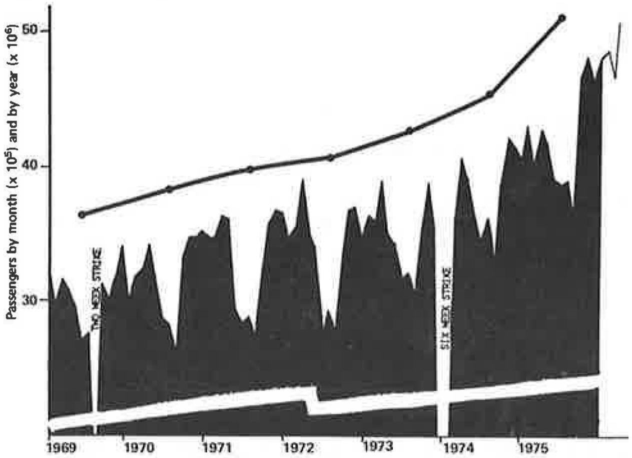


Figure 9. Patronage trends.



LEVELS OF SERVICE

Very little has been done to determine acceptable levels of service. In highway capacity the concept is used; however, in transit the concept of maximum capacity is used. Since many European systems design for standees and not for seated loads (e.g., a 12-m bus accommodates 15 seats and 102 standees), the word capacity can be misleading and a concept of level of service is needed in public transport. In most cities transit has to compete with the car, and so the base of measuring levels of service should relate to seats. The following arbitrary values are suggested:

Level of Service	Load Factor
A	0.5 x seats
B	0.75 x seats
C	1.00 x seats
D	1.50 x seats
E	1.0 x seats + 1 passenger/0.16 m^2 (0.6 passenger/ft^2) of standing space

The rationale is that having a double seat available to oneself is ideal and therefore level A; level C is often used for urban service; level D is sometimes used as a maximum standard for suburban service; level E is undesirable. These levels are chosen from the point of view of the individuals to be served. The service provided is then dependent on frequency of service standards, traffic demand, and the hardware available.

In Edmonton diesel and trolley buses prevail, but on one link a light rail transit facility is now under construction (Figure 5). The choice of hardware has more to do with labor rates, productivity, right-of-way opportunities, equipment availability, and infrastructure than with level of service. At midday at least level of service B should be provided on all routes, and in the peak hours level D could be accepted (with double the frequency, four times the volume can be carried). Because of the slow delivery of equipment Edmonton has not been able to apply level-of-service standards. Additional service is based on service to new areas and on reducing overloads. Level-of-service standards will also have to be modified for other factors used in the Highway Capacity Manual such as size of metropolitan area, length of trip (standing for a short distance is acceptable), average speed, preferential treatment for transit at intersections or roads, stops per kilometer, and frequency of service.

CONCLUSIONS

The timed-transfer route system has been shown in Edmonton to contribute an increase in transit patronage because it gives increased transit travel opportunity. At the same time the system becomes simpler for the passenger to understand.

The mode-split analysis should incorporate more factors, as was done in the Parisian formula; however, research is needed to obtain more accurate quantitative factors that can be used in Canada and the United States. More study is also needed to develop meaningful concepts of levels of service that can be incorporated in transport planning objectives. These levels of service can be different for peak or midday conditions.

ACKNOWLEDGMENTS

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Express Bus Use in Honolulu: A Case Study

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Selected results of a series of four on-board surveys taken to monitor the use of a peak-period bus system in Honolulu are presented and compared with results of an earlier door-to-door survey. The system offers express service to two general destination areas: the Honolulu CBD and the University of Hawaii. The surveys queried riders on basic socioeconomic information, characteristics of past and present travel modes, and user perceptions about service improvements. The study findings indicated that express bus patronage was significantly higher than that of the prior bus service. A significant portion of the morning riders, however, did not use the service for their return trips. The proportion of male and female riders was about even, and, among workers, the predominant occupations were professional and technical. Almost half of all riders came from households that owned two cars. About 60 percent of CBD riders and about 40 percent of riders on the university route were former automobile drivers. Increases in patronage over the survey period were in part due to gasoline shortages during the early months of 1974. The group most affected by gasoline shortages was students, who also showed a tendency over time to adjust their activity schedules to the schedule of the express bus service.

In 1972, the city and county of Honolulu and its consultants proposed a 35-km (22-mile) fixed-guideway system conforming to the linear development of the city in the east to west direction. In addition, a feeder bus system was planned to supplement the fixed route (1). At the same time, the city Traffic Department investigated the possibility of establishing an express bus service connecting the Hawaii Kai area, a rapidly growing suburb in the eastern extremity of the city, with the CBD and the University of Hawaii. The focus of attention was on one of the most critically congested corridors in Honolulu, the Kalanianaole Highway, which provides the only linkage between Hawaii Kai and major activity centers in Honolulu. The peak-hour traffic on the route during weekday mornings was about 4000 vehicles on three lanes moving toward the city.

The Traffic Department conducted a door-to-door survey in Hawaii Kai to determine the potential patronage of such a system, appropriate routes, bus stop locations, and initial bus schedule (2). A system was implemented on a trial basis in August 1973 and has since become a permanent part of the overall bus system of Honolulu.

Several months after implementation of the express bus system, a series of on-board surveys was made to monitor its use and to compare the use with findings of the door-to-door survey.

PROGRAM DESCRIPTION

Hawaii Kai Population Profile

According to the U.S. census of 1970, Hawaii Kai had 3498 housing units and a population of 12 572. The median age of residents was 25 years, and the median household income was 17 896 (compared with 12 035 for the entire island of Oahu). More than 45 percent of the Hawaii Kai adult residents had attended college, and 28 percent had completed 4 or more years. The corresponding figures for Oahu are 29 and 10 percent respectively.

Employment of the residents was predominantly professional or technical (28.6 percent) and managerial or administrative (21.2 percent). The remaining work force consisted of clerical (17.4 percent), crafts and foremanship (8.1 percent), and sales (8.3 percent). Of this work force, 72.6 percent were employed by the private sector and 23.5 percent by the public sector. The census also reported 304 college students, but did not specify the proportion of enrollment at the University of Hawaii and the community colleges in Honolulu.

Of the 3131 housing units that reported owning automobiles, 27.8 percent had one car, 61.0 percent had two cars, and 11.1 percent had three or more cars. The census also indicated that, of the 5111 workers in 1970, 83 percent drove to work, 12 percent were automobile passengers, and 1 percent took the existing bus.

The 1972 door-to-door survey showed a socioeconomic profile that had remained essentially the same as in the 1970 census. The population and housing units had, however, undergone substantial change. A housing inventory taken in December 1973 from existing land use maps provided by the Honolulu City and County Department of General Planning placed the number of units at 5261. This represents an increase of 50 percent during the 3-year

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period 1970-1973. On the assumption that the population of the area increased at a proportional rate, the 1973 population can be estimated to be 18 860 persons.

Bus Service Prior to the Express System

Prior to implementation of the express bus system, the only CBD-bound transit service available to Hawaii Kai residents was provided by a bus service with two collection lines in Hawaii Kai. This bus could make as many as 74 stops along the route between Hawaii Kai and the Honolulu CBD, and as many as 53 stops before reaching the University of Hawaii area, where a transfer to another bus or a 1.2-km (0.75-mile) walk was necessary in order to reach the university. During the morning, the average headways were about 30 min for the first collection line and about 10 min for the second. The collection portion of the service varied from 7 to 12 min depending on the particular line. The line-haul portion was approximately 47 min to the CBD and about 33 min to the stop nearest to the university. This system attracted only 1 percent of the work trips to the CBD.

Door-to-Door Survey

Approximately 4570 workers were surveyed in the 1972 Hawaii Kai door-to-door survey; of these, 4222 valid survey responses were processed. Besides being asked to give basic socioeconomic information and destinations of work trips, respondents were asked to place 12 transit service characteristics into the following three groups: very important, important, and unimportant. Each respondent was asked whether he or she would consider using the express bus if those service characteristics classified very important were met. If the response was positive, the individual was considered to be a potential rider. The survey results indicated that 58 percent of all respondents were in this category (2).

Table 1 shows that the characteristics considered very important by all the respondents and by those identified as potential riders were essentially the same (2). These rankings were in agreement with findings elsewhere in the nation (5, 6, 7).

The number of potential riders derived from the door-to-door survey provided a rough estimate of the maximum patronage that the bus system could attract. However, since not all of the reported potential bus trips fell within the peak period, and since not all of the highly ranked improvements could be satisfactorily met for all potential riders, these patronage estimates were recognized as upper limits.

By identifying the origins, destinations, and work starting and finishing times of the potential riders, Beckwith and Arakaki (2) narrowed the number of candidate peak-period bus routes to eight alternatives. These were further reduced to three routes in order to satisfy the nonstop line-haul requirement of express operations. The adopted express bus system incorporated two of the remaining three routes.

Hawaii Kai Express Bus System

The city Traffic Department developed an express bus system having 18 express bus stops within Hawaii Kai and putting about two-thirds of the 5261 housing units within two blocks and about 80 percent of the housing units within three blocks of an express bus stop. Fourteen runs are made to the CBD and six to the university; the overall seat capacity is 980 passengers during the morning peak period. Bus fares are identical to regular bus service: 25 cents for adults, 10 cents for students, and free fares for the elderly who have bus passes.

During the morning peak, the line-haul portion of the express bus system, as depicted in Figure 1, uses an exclusive bus lane 4 km (2.5 miles) in length in the most congested portion of the Kalanianaole Highway. The first segment of the exclusive lane is a traffic lane coned off each morning from outbound traffic. Thus, for this 3-km (1.9 mile) segment, there are three lanes for inbound traffic—two for mixed traffic and one for express buses—and one lane for outbound traffic. The bus lane then crosses the median to a third inbound lane, 1 km (0.6 mile) long, which was completed just prior to the inception of the express bus service. The express bus then uses regular highway, freeway, and city streets for the remainder of the line-haul portion. There are no exclusive bus lanes for the afternoon return trip because traffic is spread out more evenly.

The distribution portion is relatively compact. The CBD route terminates at six bus stops on two adjacent one-way streets forming a couplet near the center of the CBD. The University of Hawaii (UH) route terminates at a single stop at the west edge of the campus. When the express bus service from Hawaii Kai to the CBD was started in August 1973, the line-haul and distribution portions of the trip took about 25 min [in contrast to the 50 min required by automobile to cover the same distance (3)]. The collection portion of the system includes three lines as shown in Figure 2. The first line covers 10 and the second line 13 bus stops. The third line, a combination of the first two, covers 18 bus stops. The CBD route uses the first two collection lines between 6:15 and 7:20 a.m. at an average headway of 10 min and the third line between 7:35 and 7:45 a.m. at 5-min headways. The university route operates between 6:10 and 8:40 a.m. and uses the third line at average headways of 30 min. The average collection time is 10 min for lines 1 and 2. For line 3, the CBD- and UH-bound buses are scheduled to make the collection circuit in 15 and 20 min, respectively (3).

Study Program and Design

On-board surveys were taken on October 25, 1973, December 6, 1973, February 21, 1974, and May 2, 1974 during the morning peak period to learn ridership information and preferences. Each of the dates was a Thursday. The survey period covered a span of 8 months to coincide with the 1973-1974 academic year.

The survey program was conducted to provide the city and county of Honolulu with information on (a) the morning ridership boarding at each bus stop in Hawaii Kai, (b) the number of passengers disembarking at each destination stop, and (c) general ridership profiles. The original program called for complete sampling for the first and third surveys and partial sampling for the second and fourth, i.e., surveying those riders who had not responded to any of the prior on-board surveys. However, because of a rapid increase in patronage and the possibility of assessing the impact of gasoline rationing on bus ridership, the fourth survey was also a full survey. Thus, only the survey taken on December 6, 1973, was a partial survey.

Survey Instrument and Procedure

The on-board survey instrument was divided into three sections. The first section sought basic socioeconomic information about each respondent. The second section sought information on the characteristics of the respondent's previous and present travel and access modes. It asked two open-ended questions, to determine the reason why the respondent switched to the express service and to determine the reason for not using the express service

Table 1. Door-to-door survey respondents ranking needed service characteristics very important.

Rank	Needed Service Characteristic	Respondents (%) All Questionnaires	Potential Bus Riders
1	Direct home-to-work bus schedule, no en route transfers	66.3	77.2
2	Provision of service to within two blocks of job	61.4	71.0
3	Provision of bus service to within three blocks of home	58.2	67.3
4	Provision of more frequent service	57.9	68.7
5	Maintenance of bus travel time to equal automobile travel time	54.6	63.2
6	Provision of clear bus schedules and route maps	52.6	61.7
7	Maintenance of bus travel time significantly better than automobile travel time	46.1	52.8
8	Provision of free parking at express terminals in Hawaii Kai	44.6	49.1
9	Guarantee of a seat on the bus	42.3	50.1
10	Better identification of bus stops	25.5	31.0
11	Elimination of need to take children	24.9	25.9
12	Reduction of bus fare	20.5	23.5

Note: Number of valid responses was 4222 for all respondents and 2451 for potential bus riders.

Figure 1. Hawaii Kai express bus route.

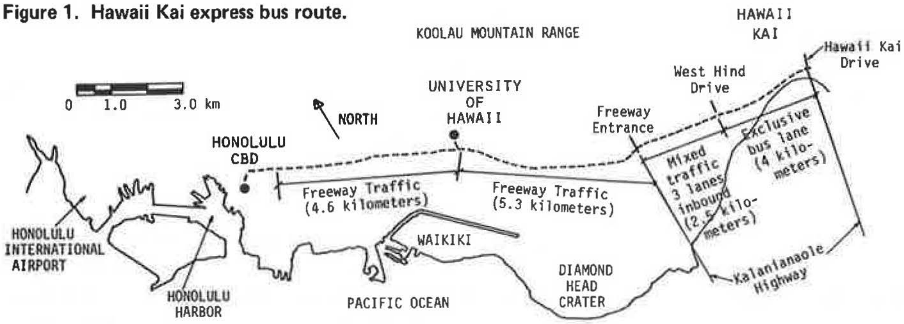

Figure 2. Express bus route coverage in Hawaii Kai.

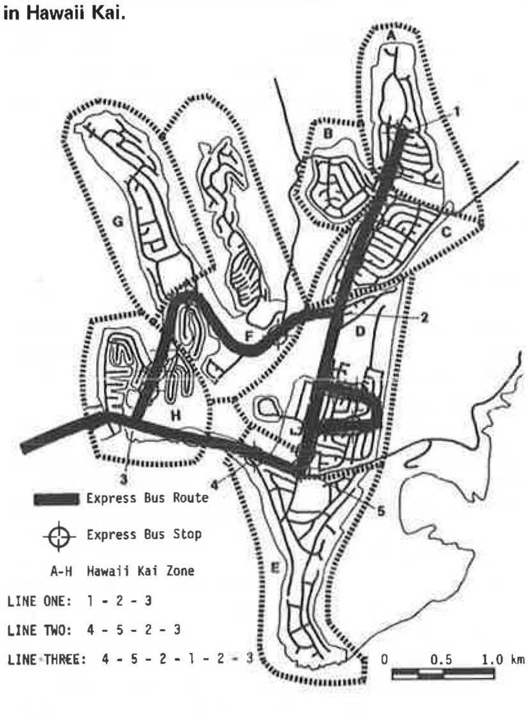

Figure 3. Questionnaire used in Hawaii Kai bus rider survey.

ABOUT YOU:

1. Your occupation__________, age_____, sex___.
2. Your normal work or school hours_____a.m. to_____p.m.
3. How many cars do you have in your household?________

ABOUT YOUR TRIP:

1. Number of blocks between your home and bus stop: ______blocks
2. How do you usually get to the bus stop in the morning? (check one)
   a. Walk____ b. Drive and Park____ c. Get a Ride____
3. Where are you going? (check one)
   a. Work____ b. School____ c. Shopping____ d. Other____
4. What is the location of your destination?
   a. Employer/School________
   b. Address________
5. How did you usually make this trip before express service? (check one)
   a. Drive your car____ b. Passenger in car____ c. Local bus____
6. Why did you switch to the express bus? ________
7. How do you reach your final destination after leaving the express bus?
   a. Walk____ How many blocks to final destination?
   b. Transfer to another bus____. Which route(s)________
   c. Automobile______
8. If you previously drove, did YOU pay for parking? ____yes ____no
   If yes, how much? $_____daily or $_____monthly
9. How much money do you think you save daily or monthly by using the bus?
   $_____daily or $_____monthly
10. Do you usually return home on the express bus? ____yes ____no
11. If you do not return home on the express bus, why? ________

ABOUT TheBUS:

1. How many days a week do you usually use the express bus? (circle one)
   1 2 3 4 5
2. If you work at a bank, would you use a late Friday express run?
   ____yes ____no. If yes, what time? ________P.M.
3. What improvement would you suggest for this service? ________
4. Your address (optional) so that we may send you current express bus information________

in the afternoon if the respondent did not do so. The third section sought information about needed service improvements: It asked one open-ended question soliciting suggestions as to how the system could be improved. Figure 3 shows the survey instrument used by the study.

Two survey monitors were assigned to each of the 12 buses used in the express service. Separate survey booklets were kept for each of the 14 CBD and 6 university runs. Individual survey questionnaires were handed out in sequence so that the rider could be correlated with his or her boarding location. The total number of passengers boarding at each stop and the bus arrival time were recorded on a trip tally sheet contained in each booklet. As the riders completed the questionnaires during the course of the line-haul trip, the surveys were collected in no particular order. The number of passengers departing and the bus arrival time at each destination stop were also recorded on a trip tally sheet.

The survey procedure permitted direct correlation between the individual response and the time of boarding and bus stop location. A similar correlation for departures was not possible. However, inspection of tally sheets showed that nearly all of the passengers disembarked at the first three stops in the CBD distribution loop. Apparently, because of the structure of the distribution loop, departing passengers found it more convenient to depart early and walk one extra block rather than to wait for the bus to bring them closer to their destinations.

The questionnaires for each survey were processed and coded for computer analysis. The following sections summarize the major findings of this study (3).

STUDY FINDINGS

Ridership

The total morning and afternoon patronage of the express bus system is shown in Figure 4. Express bus patronage was significantly higher than that attracted by the prior bus system. The ridership reached its peak in January 1974 coinciding with the height of the gasoline shortage. During this time, the state of Hawaii had adopted an odd-even rationing scheme with restricted hours of gas station operation. Figure 3 also shows that, even though there was a subsequent reduction in ridership, bus patronage after abatement of the gasoline shortage was higher than before it.

During the initial 2½ months of operation, morning trips comprised about 60 percent of the total daily patronage. This proportion decreased with time, reaching the 50 percent level after 7½ months of operation. According to the on-board surveys, the percentage of morning riders who did not ride in the afternoon fluctuated between 30 and 18 for the CBD and between 26 and 21 for the UH route (Table 2). The most common reasons given for this were schedule conflicts (finishing earlier or later than the scheduled bus) and the availability of an automobile ride home.

Age and Sex

As expected, the CBD route ridership age profile was quite different from that of the UH route. These profiles remained unchanged over the survey period. The split between male and female riders remained about even throughout the 4 surveys, although slight deviations were observed.

Occupational Profile

A comparison between the population make of Hawaii Kai reported by the 1970 census and the ridership makeup reported by the CBD on-board survey showed a substantially larger proportion of professional and technical workers in the latter. To a lesser degree, this was also true for clerical and secretarial workers. The remaining occupational groups were underrepresented among the bus ridership. The split between public and private sector employees in the CBD remained approximately the same for all surveys and matched the 1970 census findings. Thus, private and governmental sector workers exhibited the same propensity for using the express bus system.

Car Ownership

The household car ownership pattern reported by bus users is shown in Table 3. Chi-square tests on the weighted averages of both the CBD and the UH proportions indicated that the car ownership distributions were statistically the same at the 95 percent level. Almost half of all express bus riders came from households owning two cars, more than a third owned one car, approximately one out of seven had three or more cars, and only one out of fifty reported owning no cars at all. This distribution is the same as that found in the 1970 census at the 0.95 level of significance.

Previous Mode of Travel

When the travel modes used by express bus users before the initiation of that system were compared with the modes used by persons identified as potential riders in the door-to-door survey, the two were found to be statistically different at the 0.95 level of significance (Table 4). The express bus system did not succeed in attracting as many automobile drivers as the door-to-door study had anticipated. Whereas three-fourths of the potential riders identified in the door-to-door survey were automobile drivers, less than 60 percent of the actual CBD-directed and only about 40 percent of the UH-directed riders were former drivers.

The percentage of riders who formerly used the regular bus service was much higher than had been predicted by the door-to-door survey. Although about 1 out of 15 passengers was expected to have been a former city bus rider, nearly a fifth of the CBD and more than a fourth of the UH riders were diverted from the regular bus service. Former automobile passengers also constituted a higher percentage of the total patronage than had been anticipated by the door-to-door survey, which had predicted that about 17 percent of the users would be former automobile passengers. By contrast, nearly 22 percent of the CBD riders and about 27 percent of the UH riders belonged to that group. In total, about 40 percent of the CBD and about 55 percent of the UH riders were either former automobile passengers or regular bus patrons. The door-to-door survey study had anticipated that this group would account for 23 percent of the total patronage.

Access-Egress

By the use of city land use maps, an estimate was made of the number of housing units within one, two, three, four, and over four blocks from each of the nearest bus stops on the express bus line. An average block was estimated to be approximately 213 m (700 ft) long. Sixty-six percent of the housing units were within two blocks of an express bus stop; 80 percent were within three blocks, and 90 percent were within four blocks.

About 80 percent of the CBD riders and 86 percent of the UH riders walked to reach the express line. The rest either rode or drove. The 80-20 split between walkers and nonwalkers destined for the CBD was identical with the split between housing units within and beyond three blocks from a bus stop. For the university route, the 86-14 split between walkers and nonwalkers was similar to an 89-11 split between housing units within and beyond four blocks from a bus stop. This correspondence suggests that the decision as to access mode is dependent on distance from a bus stop, the approximate maximum walking distance being three blocks for the CBD riders and four blocks for the UH riders.

Table 5 shows that about three-fourths of the CBD route riders walked to their final destinations after alighting the express bus, while about one-fourth of the riders transferred to another bus. Slightly more than four-fifths of the UH riders walked to their final destinations, and the rest transferred to another bus. During the survey period, between 78 and 88 percent of those who walked from the bus to their downtown destinations traveled a distance of less than two blocks. The corresponding percentages for the UH route were 54 and 72.

Departure Times

The departure times of riders on the CBD route remained unchanged during the survey period. However, the departure times for UH route patrons exhibited a tendency to spread out during the survey period. This occurred after December 1973 and coincided with the end of one academic semester and the beginning of the next and suggests that students, having more scheduling flexibility than downtown employees, responded to the availability of the express service when arranging their schedules for the spring semester.

Comparison of Ridership Predictions With Observed Results

Beckwith and Arakaki (2) had identified 2451 potential express bus riders of which 473 were bound for the CBD and 220 were destined for the UH area. The door-to-door study recognized that these values were maximum estimates that were based on the assumption that the desired service characteristics of the new system could be met to the satisfaction of all potential riders.

Table 6 gives comparison of actual express bus ridership by residential zone (Figure 2) and predicted ridership. There was no comparative agreement at the 95 percent confidence level for the distribution of university ridership by zone (Table 7). The CBD route, however, showed good agreement with the predicted distribution by zone, and the predicted ridership level on the CBD route was approximated in the February and May 1974 surveys.

Impact of the Energy Shortage

The height of the energy shortage occurred in January 1974. The state of Hawaii responded to the crisis by initiating a gasoline allocation program, which provided for the sale of gasoline on odd and even days according to license plate numbers (4). Gas stations were required to remain open during specified periods of the day.

The impact of the shortage on the use of the express bus system is worth noting. Although a significant increase in total patronage took place (Figure 3), the socioeconomic makeup of the users remained largely unaffected. The only other discernible reaction to the shortage occurred in relation to access distances to the university route. According to the October and December surveys about 70 percent of the university riders traveled a maximum of two blocks and about 80 percent traveled a maximum of three blocks to reach the bus line. The February and May surveys, on the other hand, showed a shift to 70 percent accessing the system from within three blocks and 80 percent from within four blocks of a bus stop. Thus, the tributary area expanded during the critical period and remained at the new level thereafter. This phenomenon did not occur in the case of the CBD route.

The ranking by riders in each of the four surveys of fuel shortage as a reason for switching from another mode is listed below.

Survey	Ranking by CBD Riders	Ranking by UH Riders
Oct. 25, 1973	–	18
Dec. 6, 1973	11	5
Feb. 21, 1973	4	1
May 2, 1974	5	3

Figure 4. Thursday ridership counts on express bus system.

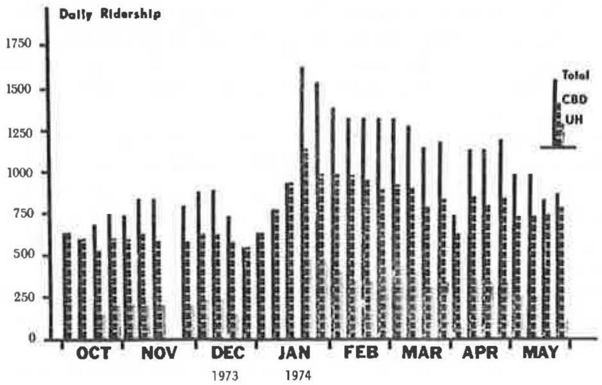

Table 2. Percentage of morning express bus riders who ride home on express bus.

Route	Survey	Morning Riders (%) Do Ride	Do Not Ride	Occasionally Ride	No. of Valid Responses
CBD	Oct. 25, 1973	75.6	23.1	1.3	320
	Dec. 6, 1973	69.0	29.6	1.5	203
	Feb. 21, 1974	81.0	18.0	1.0	406
	May 2, 1974	79.3	18.9	1.9	482
University	Oct. 25, 1973	71.7	25.5	2.8	106
	Dec. 6, 1973	79.1	20.9	0.0	67
	Feb. 21, 1974	72.0	23.3	4.7	193
	May 2, 1974	72.1	25.5	2.4	165

Note: Percentages do not add to 100 because of rounding.

Table 3. Automobile ownership of express bus riders and general population.

Automobiles Owned	Riders on CBD Route[a] (%)	Riders on UH Route[a] (%)	Riders on Both Routes[a] (%)	General Population[b] (%)
0	2.0	2.3	2.1	–
1	36.6	29.5	34.6	27.8
2	48.0	52.3	49.1	61.0
3 or more	13.5	16.0	14.2	11.1

Note: Percentages do not add to 100 because of rounding. Percentages of bus riders are weighted averages of four surveys. Percentage of general population is from 1970 census.

[a]Computed chi-square value between CBD and university distributions is 0.818. Theoretical chi-square value at $\alpha = 0.05$ and d.f. = 3 is 7.8.

[b]Computed chi-square value comparing two distributions with first cell suppressed is 4.8. Theoretical chi-square value at $\alpha = 0.05$ and d.f. = 2 is 6.0.

Table 4. Travel mode of express bus riders before initiation of express bus service.

Travel Mode	Potential Riders[a] (%)	Current Riders[b] (%) CBD Route[c]	University Route[c]
Automobile driver	75.5	57.1	39.3
Automobile rider	16.9	21.6	27.4
City bus rider	6.5	18.0	27.4
Other	1.1	3.3	6.0

Note: Percentages do not add to 100 because of rounding.

[a]Identified in door-to door survey.

[b]Weighted averages from on-board surveys.

[c]Computed chi-square values for CBD and university distributions as compared with potential rider distribution are 30.54 and 112.91 respectively. Theoretical chi-square value for $\alpha = 0.05$ and d.f. = 3 is 7.8.

Table 5. Modes used by express bus riders to reach final destinations.

Route	Survey	Walked (%)	Transferred to Another Bus (%)	Other (%)	No. of Valid Responses
CBD	Oct. 25, 1973	74.9	24.1	0.9	323
	Dec. 6, 1973	74.3	25.7	0	206
	Feb. 21, 1974	72.6	26.6	0.8	482
	May 2, 1974	75.8	22.9	1.2	410
UH	Oct. 25, 1973	82.2	17.8	0	107
	Dec. 6, 1973	81.8	16.7	1.5	66
	Feb. 21, 1974	80.9	18.6	0.5	194
	May 2, 1974	81.0	19.0	0	168

Note: Percentages do not add to 100 because of rounding.

Table 6. Comparison of potential with actual patronage.

	Potential Riders		Actual Riders							
			Oct. 1973 Survey		Dec. 1973 Survey		Feb. 1974 Survey		May 1974 Survey	
Zone	CBD	UH	CBD	UH	CBD	UH	CBD	UH	CBD	UH
A	48	23	57	10	52	12	67	20	64	21
B	36	11	28	19	25	23	39	27	46	16
C	91	25	39	10	45	13	67	22	53	27
D	128	68	93	26	116	29	149	40	138	35
E	28	19	25	6	37	6	27	16	34	21
F	45	22	6	0	5	1	15	2	12	1
G	31	22	40	14	51	22	64	23	47	17
H	66	30	59	26	57	26	69	59	68	37
Total	473	220	347	111	388	132	497	209	462	175

Table 7. Statistical analysis of comparison of potential and actual patronage.

	Deviation From Estimate of Potential Riders (%)		Chi-Square Value for Goodness-of-Fit Test[a]	
Survey	CBD	UH	CBD	UH
Oct. 25, 1973	-27	-50	8.7	42.8
Dec. 6, 1973	-18	-40	7.0	38.8
Feb. 21, 1974	+5	-5	3.2	36.1
May 2, 1974	-2	-20	6.2	19.1

[a]Theoretical chi-square value for α = 0.05 and d.f. = 6 is 12.6.

This incentive never attained first ranking among the CBD riders, even at its highest position in February 1974. At that time the UH riders ranked the fuel shortage as the top item on their list.

SUMMARY AND CONCLUSIONS

The on-board surveys conducted for the Hawaii Kai express bus routes showed that the substantial majority of riders were white-collar workers and students. General ridership profiles remained constant over the span of the surveys.

Increases in patronage occurred over the survey period. This was in part due to energy shortages experienced in Honolulu during the early part of 1974. No firm number can be ascribed to this factor alone, since the drop in patronage after the gasoline crisis did not result in return to preshortage ridership levels. The group most affected by the gasoline shortages was that of students on the university route who were willing to travel increasing distances to reach a bus stop. There was no corresponding increase for CBD riders.

The door-to-door survey had indicated that 75.8 percent of the potential riders in Hawaii Kai were automobile drivers prior to the initiation of the express bus system. The on-board surveys, on the other hand, showed that only 57.1 percent of the CBD riders and 39.3 percent of the university riders were former automobile drivers.

Comparison of ridership distributions by origin zone for the two surveys indicated a good fit for the CBD route; on-board survey counts for the latter portion of the study approximated the potential volume predicted by the door-to-door survey. Results for the UH route, however, did not fit well with predicted levels.

Even though the door-to-door survey study did not attempt to develop or use a parametric modal-split model, it provided information that was useful in identifying potential express bus routes as well as access and distribution configurations. Moreover, since the door-to-door survey was conducted 2 years after the latest census, well-timed information was made available that could not have been found elsewhere. The availability of such timely information is especially valuable in rapidly growing suburban areas such as Hawaii Kai.

ACKNOWLEDGMENTS

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Issues in Enforcement of Busway and Bus and Car-Pool Lane Restrictions

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A preliminary effort to identify emerging problems associated with the legal, regulatory, judicial, and enforcement environments related to contemporary developments in preferential treatment for high-occupancy vehicles is presented. Specific problems and issues are illuminated, and solutions or processes that should generate remedies are recommended. Directions for further research into some of the unresolved issues associated with adequately enforcing the provisions of priority treatment strategies for multipassenger vehicles are suggested.

Enforcement of restrictions for busway and bus and car-pool lanes, for the most part, has not been an issue posing serious concern to transportation officials although there are exceptions to this. The early projects were usually designed as physically separated from the general traffic lanes through the use of barrier walls, traffic cones, and other implements. The entry and exit points to such projects have been singular or few in number. This physical separation has allowed busway and bus and car-pool lane projects to be implemented without enforcement of the lanes being a major consideration.

At present, the development of preferential treatment projects for high-occupancy vehicles is proliferating. This trend is a result of the proven success of the early priority projects, an increasing awareness of the people-moving capabilities of transportation systems, and the evolving emphasis on energy conservation. Urban areas are increasingly looking toward travel corridors involving freeways, arterial highways, and even local streets where such projects can be implemented. As the diversification in design of preferential treatment projects continues, the issue of enforcement of restrictions for busways and bus and car-pool lanes takes on greater importance.

Lack of realization of the importance of the enforcement issue has resulted in a number of projects that have realized a less-than-desired level of enforcement for the particular busway or bus and car-pool operation. Moreover, the enforcement issue can have a considerable impact on the operational and safety aspects of these projects, especially those in which significant modifications of existing traffic patterns occur. The enforcement issue is thus a key factor in the development of a viable, safe, and successful preferential treatment project. Unfortunately, there are no guidelines available to assist local communities to develop successful enforcement programs for potential preferential treatment projects. A survey of the recent literature on the subject yields very little assessment of the implications of the busway or bus and car-pool lane enforcement issue. In order to begin to evaluate the issues of enforcement agency cooperation and planning, legal and judicial compatibility, and development of enforcement techniques and strategies, a questionnaire was sent through the auspices of APTA to a number of public transit agencies involved in busway and bus and car-pool lane systems. In many cases, the replies received (summarized in Tables 1 through 4) were not complete, nor was the sample of respondents fully inclusive of the entire spectrum of preferential treatment systems currently in operation. However, the information obtained as a result of this questionnaire is worth analysis as a basis for some preliminary conclusions that could be expanded and refined after additional research.

ENFORCEMENT AGENCY COOPERATION AND PLANNING

In many cases, a successfully implemented preferential treatment program is the result of the involvement of a broad mix of professionals—planners, traffic engineers, highway engineers, transit operators, and safety engineers—in the planning process. The involvement of the agencies they represent gives each a feeling of importance and proprietorship in the project and provides all of them with an impetus for the development of a successful project. A number of the affected enforcement agencies should also be included. As a member of the initial planning team, the enforcement agency can provide valuable assistance in (a) offering professional enforcement advice, (b) achieving the necessary commitments from the enforcement agency, and (c) developing specialized enforcement strategies and techniques. An appropriate scheme for integrating the enforcement program into the

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planning process is shown in Figure 1.

In the development of busway and bus and car-pool lane projects, such questions as, Is the project enforceable? or How can the project be enforced? need to be asked early in the planning process. Among those attempting to answer these questions should be the enforcement agency since it has the knowledge to determine whether a preferential treatment project is self-enforceable, requires specialized enforcement in some manner, or is unenforceable. Project planners should avoid taking a planned project, no matter how self-enforceable it may be, to the enforcement agency and saying, Here, enforce it! or, How are you going to enforce it? The enforcement agency is infinitely more likely to cooperate with the ultimate enforcement program developed if it is a part of the planning process that developed the program, especially if enforcement will be difficult.

Moreover, the enforcement agency can also provide valuable input into the traffic operations design phase in the early stages of the planning process. The signing and striping schemes, as well as other motorist-information systems, for a preferential treatment project should be reviewed by the enforcement agency to ensure that there is no opportunity for the violator to claim that because of inadequate signing or information systems he was not cognizant of the restrictions. The enforcement agency, involved as it is directly with the judicial system, also has knowledge of possible judicial tendencies regarding various traffic operation schemes.

Understandably, the enforcement agency prefers that all busway and bus and car-pool lane projects be designed to be self-enforceable or at the very most require only a limited amount of enforcement supervision. However, in the trend toward more preferential treatment projects, especially the variety involving signalized arterials and streets, enforcement of busway and bus and car-pool lane projects cannot always be handled in a routine manner. Certain projects, in order to provide the optimum operational system, may require a dramatic increase in the level and type of enforcement on a particular facility. In planning such a project, some proper and correct decisions regarding its operational strategy may require adverse effects on its enforcement policy. If the enforcement agency has been involved in the planning, it will understand such decisions, making them much more palatable. Involvement of the enforcement agency in the planning also guarantees that effects on enforcement were indeed considered.

When a specialized enforcement technique or additional enforcement personnel or both are shown in the planning process to be necessary, a commitment toward enforcement of the preferential treatment strategy by the affected enforcement agency should be sought at that time. This attempt to secure a commitment is essential in that (a) it will ensure an adequate level of enforcement, or (b) if a commitment fails to be obtained, the necessary corrective action can then be undertaken at an early stage in the planning process.

If the question of additional enforcement activity is to be resolved by supplying additional manpower and equipment, the issue of financing such an option becomes important. If the enforcement agency is contacted early enough, future agency budgets can be adjusted to include the resources required. A positive alliance between the project and the enforcement agency will be formed, since the project can serve as justification for the agency in its request for additional funding. Again, the enforcement agency is in the best position to provide insight into the problems associated with securing additional financing for enforcement activities and should be an essential party in the preliminary planning process.

LEGAL AND JUDICIAL COMPATIBILITY

An effective enforcement treatment of a preferential treatment project does not rest solely with those activities that occur at the site of a project. Keeping the preferential treatment strategy operating smoothly is only one aspect. The other is ensuring that the project oper-

Table 1. Enforcement questionnaire summary: description of projects.

Facility	Location	Operation Type	Operation Time	Busway Length (km)	Bus Volumes Daily	Bus Volumes Peak Hour	Type of Buses Allowed	Car Pools Allowed
I-5	Seattle	Express lane	24 h	1.6	360	223	Local public transit	No
Wash-520	Seattle	Shoulder bus lane	6 to 9 a.m.	2.1	46	46	Local public transit	No
Wash-522	Seattle	Shoulder bus lane	24 h	2.4			Local public transit	No
I-90	Seattle	Shoulder bus lane	24 h	0.3	115	63	Local public transit	No
US-101	Greenbrae, Calif.	Bus lane	6 to 9 a.m. 4 to 7 p.m.	6.4 14.4	285	101	All buses	Yes[a]
I-495	New Jersey	Contraflow bus lane	7 to 10 a.m.	4.0	1050	550	All buses	No
US-1	Miami	Contraflow bus lane and car-pool priority lane	7 to 9 a.m. 4 to 6 p.m.	8.8 9.8	61	20	Local public transit	No[b]
George Washington Bridge	New Jersey	Bus lane	7 to 9 a.m.	0.6	85		All buses	No
I-95	Miami	Exclusive bus and car-pool lane	6 to 10 a.m. 3 to 7 p.m.	12.0			All buses	Yes
N.W. 7th Avenue	Miami	Center-reversible exclusive bus lane	6 to 9:30 a.m. 3 to 6:30 p.m.	15.8	53	18	Local public transit	No
—	Washington, D.C.	Curb bus priority lane	7 to 9 a.m. 4 to 6 p.m.	35.2		60 to 150	All buses	No
I-93	Boston	Exclusive bus and car-pool lane	6:45 to 9:15 a.m.	0.8	42	42	All buses	Yes
—	San Juan, P.R.	Contraflow bus lane	24 h	12.8		256	Local public transit	No

Note: 1 km = 0.6 mile.

[a] If over 11 seats. [b] For bus lane.

ates in a favorable legal and judicial climate. Failure to enact the latter can easily undermine the former.

A necessary prerequisite to the design of an effective preferential project is the study of applicable existing state and local laws pertaining to traffic enforcement. Specific questions that should be answered include:

1. Do the existing laws or ordinances provide adequate authority to local or state agencies to restrict the use of lanes to certain types of vehicles? What procedures must be followed to implement such restrictive measures?
2. Do the enforcement jurisdictions have the authority to apprehend and cite violators of such lane restrictions? Does the apprehending officer have to be a witnessing officer in order to cite the violator?
3. Does the judicial system have sufficient authority to impose fines and penalties for violations of lane restrictions?

Since state and local laws vary considerably from jurisdiction to jurisdiction, each potential preferential treatment project must be investigated independently in order to determine if changes in existing legislation must be made. It is essential that a legal opinion be obtained to ascertain the sufficiency of existing laws and their enforceability.

Table 2. Enforcement questionnaire summary: types and effectiveness of prohibitions.

Facility	Other Vehicles Allowed	Prohibitions	Prohibitions Effective	Signing	Pavement Markings
I-5	Emergency	Buses only	Yes	Buses only	BUS ONLY and lane buttons
Wash-520	Emergency	Buses only	Yes	Buses only	BUS ONLY and lane buttons
Wash-522	Emergency	Buses only, allowed right turns	Yes	Buses only	BUS ONLY and lane buttons
I-90	Emergency	Buses only	Yes	Buses only	BUS ONLY and lane buttons
US-101	None	Buses only	Yes	Buses only	Safety posts
I-495	Marked police cars	Buses only	Yes	Buses only	Safety posts
US-1	Emergency	Contraflow lane: buses only Car-pool lane: 2 persons/vehicle min., no left turns	Yes	Overhead MTA BUS ONLY	Safety posts
George Washington Bridge	Emergency	Buses only	Yes	Restricting use to buses	Cones
I-95	Emergency	3 persons/vehicle min.		Overhead signs	Solid white line
N.W. 7th Avenue	Emergency	Buses only, no left turns except at designated locations	Yes for buses only; fair for no left turns	Overhead BUS ONLY	BUS ONLY
Washington, D.C.	Emergency, right-turning vehicle, bicycles, taxis	Buses, taxis, bicycles, and right-turning vehicles only	Generally	NO STANDING	BUS LANE and yellow lines
I-93	Emergency, government	3 persons/vehicle	Yes	Overhead	Asphalt dividers
San Juan	Motorcycle patrol	Buses only		Conventional	Yellow and white lines

Table 3. Enforcement questionnaire summary: legislative-judicial effects and results.

Facility	Legislative Changes Required	Fines Imposed	Prosecution Successful	Enforcement Plan[a]
I-5	No	Normal	Yes	Standard
Wash-520	No	Normal	Yes	Standard
Wash-522	No	Normal	Yes	Standard
I-90	No	Normal	Yes	Standard
US-101	No	$15		Special automobile and motorcycle patrol
I-495	No	$25	Yes	Special automobile, motorcycle, and foot patrol involving 5 officers and 4 vehicles
US-1	No	$25	Fair[b]	Special automobile and motorcycle patrol involving 6 officers and 6 vehicles
George Washington Bridge	No	$15 + $5	Yes	Standard
I-95	No	$25	Yes	Standard
N.W. 7th Avenue	No	$25	Yes	Standard
Washington, D.C.	Yes[c]	$10 to $25	Unknown	Standard
I-93	No			Standard
San Juan		None		Special motorcycle and transit route inspection patrol

[a] Standard enforcement is defined as normal police patrol using two way radio communications and only the witnessing officer being the apprehending officer. Exceptions to this standard enforcement plan are listed.
[b] Judge accepted ignorance of law as excuse.
[c] Amendments to the D.C. traffic regulations.

Once the enforcement agency has done its work by issuing a citation for violation of the lane restrictions associated with a preferential treatment project, the project enters the courtroom and is subject to judicial interpretation. In cases where it is not possible to obtain a commitment from the appropriate superior judge, the project can ensure that those judges involved are fully briefed on the project. The judges should know the objectives of the preferential treatment project and the various operational strategies incorporated in it. A successful briefing will show the judges that the project is of public value and properly designed.

Failure to properly brief the judges can mean adverse (or less desirable) rulings that could then cause a loss of enthusiasm for the project by the enforcement agency. No enforcement agency desires to have its time and effort overruled—even if correctly—by the judicial arm of government. When such a possibility exists, the enforcement agency, rather than seek this embarrassment, tends to enforce the project with less vigor.

Table 4. Enforcement questionnaire summary: enforcement performance satisfaction.

Facility	Enforcement Agency	Enforcement Agency Cooperation	Enforcement Performance Satisfactory
I-5	State and city police	Complete	Yes
Wash-520	State and city police	Complete	Yes
Wash-522	State and city police	Complete	Yes
I-90	State and city police	Complete	Yes
US-101	State police	Complete	Yes
I-495	State and port authority police	Complete	Yes
US-1	County and city police	Average to good	Yes
George Washington Bridge	Port authority police		
I-95	State police	Poor	No[a]
N.W. 7th Avenue	County and city police	Average	No[a]
Washington, D.C.	City police	Fair to poor	No[b]
I-93	State police	Complete	Yes
San Juan	State police	Average to good	No[c]

[a]Special enforcement and sense of participation are necessary.
[b]Political emphasis is necessary.
[c]Regulations by law, including penalties, are necessary.

DEVELOPMENT OF ENFORCEMENT TECHNIQUES AND STRATEGIES

In developing specific techniques and strategies for enforcing the restrictions of a busway or bus and car-pool lane, it is first necessary to determine the goals and objectives that the enforcement program will strive to achieve. Once the goals and objectives are determined, the appropriate enforcement techniques and strategy can be developed. The overriding goal of any enforcement program is to provide an effective and safe operation. If this basic goal cannot be achieved, then the project will fail. It should be noted that this goal of providing effective and safe operations is not the sole responsibility of the enforcement agency but to a very great extent rests in the design of the preferential treatment strategy.

The matter of the violation rate of a preferential treatment strategy must also be examined. Should the enforcement objective be to maintain the violation rate at a specific predetermined level or to permit fluctuations so long as they do not impair the operations of the preferential treatment strategy? If the latter is chosen, it may result in an operationally efficient busway or bus and car-pool lane project in which the violating vehicles exceed the qualifying vehicles. This high violation rate could taint the project in the public's eye.

The standard enforcement strategy is usually to maximize the enforcement effort at the outset of a project (after a reasonable familiarization period) in order to maximize user perception of the probability of apprehension. Once the user has been conditioned to this, a lesser level of enforcement may be used with varying levels of enforcement applied strategically or randomly

Figure 1. Suggested flow for integrating enforcement planning into preferential treatment project planning.

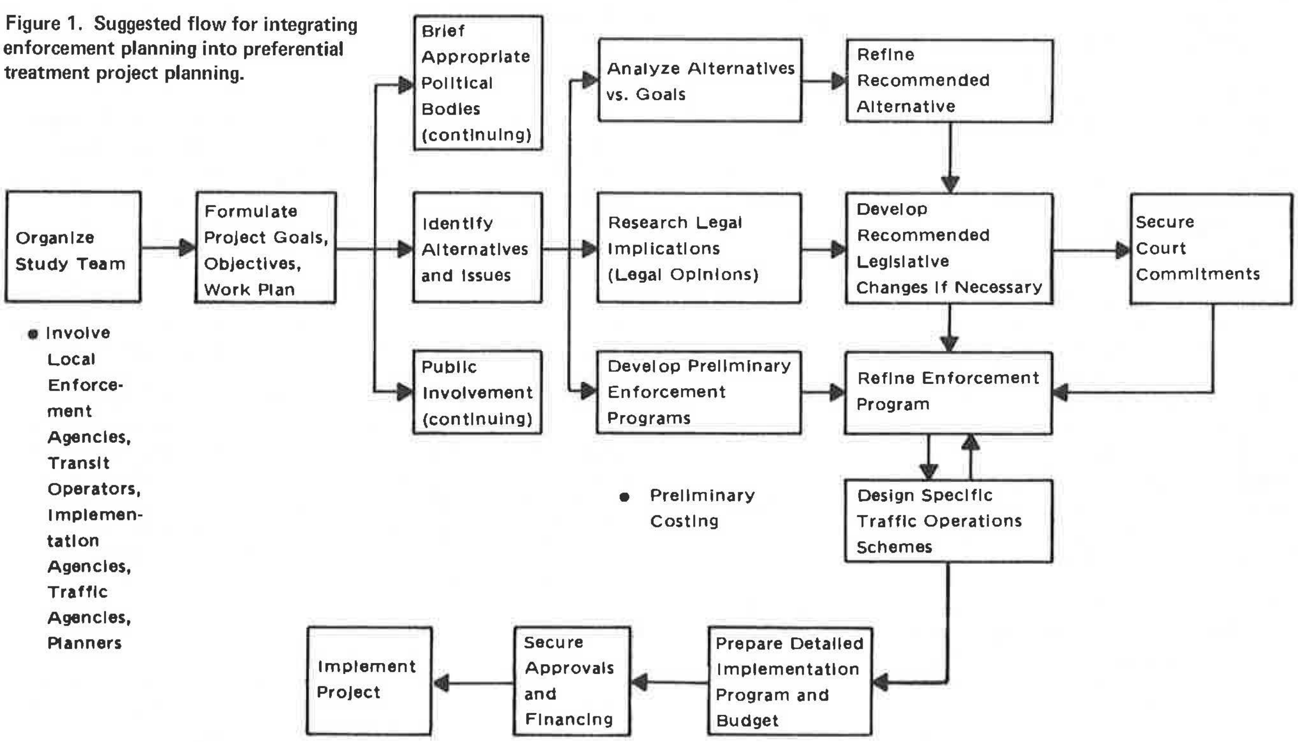

Table 5. Principal findings.

Type of Operation and Restriction	Relative Degree of Enforcement Problem	Predominant Type of Enforcement Problem
Physically separated busway, bus lane, or bus and car-pool lane	Low to none	NA
Nonphysically separated bus lane or bus (car-pool) lane on freeway	Medium to high	Illegal through trip users
Nonphysically separated bus lanes on arterial street with turning restrictions (including reversible center lanes and contraflow lanes with separation)	Medium to high	Turning vehicles violating turning restrictions
Nonphysically separated car-pool lane on at-grade, arterial streets with turning restrictions	Medium to high	Illegal through trip users and turning vehicles violating turning restrictions

throughout the operating period. One possibility is to monitor the violation rate, and if it increases past the desired level, increase the enforcement level.

Because enforcement has not been an important issue in the past, there is very little information on the effects of differing levels of enforcement manpower and strategies on the violation rate. To further cloud this issue, little is known as to how users of a particular facility—freeway, arterial, or local street—react to a particular preferential treatment strategy. This lack of information is the primary reason for the use of the time-tested strategy of heavy enforcement at the outset of a project with diminishing enforcement as the violation rate diminishes and user awareness increases.

As the enforcement issue increases in importance, much more information on motorists' reactions to different priority treatments and to the impact of different enforcement levels and strategies will be necessary to design the enforcement activity. What is the relative impact of two, four, or six troopers concentrating on a busway or on bus and car-pool lanes? What are the relative effects of patrolmen issuing citations or warnings or of simply being visible? Proper answers to these questions will allow the design of an enforcement technique and strategy that optimize the program's objectives.

Specific enforcement measures used by the majority of agencies currently enforcing preferential treatment programs usually involve the use of conventional techniques (i.e., normal patrol operations). Very little experimentation or research is being conducted into the possible use of capital-intensive as opposed to labor-intensive techniques. The use of electronic surveillance systems and the like, in conjunction with remote apprehension operations, has not been applied to preferential systems enforcement. This may be accounted for by a combination of factors including (a) the lack of necessity for resorting to such systems in order to achieve a reasonable level of enforcement, (b) the cost associated with procuring and installing such systems, and (c) legal restrictions on the use of such systems (many states require that only a witnessing officer can cite a violator).

The relation between the particular design of a preferential treatment strategy and the enforcement strategy further complicates the development of enforcement techniques and strategies. Specific design variables affecting enforcement include the number, type, and location of regulatory restrictions, the physical roadway operation scheme, and the availability of storage facilities (areas that allow for violators to be removed from the traffic stream and cited without disrupting traffic flow). Certainly, a traffic regulation such as no left turn that is in force throughout the length of a project is more difficult to enforce than one that is in force at only limited locations. Similarly, enforcement is more difficult for unlimited entry and exit to a busway and car-pool lane than for limited entry and exit.

The designation of a priority treatment for buses only or buses and car pools tends to affect the violation rate. Motorists are more likely to violate the priority facility if car pools are permitted to use it since the violator's visibility is less noticeable. The designation of a car pool has a minor impact on the enforcement efforts, for it is easier to separate vehicles by classifying them as single or multiperson occupancy. Thus, the single-passenger violator of a two-person-minimum car pool is easier to identify than the multipassenger violator of a three or four-person minimum car pool.

Once the enforcement team witnesses a violator of the system, it is best that he be apprehended immediately. To accomplish this, it is necessary to have accessible storage areas to which the violator can be removed so that the traffic flow is not impaired. If accessible storage areas are not provided, additional effort by the enforcement teams is required.

It may not always be possible to design a busway or bus and car-pool lane project so as to benefit enforcement efforts. Since the major goal is to increase the people-moving capability of the roadway, decisions adversely affecting enforcement may be necessary. For example, a bus-only designation is more easily enforced than a bus and car-pool designation but may not maximize passenger throughput or minimize total passenger travel time. Lack of available right-of-way may likewise eliminate storage facilities for apprehended vehicles, thereby compromising a desirable enforcement scheme. These problems must be addressed by the planning team in conjunction with the enforcement team.

PRINCIPAL FINDINGS

A number of preliminary observations (summarized in Table 5) can be made from the information returned via the questionnaires.

1. Exclusive busways and physically separated bus and car-pool lanes are successful without expending special efforts on enforcement. In this context, physically separated includes low-cost techniques such as safety posts and cones, as well as more expensive techniques such as barrier walls and the like.
2. Conversely, exclusive bus and bus and car-pool lanes that do not have the advantage of some form of physical separation have had significantly more enforcement problems. Specific examples include Northwest Seventh Avenue, US-1 and I-95 bus and car-pool lanes in Miami, and curb bus lanes in Washington, D.C.
3. Preferential treatment projects requiring turning restrictions on at-grade arterial streets are difficult to enforce. Violators of these restrictions expose the project to the possibility of increased accident rates.
4. To date, only conventional normal-patrol enforcement techniques have been applied to enforcement programs for preferential treatment projects.

RECOMMENDATIONS

At present, bus and bus and car-pool lane restrictions are enforceable, provided sufficient thought and effort are devoted to some of the issues discussed in this paper.

However, as diversification in the design of preferential treatment programs continues, the need for emphasis on issues associated with enforcement will increase. A number of busway and bus and car-pool lane projects presently established have not achieved a satisfactory level of enforcement; this fact tends to support the conclusion that enforcement is an important aspect of the planning process of the preferential treatment project. Unfortunately, there are no guidelines to assist the development of successful enforcement programs for projects of this nature, and additional research is needed. In planning a viable enforcement program, several policies emerge as particularly important to this process.

1. Special attention and effort should be devoted to enforcement problems when a preferential treatment program is planned that involves nonphysically separated priority lanes.
2. The enforcement program should be an integral part of the planning and design process. An effective enforcement program and strategy should be developed in specific terms in conjunction with the local enforcement agency. Key issues in the enforcement planning process will be (a) the identification of specific objectives in terms of acceptable and achievable violation rates to be maintained, and (b) identification of an appropriate level of enforcement and specific techniques for achieving this goal. A commitment should be obtained (in writing, preferably) from the enforcement agency indicating that it will enforce the restrictions of the project.
3. The legal and judicial climate will also play a role in the success or failure of a proposed enforcement plan. Legal research should be done and a legal opinion obtained regarding the existing laws and ordinances governing traffic regulations in the area in question. A commitment should be obtained from the local judicial system indicating its intent to uphold citations issued for violations of restrictions associated with a preferential treatment project.
4. There is a distinct relation between the operational plan for a preferential treatment project and the enforcement plan necessary to ensure its effectiveness. Special attention should be devoted to the design configurations, particularly signing, turning restrictions, detention areas, and such. Safety considerations should also be given special attention to minimize the probability of increases in accidents. Driver education plays a key role in this area.
5. The use of innovative enforcement techniques should be explored.
6. Local relevant political entities should be briefed periodically throughout the course of the planning and design process.
7. The preferential treatment program should include an element of before-and-after evaluation to determine the effectiveness of the project and its ability to achieve its objectives.

ACKNOWLEDGMENTS

Special thanks are given to the members of the Committee on Bus Transit Systems of the Transportation Research Board and the Subcommittee on Enforcement Techniques and Procedures. The assistance of these people, too numerous to name here, was invaluable in designing the questionnaire and in reviewing and commenting on preliminary drafts of this effort.

South Dixie Highway Contraflow Bus and Car-Pool Lane Demonstration Project

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This paper describes a series of improvements planned and implemented by the Florida Department of Transportation and Metropolitan Dade County, Florida, to increase the peak-hour people moving capacity of an 8.8-km (5.5-miles) section of US-1 (South Dixie Highway) that links the suburbs of South Dade County with the Miami central business district. One of the improvements, the contraflow bus lane, improved travel times for transit riders by 10 to 16 min and induced over 1700 more riders per day to use transit. The car-pool lane, another part of the project, improved travel times for the nearly 900 car poolers per day by 6 to 8 min. These results and other effects of the project such as automobile occupancy, traffic volume changes, enforcement, and safety are discussed. A profile of the transit user is presented, and car-pool and general lane riders compared.

Much attention has recently been given to the possibility of increasing the use of public transportation by the development of preferential lanes in and around urban areas. Similar attention has been given to the increased efficiency of the automobile when preferential treatment is given to the regular car pooler. A combination of these two approaches, the South Dixie Highway Transportation Demonstration Project, has been in operation in Dade County, Florida, since July 1974. The project was sponsored jointly by the Florida Department of Transportation and Metropolitan Dade County for the first year, after which the county assumed all financial and operational responsibilities.

The project was planned and executed by the Mass Transit Division of the Florida Department of Transportation, the Metropolitan Dade County Office of Transportation Administration, the Dade County Metropolitan Transit Agency, the Dade County Department of Traffic and Transportation, the Dade County Public Works Department, the police departments of Dade County, and the municipalities of South Miami, Coral Gables, and Miami. These agencies met for approximately 6 months and negotiated an interlocal agreement between the state and the county. The funding formula called for a 50 percent contribution by the state with the operating costs to be spent on a sliding scale over the four quarters of the demonstration. This ad hoc committee continued to meet throughout the life of the demonstration phase constantly reviewing project data and operational problems.

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

DESCRIPTION OF THE PROJECT

The contraflow bus and car-pool lanes extend 8.8 km (5.5 miles) from Sunset Drive in South Miami to just south of I-95 (Figure 1). The signalization improvements extend farther to the south. The project is in effect from 7 to 9 a.m. and 4 to 6 p.m. on weekdays, excluding holidays. Left turns are prohibited from the highway during these hours; cross-highway movements are made possible through a series of ground loops marked by signs.

The transit element of the project uses the inside, off-peak lane as a bus-only contraflow lane in the peak direction. During the morning peak, the median lane (inside lane) in the outbound direction is separated from the normal flow by removable safety posts and used by Metropolitan Transit Agency (MTA) buses proceeding in the inbound direction (Figure 2). The procedure is reversed in the afternoon. Notice of these lane configuration changes is provided by overhead variable message signs displaying MTA BUS ONLY in the bus direction and LANE CLOSED in the normal traffic direction.

At the beginning of the project, the MTA developed five new routes and expanded an existing one to make a total of 42 runs each in the morning and afternoon (5). This was later reduced to 31 morning and 30 afternoon routes as ridership patterns changed and the project hours were shortened (the original project hours were 6 to 9 a.m. and 4 to 7 p.m.). The buses are known as Blue Dash and have a logo designed specifically for them. A number of park-and-ride locations, primarily in shopping center parking lots, have been designated. One lot, located near Dadeland (a regional shopping center) and convenient to numerous suburban developments, was specifically constructed for the project. This lot is filled to its 200-car capacity nearly every day. Amenities such as shelters and schedule information are provided at all major locations and most walk-up bus stops along the Blue Dash route. The one-way fare is 50 or 60 cents depending on the loading point. An extensive feeder system provides convenient localized pickup points in the market area. From this area the buses all pass through the Dadeland park-and-ride lot before entering the contraflow lane.

The unsignalized median cuts along the corridor are blocked by safety cones to prevent left turns and NO LEFT TURN signs are placed in the left-turn storage bays at signalized intersections. Left turns are permitted onto the highway at signalized intersections, and road striping is designed to keep motorists from entering the buse lane inadvertently. In addition to these precautions, six police officers patrol the project corridor during the peak period. These officers use the blocked left-turn bays to ticket violators and to remove disabled vehicles from the roadway. The buses cross to the right side of the median at S.W. Sixteenth Avenue, where a special traffic signal holds traffic in the peak direction. From there the buses proceed in mixed mode either downtown to the Brickell Avenue office building area or to the Civic Center. In the afternoon the process is reversed, except that the buses enter the contraflow lane via a paved crossover about 0.8 km (0.5 mile) closer to the CBD than Sixteenth Avenue. The entire bus trip requires 9 min (versus about 20 min for single-occupant vehicles).

The car-pool lane uses the inside peak-direction lane for passenger vehicles having two or more occupants. At the outset of the project this lane was separated by yellow safety posts. However, the problems of vehicles attempting to enter or exit the lane as well as maintenance costs forced the elimination of this feature, leaving the lane open but clearly marked by overhead signs. A motorist (with at least one passenger) may enter or exit the lane at any point. The violation rate of the car-pool lane has averaged about 8 percent over the duration of the project, with most of these infractions occurring after dark. The enforcement effort has been focused on maintaining the viability of the lane by apprehending and ticketing violators (4).

In order to further induce the formation of car pools, a car-pool parking lot having a minimal daily charge was established in the CBD. This lot, opened in January 1975, increased in use from 35 to 100 percent daily within 2 months.

The signalization improvements were designed to improve the traffic flow along a 29.8-km (18.5-mile) portion of the highway. Three basic changes were made.

1. The off-set relationships were changed to reference each signal to the green rather than the yellow indication. This improved the green time use by vehicle platoons by providing progression for the beginning of each platoon instead of the end.
2. The cycle length of the signal system was extended from 90 to 114 s, giving extra time to traffic flow along the corridor.
3. Certain multiphase signals were reduced to two phases by eliminating or restricting left turns at some intersections and providing ground loop patterns as alternatives.

These changes have resulted in more efficient movement of highway traffic and had minimal effect on cross-street traffic.

A final element of the project was to build a downtown bus terminal that funnels not only Blue Dash buses but all buses coming into downtown through one facility.

EVALUATION OF THE PROJECT

The evaluation program was based on a predetermined set of criteria established as part of the overall goal of the project. Dade County was responsible for the program and developed the document outlining each task and its expected outputs (2). Numerous surveys were designed to determine the effect of the project on all the users of the highway. Travel times, vehicle counts, accident counts, delay studies, and enforcement studies were made in an effort to measure any operational changes that occurred on the highway as a result of the project.

The six criteria used were project objectives, system usage, service quality, local objectives, national objectives, and operator cost. These criteria were also used to measure, on a coarse level, a number of alternative configurations to determine whether the project as it currently exists is the most efficient, safe, and equitable method to increase the people-moving capacity of the highway.

Effectiveness, in the context of the evaluation, was defined as the degree to which the project increased the people-moving capacity of the highway while providing incentives for the appropriate use of this increased capacity in such a way as to improve the next service quality level provided by the facility. Effectiveness also included the degree to which other beneficial impacts relating to predetermined local and national objectives were achieved. The project's objectives, together with related impacts, were also weighed against cost to determine the cost-effectiveness of the project.

The evaluation continued over 1 year in which various vehicle and occupancy counts were taken. The occupancy counts of the Blue Dash buses were (and still are) conducted on a daily basis. MTA personnel check each bus at the last loading point in the morning and the first loading point in the afternoon. Vehicle and occupancy counts for all other users of the highway were taken on a monthly basis, for durations of 1 week, during 8 of the 12 months of the demonstration. Comparison data had been collected 6 months, 3 months, and 1 month prior to implementation of the project. Mail-back surveys, a telephone survey, and a direct return survey were conducted during the demonstration. A full-scale home interview survey was not conducted because of time and cost limitations. The telephone survey, given to a random sample of business people on and around US-1, contained questions relating to the effect of the project on their business volume. For control purposes the survey was also administered to businesses in other areas.

Only the pertinent data base will be discussed in this report in order to describe the operational and attitudinal performance of the project.

Project Evaluation Data

The initial 1-year evaluation of the project was based on data gathered prior to and following the beginning of the project in July 1974 (1). The post start-up information presented in this paper applies mainly to the first 9 months of project operation.

At the beginning of the project the number of peak-period bus trips in the corridor was increased from 10 to 84, and because of the contraflow lane, transit travel times decreased by 15 to 20 min. These improvements resulted in a corridor transit ridership level, now 2100 and steadily increasing, over five times the level that existed prior to the project. Survey results show that the great majority of these new riders diverted from their automobiles and not from adjacent routes. Service cutbacks in October and February (Figure 3), which were necessary to keep the average load factor at an acceptable level, had little lasting impact on ridership.

The implementation of the car-pool priority lane reduced automobile travel times by 6 to 8 min for users. This time saving, together with the advantage of the car-pool parking lot in downtown Miami, was effective in increas-

Figure 1. Project corridor.

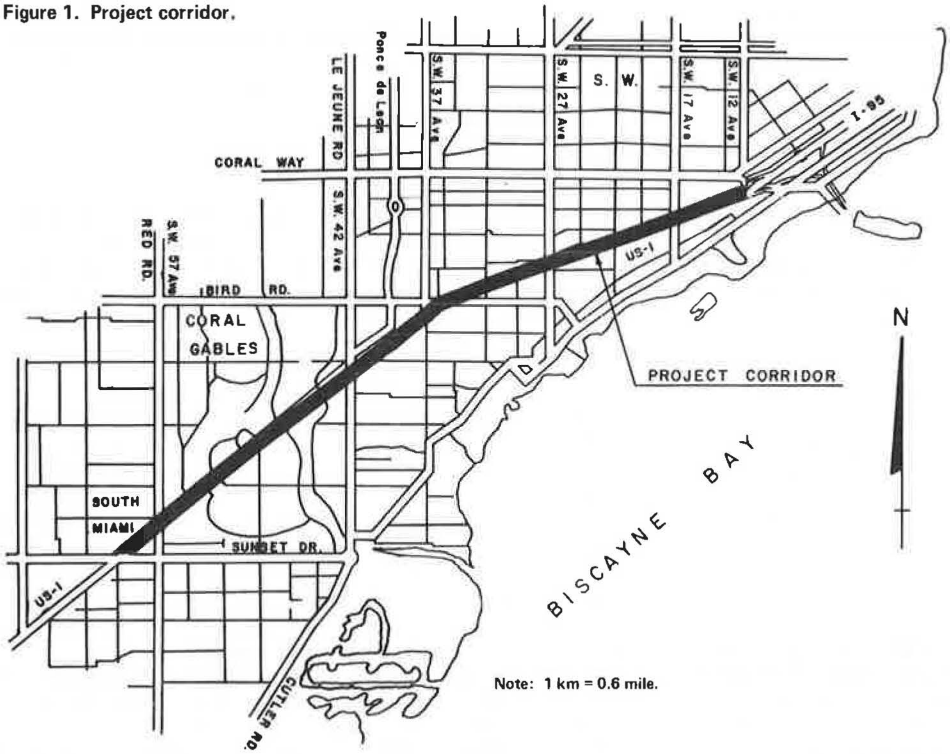


Figure 2. Lane configuration.

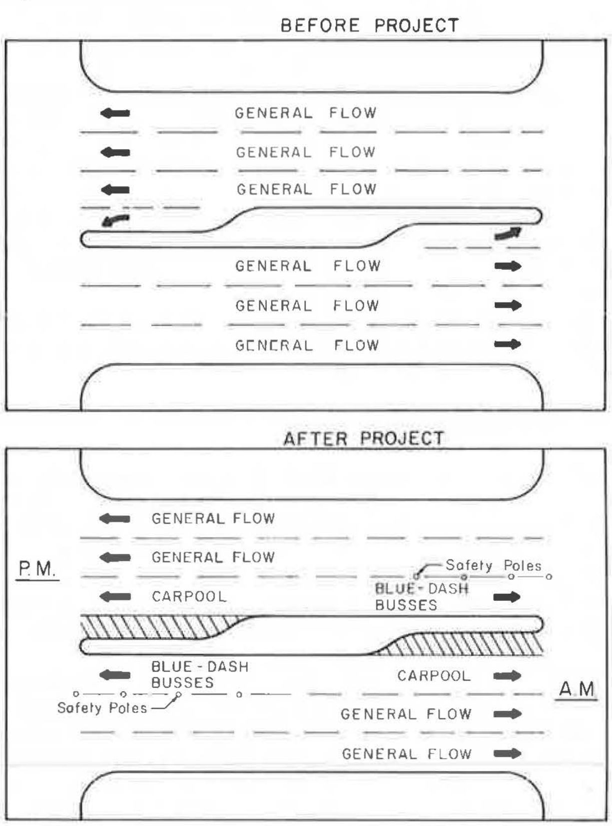


Figure 3. Monthly total ridership.

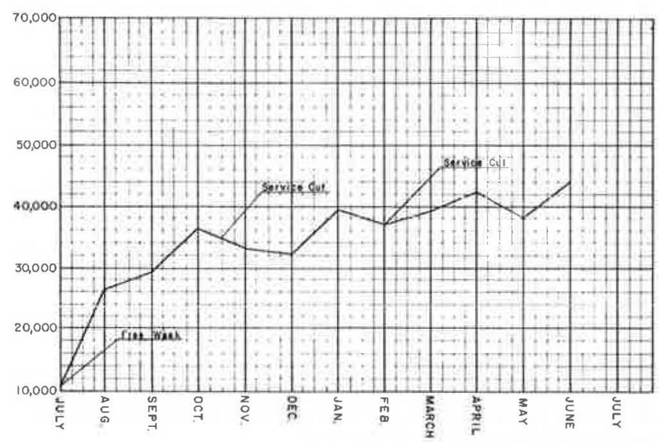
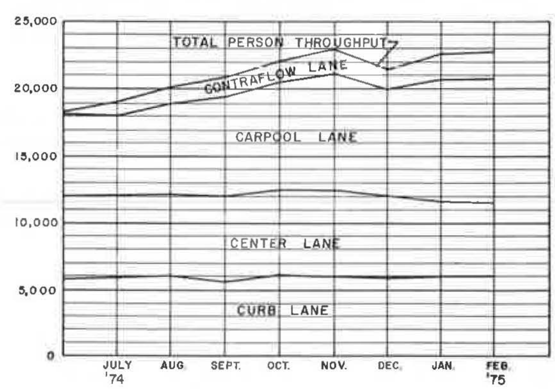


Figure 4. Cumulative lane use (persons), US-1-South Dixie Highway demonstration project.



ing the average automobile occupancy rate for all lanes from 1.30 to 1.45 during the initial 6 months of project operation. At that point, the car-pool lane was carrying up to 40 percent (representing 9000 people/day) of the peak-direction person-trips during project hours (Figure 4). Those persons using the general (center and curb) lanes in the peak direction lost an average of 15 min because of the slight increase in volume. This situation, which was compounded by a greater number of right turns from the curb lane, has since improved slightly.

These increases in transit ridership and automobile occupancy levels have improved the people-moving efficiency of South Dixie Highway in the project area to the extent that the highway now carries 2400 more persons in 350 fewer vehicles/day.

The improved people-moving capacity of the highway was reflected in substantial savings in user travel times (approximately 1000 person-h/day). This figure was based on slightly modified travel speeds and system use values that were necessary to place the before-and-after data into similar reference frames as a result of the fact that total peak-period person-trip demand on the highway increased by about 10 percent during the project time. These travel time savings accrued mainly to those persons who diverted from single-occupant vehicles in the slower general lanes to car-pool vehicles in the faster car-pool priority lane. In addition, users of the project realized savings of more than $3600/day in direct out-of-pocket costs because of the effects of shared travel expenses associated with car pooling and, to a lesser extent, of the relatively inexpensive bus travel.

The car-pool lane, which was the main factor in the travel time and cost savings, is thus a very valuable priority treatment in terms of cost-effectiveness. One key element that ensured the success of the Dade County car-pool lane was the enforcement procedure used. A total of six police officers patrolled the project area during the peak periods creating the high level of enforcement deemed necessary to enforce the left-turn prohibitions and bus and car-pool lane restrictions, as well as control the other problems normally associated with a highly congested arterial highway during peak hours.

One characteristic of the roadway that is extremely important in allowing effective enforcement, particularly of the car-pool lane, is the existence of a median separator with vacant left-turn storage bays during the peak periods. This feature allows high visibility of police officers and permits the use of direct apprehension techniques. The advantage of this situation over that of expressways or arterials with no median separation is obvious.

One aspect of bus and car-pool priority projects (especially those having contraflow bus lanes) that has received attention in recent years is the problem of safety. South Dixie Highway, which contains 15 signalized intersections and numerous curb access points within the project corridor, could be considered one of the most difficult challenges in respect to the implementation of a safe contraflow bus lane. Safety measures used include removable safety posts separating the contraflow lane from the adjacent automobile lane, elimination of left turns, and strict and highly visible enforcement of these and all other traffic regulations.

The number of accidents in the initial 9-month period of project operation was 245 (compared with 148 in the same 9-month period in the preceding year). This increase was shown to be significant at the 95 percent confidence level by the use of nonparametric statistical techniques. Of the increased accidents, many were rear-end collisions; much of the remainder were small increases in left-turn accidents and accidents that involved hitting fixed objects. The rate of bus-related accidents initially increased dramatically but then leveled off at a rate of about 2 accidents/month. On balance, the accident rate has increased, but, in the opinion of local policy makers, not so much as to offset the significant benefits derived from the project.

Transit User Profile

The three user surveys conducted during the evaluation period were the Blue Dash rider survey, the car-pool survey, and the general lanes survey. The transit survey cards were distributed by the bus operators and designed to be either mailed back or returned to the operator. Of the 960 morning riders on survey day, 77 percent returned the cards.

The great majority (94 percent) of transit riders use the service to go to and from work. This was expected because of the nature of the service and the market area. The modal shift to transit was surprisingly high for an automobile-oriented area such as Dade County: Nearly two-thirds of all patrons had driven to work by themselves before the project, and overall 77 percent had used automobiles for their trips prior to the project.

Previous Transit Mode	Bus Riders (%)	Previous Transit Mode	Bus Riders (%)
Automobile with single occupant	65.1	Bus	17.1
Car pool	12.5	Bicycle	3.5
		Other	2.8

Most riders had changed to transit because of the convenience of the service.

Reason for Change to Bus	Bus Riders (%)	Reason for Change to Bus	Bus Riders (%)
Low cost	49.1	Convenience	77.4
Speed	47.4	Other	14.9

The total in the above and later tabulations is greater than 100 percent because of multiple-response counts. It is obvious that speed, though important, is not the overriding factor in shifting to transit, but convenience may have been perceived as a combination of speed, low cost, and other considerations.

Park-and-ride is the most popular mode of access to the transit system and convenient bus stops are second most popular.

Mode of Access to Bus	Bus Riders (%)	Mode of Access to Bus	Bus Riders (%)
Walk	36.5	Bus	1.5
Automobile	45.0	Bicycle	0.7
Automobile passenger	15.8	Other	0.5

The Dadeland park-and-ride lot is the most heavily used facility with 16.3 percent of the riders boarding at that location and some driving over 16 km to reach it.

Six of every 10 riders are female (compared to 7 out of 10 for the MTA system as a whole). The age of the average user is lower than that for the system as a whole (39 percent fall in the 20 to 29 age group). Income ranges are much higher than the county average for bus riders. Nineteen percent reported a family income between $10 000 and $15 000/year and 22 percent between $15 000 and $20 000 or more.

The car-pool and general lanes surveys were of the mail-back variety and were distributed on one day during the afternoon peak period. The general lanes in this context are the two nonpriority lanes in the peak direction.

Twenty percent of the cards given to car poolers and 41 percent of those given to the general lane users were returned.

The CBD generates the largest number of car-pool trips in the afternoon, whereas the South Miami area generates the largest number of morning trips. This origin and destination split also holds true for single-occupant vehicles. The South Miami area is approximately 19 km (12 miles) from the CBD, but car-pool activity also originates as far south as Homestead, 56 km (35 miles) from the CBD. The great acceptance of the car-pool lane makes it important to ascertain why people arrange to double up.

Reason for Car Pooling	Car Poolers (%)	Reason for Car Pooling	Car Poolers (%)
Time advantage	58.7	Companionship	37.4
Monetary reasons	14.2	Other	15.5
Fuel savings	62.6		

The most commonly given reasons were fuel and time savings. Thus, with increasing fuel prices, the use of the car-pool lane will increase and it will gradually lose the time advantage. Future study of this phenomenon will take place as vehicle counts warrant it.

Fifty percent of general lane users do not use the buses because they need their cars during the day, 30 percent complain of inconvenient routes, and 10 percent complain of inconvenient schedules. The same basic question was also asked of this group as to why they do not car pool. Again, the most frequently mentioned reason was need of the car during the day. The second most frequently mentioned reason was inability to find car poolers. Only 17 percent indicated that they would want to help in forming car pools despite the fact that this would remove nearly 200 vehicles from the highway each day. Since all of the car pools were formed through the users' own initiative, and only a small percentage of those not car pooling desire help, the county has not planned to provide an organized car-pool matching service.

In both the car-pool and general lanes, males outnumber females two to one. However, the income distribution of car poolers is not so broad as that of general lanes users.

Income Distribution ($)	Car Poolers (%)	General Lane Users (%)
0 to 3000	2.2	2.4
3000 to 6000	5.0	2.4
6000 to 10 000	9.4	13.5
10 000 to 15 000	12.2	27.1
15 000 to 20 000	18.0	16.4
20 000 and over	53.2	38.2

CONCLUSION

The South Dixie Highway Project was designed to give south Dade County commuters a choice of transit mode. It introduced the public to alternatives to the one-person, one-car philosophy prevalent in this country for many years. For the Blue Dash bus riders, a fast inexpensive alternative to the car was provided; for car poolers, the car-pool lane provided shorter travel times and lower costs than the single-occupant vehicle but maintained the convenience of the private automobile. By the criteria established, the project was successful in fulfilling its goal of moving more people in fewer vehicles.

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Park-and-Ride in the Shirley Highway Corridor

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The market for fixed-route transit operations is not limited to travelers living within walking distance of transit stops. As demonstrated by the Shirley Highway Express-Bus-on-Freeway Project, well-planned park-and-ride operations can lead to sizable increases in bus patronage. Park-and-riders, commuters who travel by automobile to a bus stop and then by bus to work, greatly expanded the market for the fixed-route bus service in the Shirley Highway corridor. After briefly describing the park-and-ride arrangements in this suburban corridor, this paper presents the results of an investigation of the perceptions and mode choice influences of the park-and-riders at two new lots. On-board surveys were used to determine the importance of 12 factors in the commuter's decision to switch from automobile to park-and-ride bus service. The users' subjective satisfaction assessments for these factors and their reported travel-time and costs savings (or losses) were also obtained. These results suggest that several factors in addition to time and cost should be considered in planning park-and-ride facilities.

As traffic congestion and the demand for parking in the downtown sections of many large metropolitan areas have increased in recent years, alternatives to automobile commuting to and from work have become more popular. Park-and-ride transit where the automobile is used to travel to the bus stop is a promising alternative. This paper reviews the performance of a park-and-ride system in the Shirley Highway corridor of northern Virginia and presents a description of the commuters using it. The paper examines the user's perceptions of service features of the system and identifies the factors that influence commuters' mode choice decisions when park-and-ride is developed as an element of a comprehensive transit service improvement using exclusive bus lanes. While the results of this investigation apply directly only to the Shirley Highway corridor, this experience will be of use to transportation planners in the design of strategies to meet the growing demand for commuter transit service from distant suburban communities.

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DESCRIPTION OF THE SYSTEM

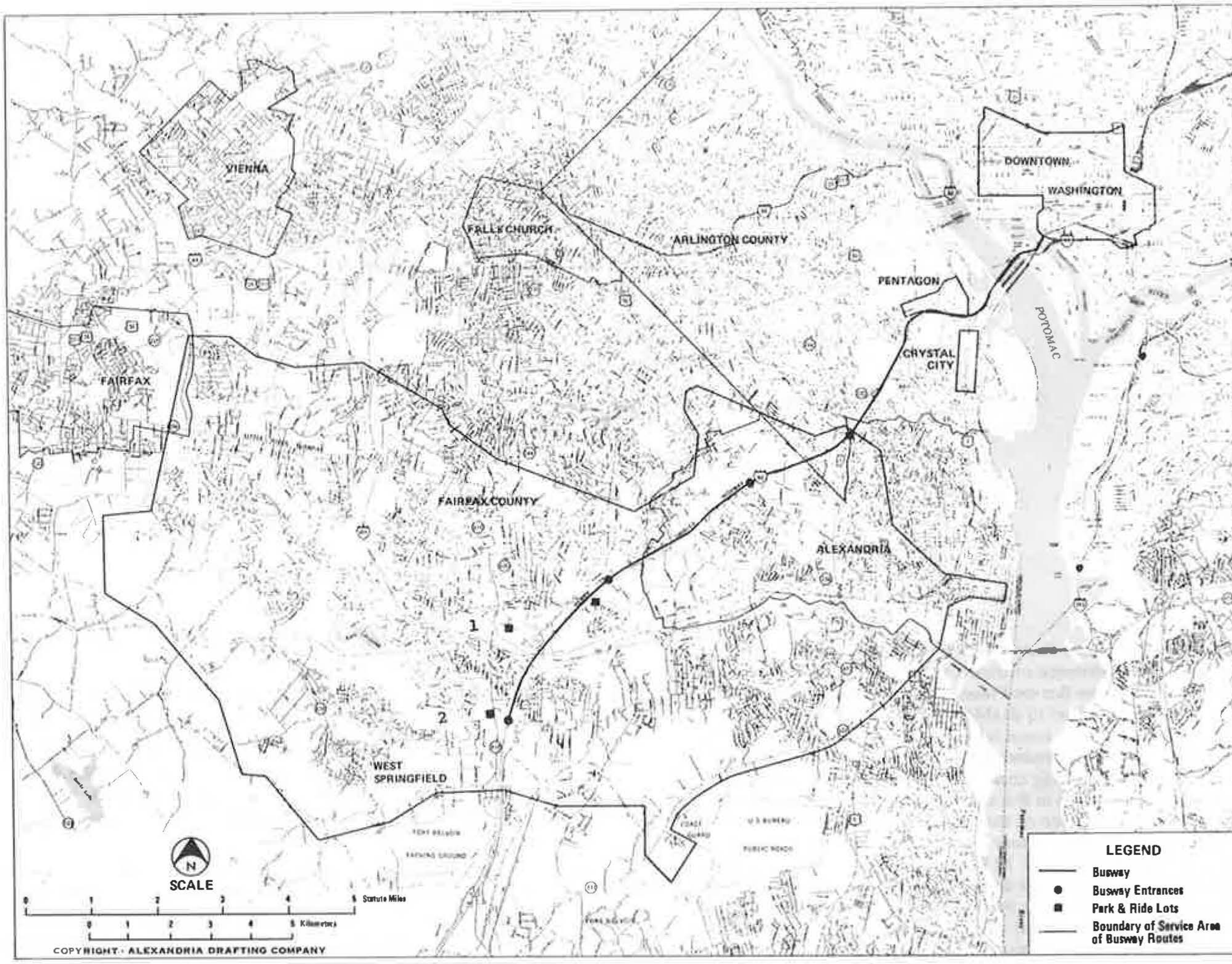
Park-and-riders are an important portion (about 30 percent in November 1974) of bus commuters traveling within the Shirley Highway corridor. Figure 1 shows the area of influence of the bus-on-freeway project and the relative locations of the major park-and-ride lots. The area within the lines is the primary service area of the project routes.

One of the major elements of the project is residential fringe parking coordinated with new transit service on exclusive bus lanes (1). These well-planned park-and-ride facilities provide geographic flexibility for the transit operator by extending the market area of the bus system and increase operating efficiency by minimizing the slower (collection) portion of the trip. After the automobile access trip, commuters board express buses that travel over exclusive lanes to destinations in downtown Washington, D.C., the Pentagon, or Crystal City, Virginia.

These corridor park-and-ride services have been very successful in attracting automobile commuters. The estimated number of daily park-and-riders in the Shirley Highway corridor grew from 4100 in October 1971 to about 7500 in October 1974, and represents 25 and 30 percent of daily corridor bus ridership respectively. Of the more than 900 park-and-riders responding to a November 1973 survey of corridor bus commuters, about 65 percent indicated that they had commuted by automobile prior to using park-and-ride (about 50 percent had driven alone). Thus, in 1974, of 7500 park-and-riders, an estimated 4800 had formerly commuted to work by automobile.

Many transit planners contend that very few suburban commuters will use bus service if they are from multiple automobile-owning or high-income families. This certainly was not true for the park-and-ride bus commuters in the Shirley corridor (Table 1). Park-and-ride commuters have family incomes that are comparable to those of automobile commuters and substantially higher than those of walk-on bus commuters. Similarly, corridor park-and-riders are from families owning about the same number of cars as automobile commuters and considerably more than bus commuters. Park-and-riders and walk-on bus commuters had lower age distributions

Figure 1. Shirley Highway express bus service area.



than the automobile commuters. This increased tendency of younger persons to use the bus service was true even among those who had income distributions similar to those of automobile users.

There are many locations in the Shirley Highway corridor where commuters park-and-ride. However, only three lots have been developed as official park-and-ride locations. Two are in large shopping centers, Springfield Plaza and Shirley Plaza, and the other, Backlick (located at a future Metrorail stop), is a permanent parking facility built specifically to serve park-and-riders. The park-and-ride survey was conducted at the two largest lots—Springfield Plaza and Backlick. Although both the Backlick and Springfield lots are official park-and-ride lots, they are quite different with respect to the quality of service that they provide to bus users. The Backlick lot, which opened in October 1972, is away from shopping development. It has a capacity of 400 automobiles, a drop-off area, a bicycle rack, and a public telephone. However, it is somewhat inaccessible to Shirley Highway and beltway motorists, and the average walk from the automobile parking area to the bus boarding point is about 55 m (60 yd). The Springfield park-and-ride lot, which opened in June 1971, is a designated portion of a shopping center parking lot. It is accessible from Shirley Highway (I-95) via the Springfield exit, and the bus boarding point is near the designated park-and-ride spaces.

Both of these park-and-ride lots are served by the same bus route operated by the Washington Metropolitan Area Transit Authority. At the time the survey was conducted (February 1973), the route began at the Backlick lot and picked up passengers at the Springfield Plaza lot before entering the highway at the Springfield entrance. Thus riders from Backlick were assured of a seat while some riders at Springfield had to stand. (This route was modified in March 1973, reversing the sequence of service at the two lots.) Service is provided by new buses with special interior features (wider seats and carpeted walls and floors). Bus headways in February 1973 averaged 15 min (service is offered only during the peak periods), and travel times between Farragut Square in downtown Washington, D.C., and the Springfield Plaza and Backlick park-and-ride lots averaged 32 and 39 min respectively for trips of 24.5 and 26.5 km (14.7 and 15.9 miles) respectively.

PROJECT SURVEY

Procedure

Surveys to obtain information about the influence of selected features of the park-and-ride service on commuters' mode choice decisions were conducted during the first week of February 1973 at the two major lots—Backlick and Springfield Plaza (designated 1 and 2 respectively in Figure 1). The first 47 passengers boarding each bus were given questionnaires and asked to complete and re-

Table 1. Distributions of selected demographic characteristics of corridor commuters.

Characteristic	Percentage of Users of Transit Mode		
	Park-and-Ride (bus)[a]	All-automobile[b]	Walk-on (bus)[a]
Annual household income ($)			
Under 5000	—	—	1
5001 to 15 000	19	28	34
15 001 to 30 000	66	56	53
Over 30 000	15	14	12
Total	100	100	100
Automobiles/household			
0	1	2	10
1	35	37	63
2	52	50	23
3 or more	12	11	4
Total	100	100	100
Mean automobiles/household	1.78	1.72	1.31
Age (years)			
Under 21	4	1	3
21 to 39	60	44	60
40 to 65	36	54	36
Over 65	0	1	1
Total	100	100	100
Sex			
Males	62	73	56
Females	38	27	54
Total	100	100	100
Number of observations	910	3130	2400

[a]November 1973 survey of bus commuters in the Shirley Highway corridor.
[b]October 1971 survey of automobile commuters in the Shirley Highway corridor.

turn them before leaving the bus. Of approximately 430 people boarding, 420 were given forms and 328 returned them. Two different questionnaires were used—one for former bus users and one for former automobile users. (Park-and-riders were asked their former transit mode by the personnel distributing the forms.) Former all-automobile users were given a yellow form and former all-bus commuters a green one. (Except for the introduction and questions on previous transit mode, the questionnaires were identical.)

The survey form had four sections printed on a stiff paper folder for easier writing while riding the bus. After completing the introductory section dealing with the details of his previous transit mode, the park-and-rider opened the folder to the main section of the questionnaire. [Copies of these questionnaires are presented in another report (2).] The second section focused on the bus service-related features people consider when first deciding to change the way they commute to work and asked the park-and-rider to assign an importance rating to each of a list of such features. (The order of the list was reversed on half of the forms to minimize order effects.) The next section solicited user satisfaction ratings of the same features by asking the rider to assign a satisfaction rating to each of them. The fourth section of the survey form requested detailed travel time and cost information for the previous and present trip, demographic data, and how the user first heard of the bus service at the lot.

Characteristics of Park-and-Riders Using the Service

The survey provided considerable information about the demographic characteristics and trip making behavior of the park-and-riders (2). The characteristics of the former all-automobile commuters, the former regular bus riders, and the users of ad hoc park-and-ride locations are similar (Table 1).

Access to the two lots is primarily by automobile—about 70 percent of the riders drive alone, about 10 percent drive with passengers, and about 4 percent are dropped off. Over 10 percent park near the lots, indicating that some people may have shorter walking distances that way. About 80 percent of the park-and-riders use the lots 5 days/week. The major destination of those boarding at Springfield is downtown Washington (88 percent) while the Pentagon and downtown Washington, with 45 and 41 percent respectively, share the market from Backlick. About 60 percent of the former all-automobile commuters drove alone before using the lots, while over 30 percent car pooled before taking the bus. A third of the former bus commuters walked to a bus boarding point and almost a third parked near a bus stop before using the lots.

The opening of the Backlick lot was accompanied by a concerted advertising campaign that included newspaper advertisements and mass mailings. Almost one-third of the users at the lot first heard of the service through the mail advertisements, another third heard by word of mouth, 17 percent saw the newspaper advertisements, and 10 percent saw the roadway signs indicating the location of the lot. Over half began using the lot when it first opened, 22 percent during the first month, and about 10 percent each succeeding month.

The distributions of access trip distances and travel times indicate how far the bus market can be extended in a suburban area. For the majority of the users of the bus service, the distance between home and the lot was greater than 3.2 km (2 miles); for 20 percent of the park-and-riders, it was as much as 8 km (5 miles). However, even with this large market area, the access time was only about 25 percent of the total door-to-door time. Thus, automobile access can extend bus service over large areas with relatively small time penalties for the commuter.

Factors Influencing Automobile Commuters to Change to Bus Service at Park-and-Ride Lots

The Importance of Service Features

Many factors are important to people when they change their modes of commuting to work. The development of a high-quality park-and-ride service at the two lots provided an opportunity to examine new commuters' assessments of the factors that were important when they first decided to change from all-automobile commuting to bus service at the lots. This study of mode choice behavior relied on the users' perceived values of 12 characteristics of the available modes. Although no attempt was made to develop a quantitative model of park-and-ride mode choice, the results provide insight into the variables that should be considered when suburban park-and-ride facilities are developed.

Table 2 ranks these features based on the percentage of respondents indicating either of highest importance or very important (2). Former automobile commuters at both lots agreed on the relative importance of the 12 features. About 80 percent rated the same 3 features highly: (a) stress and frustration of commuting, (b) schedule reliability, and (c) convenience of arrival and departure times. Over 50 percent rated parking convenience and the difference in door-to-door travel time very high. Seat availability was ranked fifth by the Backlick lot users and seventh by those at Springfield.

Former automobile users at the two lots differed in their assessment of difference in total daily commuting cost: 46 percent of the Springfield riders and only 33 percent of the Backlick riders rated this high. This may reflect the destinations of the users, for about 90 percent of the Springfield riders but only 40 percent of the Backlick riders work in downtown Washington where parking charges are high.

Only 40 percent of the former all-automobile commuters rated availability of evening bus service and security of the parking lot very highly. Riders at both lots gave low ratings to the same three features: (a) making the automobile available to other members of the household, (b) the difference in the amount of walking required, and (c) shelter at the boarding point.

The variations among the importance responses of different sex, age, and income groupings of former automobile users at Backlick were also studied. This analysis indicated that the rankings of the responses of each group were similar to those of its counterpart (e.g., rankings of responses of male commuters were similar to those of female commuters). Former bus users were in general agreement with former all-automobile commuters on the relative importance of the 12 features.

Satisfaction Responses to Service Features

The satisfaction responses are a subjective assessment of the quality of the service provided at the park-and-ride lots. They are, therefore, affected by the service provided at the lots (e.g., actual bus adherence to schedule times) as well as the perceptions of the persons surveyed.

A summary of the satisfaction responses of the former automobile users and users of the prior bus service is given in Table 3 (2). Except for seat availability and parking convenience, park-and-riders at the Backlick lot were generally satisfied with the park-and-ride service. The former bus users were less critical of seat availability, perhaps because they are more accustomed to crowded buses than are former automobile users. Similarly, former automobile commuters, accustomed

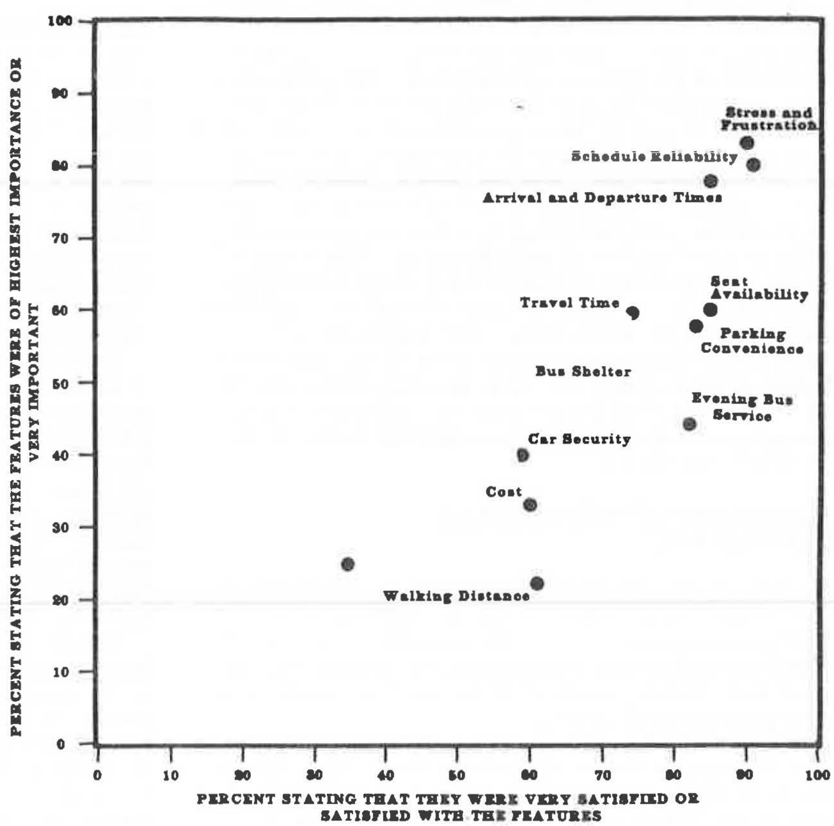
Table 2. Percentage of respondents in February 1973 park-and-ride survey indicating features that were of highest importance or very important.

	Backlick Lot		Springfield Lot
Feature	Former Automobile Users	Former Bus Users	Former Automobile Users
Difference in the level of stress and frustration of commuting	83	71	86
Schedule reliability	80	76	85
Convenience of bus arrival and departure times	78	77	85
Parking convenience	58	36	62
Seat availability	54	64	42
Difference in door-to-door travel time	54	51	69
Availability of late evening bus service	44	40	40
Security of this parking lot	39	21	42
Difference in total daily commuting cost	33	28	46
Shelter at bus boarding point	25	22	13
Difference in required walking	22	19	20
Making automobiles available to others	12	—	3

Table 3. Percentage of respondents in February 1973 park-and-ride survey indicating that they were very satisfied or satisfied with features.

	Backlick Lot		Springfield Lot
Feature	Former Automobile Users	Former Bus Users	Former Automobile Users
Bus schedule reliability	91	90	74
Level of stress and frustration of commuting	90	84	80
Convenience of bus arrival and departure times	85	88	86
Seat availability	85	91	12
Parking convenience	84	72	91
Availability of evening bus service	82	82	88
Door-to-door travel time	74	81	85
Amount of walking required	61	50	88
Total daily commuting cost	60	57	44
Security of this parking lot	59	56	67
Shelter at bus boarding point	35	25	3

Figure 2. Importance versus satisfaction responses of former automobile users at Backlick.



to the parking situation in downtown Washington, appreciated the availability of parking at the lot more than did former bus users.

Satisfaction responses of former automobile users at Springfield Plaza differ from those of their counterparts at Backlick. In contrast to the relatively high degree of satisfaction with schedule reliability and seat availability reported by the former automobile users at Backlick, former automobile users at Springfield reported less satisfaction with the reliability of the bus service provided them and substantially less satisfaction with the availability of seats. Another difference was the lower satisfaction with the walking distance to the boarding point shown by former automobile users at Backlick. In general, the differences in the satisfaction responses of former automobile users are consistent with the differences in the services provided at the two park-and-ride lots. The rankings of the satisfaction responses varied only slightly with age, sex, or income.

Satisfaction Versus Importance Responses

Commuter satisfaction and importance ratings were correlated to investigate further actions that might attract automobile commuters to bus service at park-and-ride lots. The satisfaction and importance responses can be interpreted in the following way.

1. If bus commuters indicate that a feature is relatively unimportant, then any related improvement in this feature should have a low priority even if commuters have expressed dissatisfaction.
2. If bus commuters express dissatisfaction with a feature and place relatively high importance on it, related improvements should be assigned high priorities.
3. If the importance and satisfaction responses of a feature are high, new bus patrons will be attracted and retained.

The relationship of satisfaction and importance responses of former automobile users at the Backlick parking lot is presented in Figure 2. Points in the lower left correspond to features that were rated as unimportant and with which commuters were dissatisfied. Points in the upper right correspond to features that were rated as highly important and with which commuters were satisfied. In general, the former automobile users were satisfied with bus service features that were important to them.

The largest patronage increases would result from strategies directed at interpretation 2 above. For example, at the time of the February 1973 survey, former automobile users at Springfield were dissatisfied with seat availability, which they rated high in importance. At that time, there were about 125 and 250 cars respectively parking in the Springfield and Backlick lots during the peak period. In March 1973 the order of bus service at the two lots was changed so that seat availability and schedule adherence were improved for riders boarding at the Springfield lot. This reduced travel time for riders boarding at the Backlick lot from 39 to 35 min and increased travel time for riders boarding at Springfield from 32 to 44 min.

A second survey identical to the first was conducted at the two lots during the last week of March 1973. At Springfield satisfaction responses of persons not surveyed during the first survey indicated a marked change in rider approval of the availability of seats and bus schedule reliability. At Backlick satisfaction with bus schedule reliability did not change, but satisfaction with the availability of seats declined slightly.

By June 1974 the number of cars parking in the Springfield lot during the peak period had increased to more than 325. Peak-period parking at the Backlick lot remained constant at approximately 250 cars. Some of the increase in the use of the Springfield lot can be attributed to improvements in schedule adherence and seat availability. However, it is also likely that some of the increase at Springfield has occurred because the lot is visible from the Shirley Highway and more accessible to the southern part of the corridor.

Influence of Travel-Time and Parking Cost Savings

Travel-Time Savings for Former Automobile Users

Most inquiries into travel behavior have found that commuters consider travel time and cost as important factors in their mode choice decisions. A comparison of the reported times and parking costs required in commuting by automobile with those required by the present park-and-ride system provides some insight into the significance of these factors for the Shirley Highway corridor commuter.

The perceived or reported travel-time distributions for the various components of the present park-and-ride commute trip and the former automobile trip for the Backlick lot users are presented in Table 4. (The distributions were almost identical at Springfield.) Most of the park-and-riders used less than 20 min to drive to the lot, waited less than 10 min for a bus, spent less than 30 min on the bus, and had an average total travel time of 49.7 min. Previously, they had driven and parked in an average of 46.9 min, and walked to the office in about 6 min. Thus, on an average, the door-to-door time saving was only 3 min for a 50-min trip. A more detailed picture of the door-to-door travel time savings for both Backlick and Springfield users can be seen in Table 5. Sixty-eight percent of the users at both lots had a perceived time saving for the trip while the remainder had increased travel times. The reported travel times of the travel time conscious group (survey respondents who rated travel time as of highest importance or very important) are also presented in Table 5. Even for this group, about 30 percent lost time by using park-and-ride.

Other factors such as stress and frustration and bus service quality were perceived as very important by most park-and-riders. Nonetheless, reported travel-time savings were significant for a majority and cannot be neglected when developing park-and-ride facilities.

Parking Cost Savings for Former Automobile Users

Since parking is free at the park-and-ride lots, downtown automobile commuters often save parking charges when they use the lots. Almost two-thirds of the Backlick riders had previously parked free, but the average cost for those who did pay was $28.70/month. At Springfield, only 29 percent had previously parked free, and the rest paid an average of $29.38/month (Table 6). For comparison, the monthly bus fare was about $29.

The difference in total daily cost to commute was rated more important by the Springfield riders than by the Backlick users. The reported parking costs of the cost conscious group (survey respondents who rated difference in total daily commuting costs as of highest importance or very important) are also shown in Table 6. At both lots, this group saved more in parking charges than other, less cost-sensitive park-and-riders.

SUMMARY OF MAJOR FINDINGS

1. The coordinated development of park-and-ride facilities with express bus lanes and high-quality transit service extended the transit market area and substantially increased transit ridership within the Shirley Highway corridor. The number of daily park-and-riders increased from an estimated 4100 in October 1971 to 7500 in October 1974. Bus commuter surveys have shown that park-and-ride use increased from about 25 percent of the corridor bus ridership in 1971 to about 30 percent in 1974.

2. The majority of corridor commuters are from the higher income, multiple automobile-owing households that are usually associated with all-automobile commuting. Over 60 percent of these former all-automobile commuters drove alone before using the official lots, and about 30 percent car pooled before taking the bus.

3. The surveys at the two major lots suggest the following considerations for the planning and development of suburban park-and-ride facilities:

a. The lot should be served by high-quality bus service to encourage the use of transit. Bus service features such as schedule reliability, convenience of arrival and departure times, and seat availability should be given planning priority.

b. The lot location must be convenient.

c. The lot location and the high-quality bus service must be perceived by the new user as reducing the level of stress and frustration of commuting.

d. For relatively affluent commuters, the perceived travel-time difference between automobile and bus may be more important than the cost difference.

e. Convenience items such as bus shelters, minimal walking distances, car security, and the availability of late-evening bus services are not perceived as very important features.

4. The perceived satisfaction ratings for various features of the park-and-ride service indicated that the former all-automobile commuters are satisfied with the bus service features that are important to them.

5. Satisfaction responses of park-and-riders differed according to their former mode of transit. Former automobile commuters were less sensitive to parking arrangements at the lot and more sensitive to the availability of a seat than were users of the previously existing bus service.

6. Commuters' reactions to the park-and-ride service were independent of age, sex, or income.

CONCLUSIONS AND THOUGHTS FOR FUTURE RESEARCH

In terms of developing suburban park-and-ride facilities to attract former automobile users, the following planning consideration is suggested by this survey: Bus service at the lot should be of high quality to encourage the use of transit. Bus service features such as schedule reliability, convenience of arrival and departure times, and seat availability are all very important to a potential park-and-rider. The lot location and the bus service must be perceived by new users as reducing the level of stress and frustration and providing convenient parking. For affluent commuters, the perceived travel-time difference is more important than the daily cost difference. Lot convenience items such as bus shelters and minimal walking distances, car security, and the availability of late-evening bus service are much less important for new park-and-riders. [Several additional planning guide-

Table 4. Percentage of former automobile commuters at Backlick lot by travel time for trip components.

Trip Component	Travel Time (min) 0 to 10	11 to 20	21 to 30	31 to 45	46 to 60	61 to 75	75	Avg Travel Time (min)
Present park-and-ride trip								
Home to bus stop	58	29	10	1	2	—	—	13.1
Waiting for bus	98	2	—	—	—	—	—	4.9
Line haul	2	36	42	17	2	—	—	26.2
Walk to work	94	3	2	—	—	—	—	5.5
Door-to-door	—	—	9	40	32	15	4	49.7
Former automobile trip								
Home-to-work (park)	1	2	16	38	34	4	4	46.9
Walk to work	90	9	1	—	—	—	—	6.0
Door-to-door	1	—	8	28	39	16	5	52.9

Note: 92 respondents of February 1973 park-and-ride survey.

Table 5. Percentage of former automobile commuters by time saved and lost.

Survey Lot and Group	Time Saved (min) 30	30 to 21	20 to 11	10 to 1	Time Lost (min) 0	1 to 10	11 to 20	21	Avg Time Saving (min)
Backlick									
All (92)	5	8	10	34	11	17	10	5	3.2
Travel time conscious group (49)	8	12	14	33	4	16	6	6	7.9
Springfield									
All (33)	9	15	15	18	—	12	6	24	1.3
Travel time conscious group (23)	9	22	9	22	—	9	9	22	2.5

Table 6. Percentage of former automobile commuters by monthly parking costs.

Survey Lot and Group	Cost Per Month ($) Free	0 to 10	11 to 20	21 to 30	31 to 40	More Than 41	Avg Cost ($)
Backlick							
All	64	12	2	6	8	8	28.70
Cost conscious group (49)	17	23	—	15	23	28	35.97
Springfield							
All (33)	29	14	11	11	20	15	29.38
Cost conscious group (16)	—	8	15	23	38	16	31.35

lines based on the experience of park-and-ride lots throughout the United States are discussed (3).]

This study has focused on the perceived reactions of new users of park-and-ride bus service. An additional approach would be to survey nonusers to obtain their preferences about park-and-ride as a commuting mode. An analysis of the two assessments would then provide considerable insight into mode choice decisions. This survey methodology could also be applied at park-and-ride lots in different suburban environments to develop a comprehensive set of planning guidelines and, perhaps, a mode choice model applicable to different types of commuters and a wider range of park-and-ride service levels.

ACKNOWLEDGMENTS

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High-Performance Bus Rapid Transit Systems: A Design-Process Experiment

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This paper evaluates an experimental approach for designing a bus rapid transit system. The particular system was to serve a single large destination, the University of Washington, and to meet desired levels of performance within a series of constraints regarding its physical characteristics. Five groups of students were given this design problem and asked to find satisfactory solutions using the Urban Transit Analysis System (UTRANS), an interactive graphic system, within a 10-week period. The experimental definition included a large and complex network, a demand set, a cost-benefit framework that includes 23 performance measures, a group-determined set of weights of relative importance for the performance measures, acceptable and ideal standards for the performance measures, a group-determined set of parameters for the modal-split model contained in UTRANS, and a set of upper limits on the size of the system. The five teams generated and evaluated 82 alternative designs and finally recommended 7, all of which had acceptable levels of performance for all 23 objectives. These 7 final designs were compared in physical and performance terms and found to be similar. The design strategies used are discussed briefly, and the experience of one team that processed 28 design alternatives is illustrated. All final designs were quite conventional; no unusual designs having a high level of performance were discovered. The major finding was that inexperienced persons could solve this complex problem in a relatively short time with the aid of the UTRANS system.

This paper reports some results of an experiment designed to assess the utility of an interactive graphics system in the solution of a complex bus rapid transit (BRT) design problem and to determine whether a group of students, most of whom had no prior experience in designing a BRT system, could do so with the aid of such a graphics system. Five teams of students were asked to design a BRT system for the northern portion of Seattle by using the Urban Transit Analysis System (UTRANS). Twenty-three objectives of the problem were specified; the goal of each team was to construct a design that would satisfy or surpass all 23 objectives.

The research design for the experiment was relatively simple. The students were grouped into five teams of three persons each. One person from each team was given a short period of intensive training in how to operate UTRANS, and all were given some basic instruction on the theoretical and practical characteristics of UTRANS. Each team was assigned the same problem and was to work independently. Competition between teams was encouraged. Each team was to have the same amount of computer time (in 2-h blocks) available. The teams were formed by a random selection process, except that each team included at least one person who had had some previous computer experience.

Each team developed a first-cut design on paper and then began the interactive design process. This consisted of looking for ways to improve the current design, making some changes, and then evaluating the modified design. The team was expected to develop some type of design strategy that they felt would, more often than not, help them find a series of successively better designs. The iterative process was to continue until all the available computer time had been used, and the best (not necessarily the last) design obtained was to be presented to the class for discussion and evaluation. Judgments on how to modify a design at each stage of the iteration were to be made by team members using whatever decision-making procedure suited them. Three evaluation objectives for the experiment were determined:

1. How similar or different are the final designs in both visual and quantitative terms?
2. How successful was each team in satisfying the 23 design objectives? How similar or different were the five teams in this respect?
3. What were the characteristics of the design strategies evolved by the successful teams? What were the reasons for unsuccessful efforts on the part of any team?

DEFINITION OF THE BRT DESIGN PROBLEM

Network and Demand Data

The problem selected was the design of a peak-period BRT service from many residential origins to a single destination (i.e., a many-to-one service). The northern part of Seattle was chosen as the setting of the problem (Figure 1). The major destination was the University of Washington, which has a daytime population in excess of

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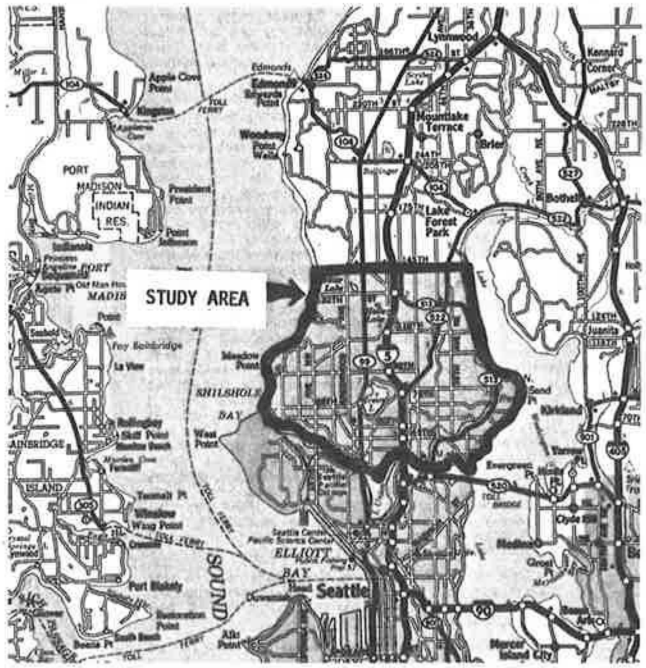


Figure 1. Location of the study area.

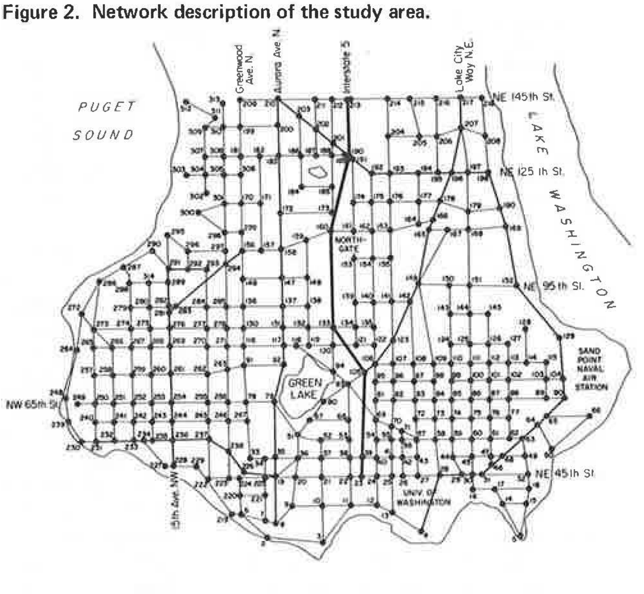


Figure 2. Network description of the study area.

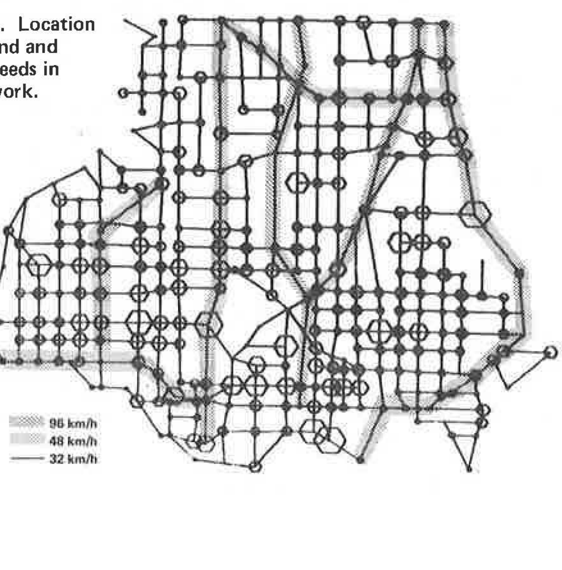


Figure 3. Location of demand and travel speeds in the network.

40 000 (students, faculty, and staff). The actual street system is represented by the network shown in Figure 2, which includes all of the principal streets in the area. The area is bisected by the Interstate 5 freeway, which has six major interchanges in the study area. Figure 3 shows, by a hexagon at each node, the locations of people living in this area who travel to the university daily; the size of the hexagon is proportional to the number of people in the area. The speed assigned to each link in the network is also shown in Figure 3. These two data sets, the network coded with travel times and demand set, are the basic elements that define the spatial structure of the problem.

Behavioral Assumptions

The heart of UTRANS is a modal-split model called the n-dimensional logit model (1) and a capacity-restrained transit assignment model. This model forecasts how any particular BRT design may be expected to perform. It divides all travel to the university among the three modes included in UTRANS: drive, park-and-ride, and walk-and-ride. All 23 performance measures are derived from the results of this modal split and assignment forecast; thus, it is most important for the planner (designer) to understand how it works. Ridership on the transit system is predicted on the basis of the relative disutility to the trip maker of traveling by any of the available modes.

The disutility of travel by each mode was estimated from an analysis of the responses of the students to an attitudinal calibration procedure developed and implemented by Gehner (2). The disutility equations obtained represent the average of the judgments of the group regarding the relative disutility associated with each part of the trip. They are shown below.

Mode	Computation of Disutility
Drive	0.0 + [0.04 x (driving time, min)] + [1.59 x (parking fee, \$)] + [0.06 x (walking time, min)]
Walk-and-ride	0.3 + [0.06 x (walking time, min)] + [0.10 x (waiting time, min)] + [1.97 x (bus fare, \$)] + [0.009 x (bus ride, min)] + [0.06 x (walking time, min)]
Park-and-ride	0.45 + [0.04 x (driving time, min)] + [1.59 x (parking fee, \$)] + [0.10 x (waiting time, min)] + [1.97 x (bus fare, \$)] + [0.009 x (bus ride, min)] + [0.06 x (walking time, min)]

The interpretation of these equations is relatively straightforward. For example, the park-and-ride mode equation shows that a five-cent reduction in the bus fare is valued at 0.05×1.97 or 0.098 disutility units, and since 1 min of waiting time is valued at 0.10 disutility units, one can presume that a typical trip maker would be willing to wait approximately 1 min longer for each five-cent reduction in the bus fare. Or, since a minute of bus riding time is valued at 0.009 disutility units, it would be necessary to reduce the ride time of a bus trip by almost 10 min to have the same effect on the rider as a reduction of only 1 min in waiting. These are the kinds of trade-offs that the designer must be aware of and be able to apply to the problems of improving the system's performance.

The value of the impedance coefficient for bus riding time (0.009 disutility units/min) is very low, especially in relation to the value of time spent driving (0.04 disutility units/min). This difference results in a strong preference for riding the bus rather than driving. If this attitude were widely held, it would provide an optimistic situation for high levels of transit ridership.

Performance Measures Used to Evaluate Alternative BRT Designs

All evaluations of alternative designs were based on the values of the 23 performance measures shown in the benefit and cost evaluation trees in Figure 4. The 10 benefit measures are defined so that more is better, and the 13 cost measures are defined so that less is better. Considerable classroom time was spent discussing these measures and their definitions. They are not ideal in every respect but are relatively independent of each other and adequate for the purposes of this experiment.

The values of these performance measures are derived from the mode split and assignment calculations of UTRANS and from other input data. They represent forecasts of performance and must be interpreted in relation to the behavioral assumptions described by the disutility equations discussed above. Once these performance measures have been defined and discussed their relative importance must be determined, since they are not all equally important.

Estimation of Relative Weighting of Performance Measures

The performance measures were then weighted by the students to provide values for their relative importance. Each student's weights and the entire groups' average values were calculated by the method of hierarchical comparisons (3). The average values are shown below.

Performance Measure	Relative Importance Weight	Group Rank
Benefits		
Percentage within 5-min walk of bus stop	0.271	1
Percentage within 5-min drive of lot	0.152	2
Percentage of bus capacity used	0.109	3
Percentage using walk-and-ride mode	0.102	4
Percentage of fuel saved	0.082	5
Bus-operations profit	0.079	6
Percentage of lot capacity used	0.077	7
Percentage using park-and-ride mode	0.070	8
Lot-operations profit	0.052	9
Probability of obtaining a seat	0.000	10
Costs		
Average waiting time	0.347	1
Average access time walking to bus stop	0.232	2
Average access time driving to lot	0.175	3
Average riding time in bus	0.128	4
Average lot fee	0.024	5
Average bus fare	0.021	6
Crowdedness of bus	0.013	7
Bus capital cost	0.012	8
Walk-and-ride equity	0.010	9
Park-and-ride equity	0.008	10
Impact of park-and-ride lot	0.008	11
Park-and-ride lot capital cost	0.008	12
Impact of bus operations	0.007	13

The top four performance measures in each category received a very large portion of the total weight. These results were adopted by the group as one of the means by which to evaluate the alternative designs and, in operational terms, became important rules of the game. For example, a design that has a very low average waiting time will receive a high evaluation because of its heavy weight. Conversely, the designer need not pay much attention to the impact of bus operations or the probability of obtaining a seat since both have low weights.

Estimation of Acceptable and Ideal Standards for Performance Measures

The next step in the definition of the problem was for each participant to indicate acceptable and ideal levels for each performance measure. The average values for the group are shown below.

Performance Measure	Acceptable	Ideal
Benefits		
Probability of obtaining a seat	0.7	0.9
Percentage within 5-min walk of bus stop	52.0	79.3
Percentage within 5-min drive of lot	47.3	78.7
Percentage of bus capacity used	61.0	83.0
Percentage of lot capacity used	62.5	85.6
Percentage using walk-and-ride mode	19.3	34.3
Percentage using park-and-ride mode	20.3	34.7
Percentage of fuel saved	13.7	30.1
Bus-operations profit	-4 433.0	966.7
Lot-operations profit	-43.3	160.0
Costs		
Average riding time	13.2	7.2
Average waiting time	6.9	2.7
Average access time walking to bus stop	8.3	4.1
Average access time driving to lot	7.8	3.5
Average bus fare	30.7	10.7
Average lot fee	37.1	11.7
Crowdedness of bus	1.0	0.5
Walk-and-ride equity	15.0	5.0
Park-and-ride equity	10.3	2.3
Impact of park-and-ride lot	5.7	3.0
Impact of bus operations	57.8	29.5
Bus capital cost ($)	2 000 000.0	1 000 000.0
Park-and-ride lot capital cost ($)	500 000.0	500 000.0

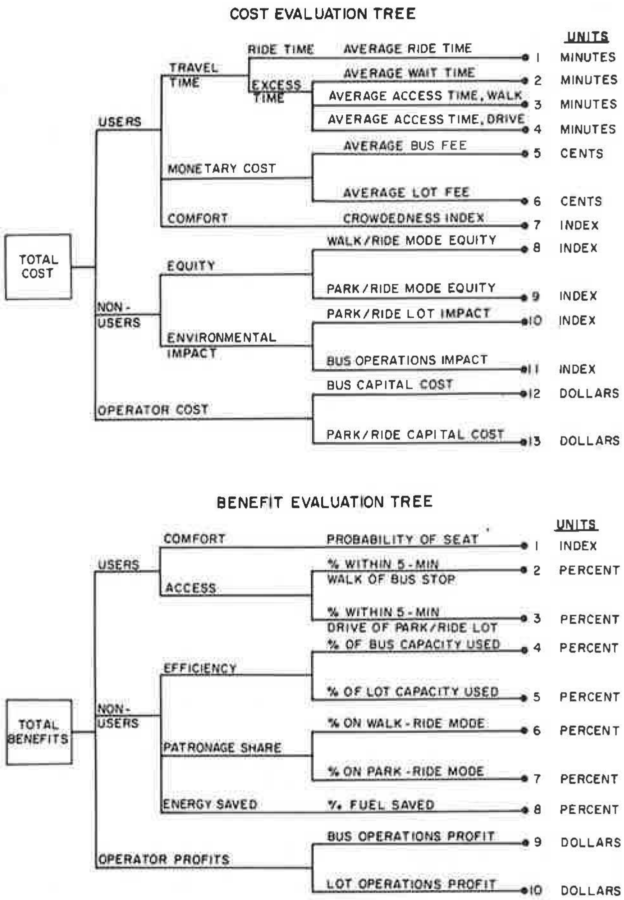
These values defined the performance objectives for the design problem since the design teams were asked to design a system that would, minimally, meet or surpass all of the acceptable standards. The teams were also asked to try to design a system that would meet or surpass all the ideal standards, but it was recognized that this was probably not possible. This standards-setting exercise produced a set of acceptable standards that was reasonably loose and a set of ideal standards that was quite high. (One of the reasons the acceptable standards were so low was that many students viewed the task of solving the design problem with great trepidation and generated low acceptable standards as an initial way of reducing the magnitude of the problem. Still, with the exception of the very large bus-operation deficit that was judged to be acceptable, the standards were not unreasonable in view of the performance of many actual bus operations.)

These estimates of relative importance and of standards for the performance measures provide the means of evaluating alternative designs. The best design is the one that maximizes a weighted index obtained from values for each of the performance measures. The establishment of acceptable standards also defines a set of constraints that determine acceptable designs.

Hardware, Software, and Environmental Constraints

A further definition of the design problem was made by imposing a set of constraints. Some of these constraints were due to hardware or software limitations of the computer system. Others were included to represent typical environmental constraints that always appear in problems

Figure 4. The benefit-cost evaluation framework.



of this nature. These constraints were (a) no more than 70 bus stops and 20 separate bus lines, (b) no more than 20 park-and-ride lots and no lot larger than 1000 spaces, (c) an all-day parking fee of 25 cents and an average walking time to the destination of 10 min for the automobile mode, and (d) a walking time of 5 min to the final destination for the bus mode.

Together, the six elements just described (i.e., the network and demand data; the three disutility equations; the 23 performance measures; the relative importance weights; the acceptable and ideal standards; and the hardware, software, and environmental constraints) constituted the formal definition of the design problem. In addition to assimilating this information, the student had to be able to derive trade-off estimates from the coefficients of the disutility equations and master the procedures needed to operate UTRANS. This process of problem definition and the presentation of the UTRANS model required about 15 h of classroom instruction and was an essential background for conducting the design process.

CHARACTERISTICS OF PARTICIPANTS AND UTRANS OPERATION

Participants

Fifteen students, undergraduate and graduate, took part in the experiment. Only one of these had had any previous experience with interactive graphic systems and only one had previously worked with UTRANS. None had had any experience with BRT system design. Most had been motivated to participate by the desire to obtain some hands-on experience with an interactive graphics system. Unfortunately, because of the large size of the group and the limited hardware available, only one person from each team was allowed to operate the computer, although the others were able to observe the operation of UTRANS closely and participate in the problem-solving process (both on and off line).

UTRANS Operation

The origins, evolution, and characteristics of UTRANS are well documented (4, 5, 6, 7) and will not be discussed extensively here. Briefly, UTRANS is operated as shown in Figure 5. It is structured to assist a planner in generating and evaluating alternative BRT system designs for service to major urban activity centers but is limited to cases having many dispersed origins and one major destination. In operation, the planner is presented with a display of the street network, the demand patterns (i.e., the location of the people who desire to travel to the major activity center), and a display of land values superimposed on the street network. The planner lays out a first-cut transit system design, entering the route structure and operating variables through a graphics terminal. The design variables are then input to a modal-split and transit-assignment model that estimates the proportion of trip makers who will use each of three modes to go from their homes to the destination. This model is the heart of UTRANS since the evaluation of alternative designs is derived wholly from its prediction of the expected performance of each design. The prediction procedure is based on the following assumptions:

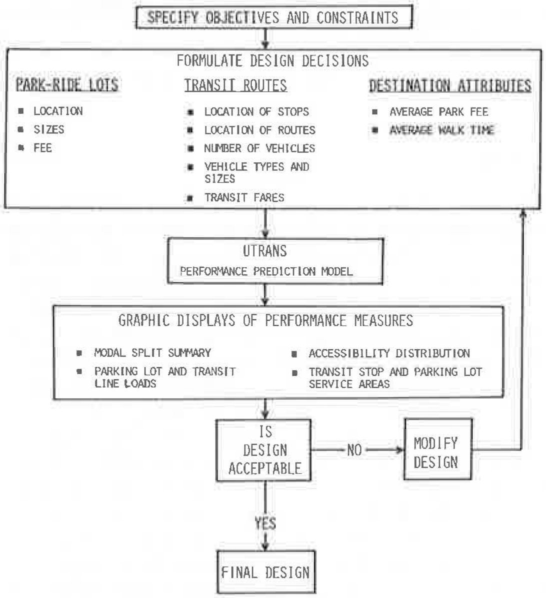
1. Each trip maker selects from among walk-and-ride, park-and-ride, or drive modes;
2. The trip maker's choice depends on the relative difficulty (or impedance) that he or she perceives for each mode;
3. The total impedance of a mode is the sum of the impedances associated with the several elements of a trip by that mode;
4. Each element of a trip is multiplied by an impedance coefficient that estimates the relative disutility associated with that type of activity;
5. The smaller the total impedance of each mode the more likely it is that a trip maker will select it;
6. The share of the available patronage attracted by each of the three modes is inversely proportional (in a negative exponential manner) to the overall impedance of the mode; and
7. The patronage shares are limited by the capacity of the transit system.

The outputs of the model are as follows:

1. The percentage of trip makers who use each of the three modes;
2. For each transit stop and park-and-ride lot, the volume of patrons who walk or drive (if the stop has a parking lot) to it;
3. For each transit line and parking lot, the costs and revenues of operation (including capital costs); and
4. The total systems costs and revenue on a daily (24-h) basis (the difference between these two figures is the overall daily profit or loss to the system). This information is presented to the planner in tabular and graphic form on the graphics terminal.

In the first cycle, the planner structures a first-cut design and the computer evaluates it and presents him with a variety of displays for examination. His task is then to develop ideas to modify the design in order to improve it. He may add park-and-ride lots, change park-

Figure 5. Steps in the operational use of UTRANS.



ing fees, increase the number of buses on a route, or modify the first-cut design in any other way. The revised design is evaluated by the computer and a new set of displays and a new listing of performance measures are presented. This procedure is repeated until the planner achieves a satisfactory design or is otherwise forced to conclude his effort. This is the process that was used by each of the five teams in the experiment.

RESULTS

The results of the experiment are described in relation to the three evaluation objectives posed as questions above. The five teams submitted seven designs (two teams submitted two designs each), which will be analyzed to address these questions.

Visual and Quantitative Characteristics of the Recommended Designs

Photographs of the seven recommended designs are given in Figure 6. They are all complex and are difficult to compare in visual terms. Most of the designs used a variety of line configurations throughout the study area; design 5 differs in that it contains mostly east-west lines to the west of the Interstate 5 freeway and mostly north-south lines east of the freeway. All of the designs cover the study area with stops at a fairly uniform density.

All of the designs had similar physical attributes (see Table 1). A correlation analysis of these attributes showed that all the pairwise correlation coefficients were greater than 0.98. The only constraint that was binding in nearly all designs was the number of bus stops. The least binding constraint was the number of park-and-ride lots since no team that tried a design with a large number of park-and-ride lots found it successful. In future work, an effort will be made to increase the number of bus stops allowed (currently a hardware limitation) so that the designer has greater latitude in creating innovative designs.

Comparison of the Performance of Recommended Designs

Values of the performance measures can be used in conjunction with the relative weights and standards to obtain abstract total costs and benefits for each design (3). The rank ordering of the final designs obtained from an incremental benefit versus cost analysis and the final cost versus benefit ratios is given below. This rank ordering obscures the high degree of similarity among the designs; only design 2 is significantly different from the others in terms of total performance.

Rank	Design	Cost/Benefit Scores	Rank	Design	Cost/Benefit Scores
1	4b	0.28	5	3	0.31
2	5	0.28	6	1a	0.31
3	4a	0.30	7	2	0.38
4	1b	0.30			

Pairwise comparisons of the designs were made by calculating simple correlation coefficients between performance measures.

Design	1b	2	3	4a	4b	5
1a	0.95	0.84	0.92	0.80	0.89	0.65
1b		0.86	0.94	0.87	0.93	0.72
2			0.85	0.88	0.84	0.81
3				0.79	0.88	0.64
4					0.93	0.90
4b						0.77

All of these coefficients are positive and quite large (the overall average value is 0.83) because all of the final designs were similar in terms of their performance. Only design 5, which has below-average correlation coefficients, is somewhat different from the others.

A large part of the reason for such highly similar designs may be attributed to the fact that most of the design teams were limited by the same constraint (the number of bus stops) toward the end of the design process. A second reason for the similarity of the designs is that the design teams were quick to imitate each other's successes. If one team found a way to increase the values of certain measures, then other teams who heard about it were quick to employ the same technique. Beyond these two possible explanations, there is the possibility that there is a very large number (e.g., thousands) of alternative design solutions for this problem that have a high level of performance. If this is true, then the similarity of the recommended designs should be viewed as an expected, rather than an unexpected, result.

The performance measures can be arranged in three groups. Group 1 contains the five measures that were consistently above the ideal standard in all seven final designs. These measures were the most easily satisfied: average waiting time, average parking lot fee, percentage within 5-min drive of lot, percentage of fuel saved, and lot capital cost. The 13 measures in group 2 were consistently above the acceptable standard but did not exceed the ideal standard; these were the most difficult measures to improve and none of the design teams could raise them to the ideal level. They were: impact of parking lot, bus-operations profit, average riding time in bus, average access time walking to stop, average bus fare, probability of obtaining a seat, percentage of bus capacity used, percentage within 5-min walk to bus stop, percentage using walk-and-ride mode, walk-and-ride equity, percentage using park-and-ride mode, park-and-ride equity, and bus capital cost. Group 3 contains the five measures for which mixed results were obtained, with some exceeding the ideal standards while others were between the acceptable and ideal standards. These were: percentage of parking lot capacity used, crowdedness of bus, impact of bus operations, average access time driving to lot, and lot operations profit.

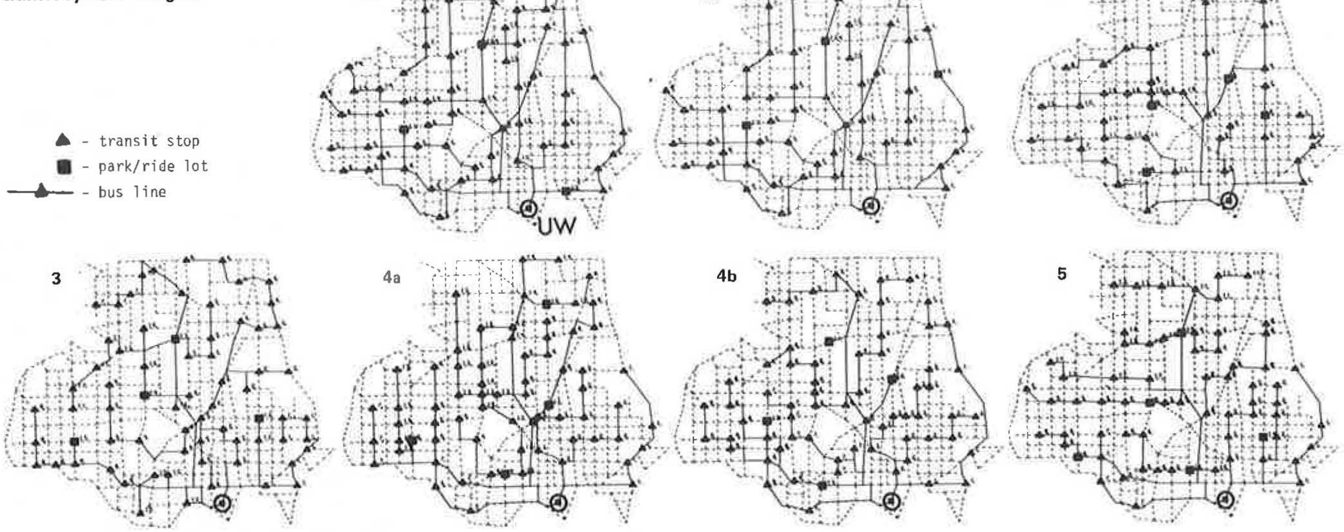


Figure 6. The seven recommended transit system designs.

Table 1. Comparison of the physical attributes of the seven recommended designs.

Item	Number of Buses	Number of Lines	Number of Stops	Number of Park-and-Ride Lots	Number of Park-and-Ride Lot Spaces
Constraint	None	≤20	≤70	≤20	≤20 000
Design					
1a	81	14	63	3	1 200
1b	93	13	57	3	1 050
2	44	11	41	4	1 135
3	65	16	68	4	1 200
4a	74	15	70	4	1 150
4b	87	13	68	4	1 220
5	85	16	68	5	1 450

The measure for bus capital cost (at the end of group 2) is noticeable since all designs barely exceeded the acceptable standard. Apparently the acceptable limit is a maximum cost for the bus transit system; this in effect produces one additional constraint that the design must meet. That is, if the students had been given a larger budget, they could have purchased more buses and thereby improved service levels, which would have improved many of the other performance measures. It also appears that, at the level of system performance obtained in the final designs, the trade-off between bus capital cost and other costs, such as environmental impact, would have readily allowed greater costs in these other areas if additional capital expenditures had been allowed. If the highly optimistic behavioral assumptions of the experiment are valid, the major limitation to obtaining high levels of ridership on the transit system is the number of buses that can be purchased with the budget allowed.

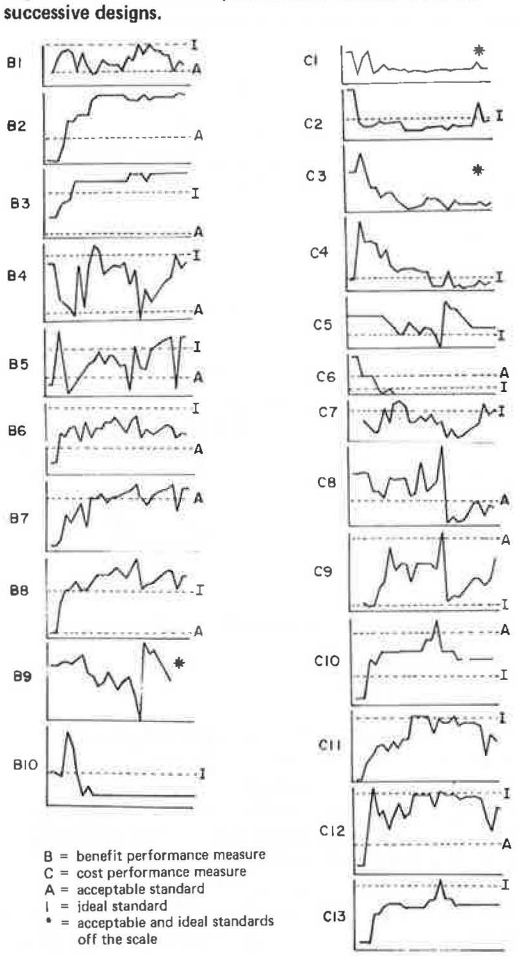
For the remainder of the performance measures, only the pattern of the results is of general interest. If these groupings are typical of the results that can be expected from alternative design studies, then the evaluation process could be greatly simplified by focusing on the performance measures that are substantially different among the designs (e.g., in this case 5 out of 23). This would be much more practical and comprehensible than trying to deal with the entire set simultaneously. This result needs to be tested several times before its general validity can be established, but it is consistent with at least one previous study of this question (8).

Problem-Solving Strategies

Each team was urged to devise some type of problem-solving strategy prior to beginning work on the computer. Previous experience had shown that an incremental approach, which starts with a simple design and then adds to it, tends to be a more successful strategy than a grand design approach that creates a large and complex design and then modifies it in successive stages. Since all of the teams viewed the problem as very formidable, all opted for the incremental strategy as the least risky approach to a satisfactory solution. Beyond this, very little can be said of a general nature about the strategies employed and the experiences of the five teams. All teams did experience some difficulty with particular performance measures, but the measures differed among the teams depending on the nature of their early designs. In general the teams did not use the performance measure weights in attempts to obtain designs that had high levels of performance in the heavily weighted measures. Instead they concentrated on surpassing the acceptable standards and on attempting to reach the ideal standards for all performance measures without regard for the relative importance weights.

Perhaps the best way to convey the nature of this experience is to show the results of one team's total design experience. Figure 7 illustrates the tracks of all 23 performance measures for the 28 designs generated and evaluated by the team. By plotting these tracks in relation to the acceptable and ideal standards, the team was quickly able to see which performance measures were moving together, which were related inversely, and which were the most independent. They could also see where improvement in performance was most needed. After about 15 designs, this team became thoroughly frustrated because of their inability to find a way to bring certain performance measures above the acceptable level. At this point, they gave up their intuitively based trial-and-error procedures and began some systematic experiments designed to determine what would be required to move the troublesome performance measures in the desired direction. These successful experiments provided the information needed to eventually arrive at a design that had an acceptable or ideal level of performance across the board.

Figure 7. Tracks for the performance measures for 28 successive designs.



The other teams did not generate and evaluate as large a number of designs, but most used a similar strategy. Altogether, the five teams generated and evaluated 82 different designs.

CONCLUSIONS

The results of this experiment indicate that a group of inexperienced persons can, by using UTRANS, design a complex and high-performance bus transit system in a period of about 10 weeks. The fact that the designs were so similar, both in physical and performance terms, was an unexpected result, since the students had entered the design process with few preconceived notions or design principles in mind and were expected to produce some very different designs. Instead, the designs produced were rather conventional, and no unusual or innovative concepts emerged from the process. (By the end of the course, several students felt that they were now ready to begin some innovative design work.)

The results obtained depend on the values of the parameters chosen for the modal-split model, the relative importance weights given to each performance measure, the objectives specified for the problem in terms of acceptable and ideal standards, and the constraints imposed on the physical attributes of the design. These conditions were generally fairly loose and led to the discovery of acceptable designs early in the course. This early success allowed several teams to try to find a plan that would surpass the ideal standards in every respect, but none were able to do so.

The high degree of similarity in the results obtained is encouraging in one respect. If such results were obtained frequently, the task of conducting the comparative evaluation and selection of a preferred design would be greatly simplified. However, additional studies are needed before it can be determined whether highly similar designs are more or less likely to occur than highly varied ones.

Future investigations of this topic are needed in at least three areas. First, the relations between the design variables and the various performance measures must be defined so that the designer can use them to make decisions as to how to modify a particular design so that it will have better performance. For example, if the designer wants to increase the performance measures J and K without reducing X and Y substantially, he needs to be able to determine which changes in which design variables would be most likely to produce the desired result. The availability of this type of information would be of great assistance, but it is not currently accessible in an easy-to-understand form. Second, the relations between the various performance measures should be defined so that the designer can know which ones are highly correlated and which are relatively independent. If it could be shown that certain performance measures are always highly and positively correlated, then some of them could be eliminated to avoid the double-counting problem that may be a factor whenever two performance measures move too closely together. Third, the search for unconventional designs that have high performance ratings should receive more attention. For example, in the experiment reported here, designs with a large number of small park-and-ride lots were not investigated to any substantial degree. Until all the major options have been investigated, the true solution for this type of design problem will not be known.

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Abridgment

Evaluation of Public Transit Services: The Level-of-Service Concept

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In recent years privately owned urban mass transportation has almost disappeared and been replaced by public operations. While there are many reasons for this change, the key factor appears to have been the rapidly increased costs of operation. Inflation has affected all labor-intensive industries but has been particularly severe on transit, which has required ever-increasing subsidies.

These increased subsidies have made the need for evaluation of transit increasingly evident. New evaluative methods for measures of both efficiency and effectiveness are required.

EVALUATION FRAMEWORK

There are four primary elements of service to be evaluated: cost, amount, impacts, and quality. The cost of service applies to the user and to the governments that supply subsidy funds. In terms of public administration theory, its evaluation is a management or efficiency evaluation. The amount of service can be readily quantified and the impacts of service can be construed to be part of a substantive evaluation. However, the quality of service is difficult to describe meaningfully since there are no generally accepted sets of standards or criteria by which quality can be measured.

Thus, there is the problem of qualitative evaluation and its integration with quantitative review. A possible model for the evaluation of transportation that could provide such an integration is shown in Figure 1.

The quality measures of urban transit can be placed in two categories, transportation hygiene factors and level-of-service (LOS) indicators. If the hygiene factors theory of job motivation is extended to a transit operation, there would be certain attributes that would create satisfaction, but the absence of such attributes, although it might discourage and displease riders, would not dissatisfy to the point of causing people to change modes.

The theory of transportation hygiene has value in that such a categorization may explain why operations with clean safe equipment may have very few riders: All hygiene factors may be met (no dissatisfaction), but the level of service be very poor (no satisfaction either). In these terms, only the LOS indicators motivate behaviorial change by those who have an option; hygiene factors are subjective qualities that are necessary but are never permanently satisfied, need continual improvement, and seem, in this context, most related to maintenance and equipment costs. While there is tremendous need to investigate and develop meaningful measures for transportation hygiene factors, this paper further addresses only LOS.

LEVEL OF SERVICE

The familiarity of local officials and technicians with the LOS concept in pedestrian planning (2) and traffic engineering appears to be the source of the term in public transit evaluation. (If transit LOS standards can be defined in terms already comprehended by policy makers and technicians, so much the better.) As the Institute of Transportation Engineers has noted (3), "Levels of service are tools equally useful to the traffic engineer and the administrator, yet also apparent to the average driver."

The following parameters are used to define transit LOS: a composite of basic accessibility, travel time, reliability, directness of service, frequency of service, and passenger density. The operationalism of the concept must be evaluated according to whether it is (a) user oriented rather than operator oriented, (b) operations oriented rather than facility or equipment oriented, (c) trip (or link) specific rather than area related, (d) quantifiable by an independent observer, (e) independent of an evaluation of efficiency measures and effects or impacts, and (f) exclusive of any transportation hygiene factors.

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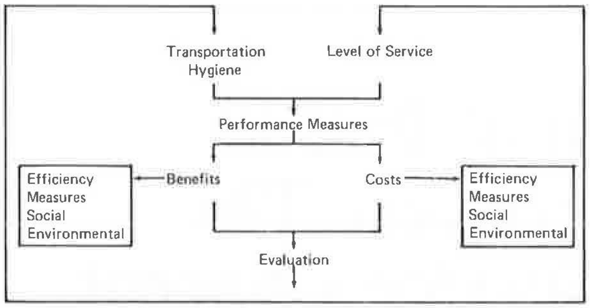
Figure 1. Transportation evaluation model.



CONCEPTUAL INDICATORS AND OPERATIONAL DEFINITIONS

At present, there is no consensus as to what indicators should be used, their relative importance or meaning, or how to measure some of them (4, 5, 6, 7). Public and private researchers and administrators have proposed numerous factors (4, 8, 9, 10, 11, 12, 13, 14), but few have quantified these measures. Work completed more than 15 years ago by the National Committee on Urban Transportation (NCUT) (15) is almost the only source of criteria and standards that are close to being the equivalent of commonly accepted principles. The first problem then is to develop operational definitions.

It is first necessary to determine basic accessibility. If there is no transit reasonably available, then there can be no LOS, but if we assume basic accessibility (indicator 1) then the relative accessibility can be used to determine the transit access time (indicator 1A), which is defined as the time necessary to get to transit from the trip origin and then from transit to the trip destination. A basic requirement for this indicator is that the trip be accessible to pedestrians at least at one end. While this indicator is defined in terms of time, it may also be defined in terms of distance, but this requires several subdivisions into modes of access (Table 1). Level C represents the commonly accepted distance for pedestrians to travel to transit. Under this standard time remains constant and distance changes in relation to mode.

Indicator 2, travel time, measures the ability of transit to compete with the private automobile. The index for this is simply the travel time by transit divided by the travel time by automobile (15), shown below. In this case, transit access time is not included in the calculation of total travel time.

Level of Service	Index	Comment
A	<1.00	Best service; transit is faster than automobile
B	1.00 to 1.10	Transit is 10 percent slower than automobile
C	1.11 to 1.34	Transit is up to 33 percent slower than automobile
D	1.34 to 1.50	Transit is 50 percent slower than automobile
E	1.51 to 2.00	Transit is no more than twice as slow as automobile
F	>2.00	Transit is more than twice as slow as automobile; service available only for transit-dependent people

Indicator 3, the reliability of transit, is related to frequency: the more frequent the service, the lower the importance of early or late service (Table 2). Similarly, the less frequent the service, the more important the reliability. LOS C with a service frequency of 9 to 12 min is the same as that recommended by NCUT for peak-hour operations (15).

Some may say that transit should not be expected to adhere to strict on-time performance since traffic congestion, accidents, or weather may severely hamper operations. In most places poor weather is always a problem during certain seasons and can be calculated into time tables. Accidents can also sabotage adherence to schedules but, in truth, they either rarely hurt schedules or are so common as to always prevent adherence. Traffic congestion is a continuing fact in most cities during peak travel hours; the extra time needed for travel should be included in the assigned schedule times. Finally, some argue that reliability is less important than a tight schedule that encourages drivers to provide the fastest service possible (6). However, properly developed trip tables accomplish the same result while providing accurate information to the public. There is no reason that schedules for employees and those for the public cannot be identical.

The fourth indicator is the directness of service. People generally do not like to transfer to complete a trip and the time necessary to transfer is as important to riders as the actual need to make a transfer and the number of transfers to be made, as shown below.

Level of Service	Number of Transfers	Wait Time (min)	Level of Service	Number of Transfers	Wait Time (min)
A	0	–	D	2	<5
B	1	<5	E	2	>5
C	1	5 to 10	F	3 or more	–
D	1	>10			

Indicator 5, the frequency of service, should be a function of demand, which is related to the population densities at each trip end. However, frequency of service is a chicken-and-the-egg situation: There must be some initial (policy) frequency. Policy headways based on varying population densities are suggested in Table 3.

The final indicator is the passenger density, indicator 6. From the perspective of the user, any density greater than 1 person/seat is undesirable and, where standing would be required for considerable periods of time or at high speeds, the undesirable becomes the unacceptable (see below).

Level of Service	Passenger Density
A	Individual separated seat or high-back row seat per passenger
B	1 seat/passenger; parallel rows of upholstered seats with minimum of 0.46 m^2/person
C	1 seat/passenger; parallel rows of molded seats with minimum of 0.46 m^2/person
D	Perimeter seating; 0.28 to 0.46 m^2/person, or 100 to 110 percent of seated load
E	0.19 to 0.28 m^2/person, or 111 to 125 percent of seated load
F	0.19 m^2/person or less, or more than 125 percent of seated load

At the other end of the scale, individual seating has greater psychological appeal than the traditional parallel rows of double transverse seating. Molded fiberglass seats and perimeter seating are also less desirable. The NCUT (15), like many transit operators and consultants (16, 17), considers a standing load evident of good planning and policy during peak periods, but this is an obvious effort to increase operator productivity. There are many similarities between this density indicator and others that are considered to be transportation hygiene factors, rather than indicators of LOS. The critical difference is that passenger density is crucial in creating rider satisfaction; low density pleases riders, while high density displeases but rarely totally dissatisfies them.

ALTERNATIVE CONCEPTUAL INDICATORS

Several measures have been deliberately excluded from the proposed LOS indicators.

1. Ridership is a response to an offered LOS. As such, it is an important performance indicator, but it in no way directly measures LOS.
2. Public cost (subsidy required) is created by the LOS offered. The individual cost, or fare, depends on the willingness of the rider to pay for the LOS offered. That willingness may be constrained by the ability to pay or by the availability of alternative means of travel. There is ample evidence that people are willing to pay (if they are able) higher prices for higher quality service.
3. Personal security, frequently a problem of psychological perception, is a transportation hygiene factor. From the perspective of a rider, there is a dichotomy: The system is either safe or dangerous. In reality, it is a continuum—a relative degree of safety—and, as studies by the American Public Transit Association (11, 12) and the Metropolitan Washington Council of Governments (18) discovered, personal security is generally a minor concern of passengers.
4. Marketing, planning, and public information services are all vital components in the provision of transit services and are therefore considered part of the transit organization. However, they do not affect the operating service at a given time and are, instead, a means to generate changes in travel behavior. Moreover, if the rider with a mode choice is displeased with the LOS provided, any change in his travel behavior created by marketing is temporary. Certain basic components (bus stop signs, timetables, and such) of public information and marketing are also transportation hygiene factors. There are many operations that do not have such basics, but riders prefer to have them, if their need is perceived.
5. Passenger comfort, whether in the form of shelters, air conditioning, nonglare glass, or other amenities, is a standard improvement to a transit operation. These particular examples reflect facilities, not operations. While they are important considerations, they do not indicate the quality of the service provided. (In this specific set of examples, service is defined strictly: It is the provision of transportation between two points.) Therefore, these examples are hygiene factors. However, there are aspects of passenger comfort that should be considered for future inclusion in the LOS measure, since comfort is of concern to the rider. [One measure already included is passenger density and the type of seat provided (indicator 6).] Any potential comfort indicator should also include the smoothness of the ride.
6. Interior and exterior vehicle cleanliness is viewed as highly important in many rider surveys, but, while there may be degrees of cleanliness that could be developed into a standard, it is still a hygiene factor.

AGGREGATION OF THE INDICATORS

To reiterate, it is hypothesized that there are six LOS indicators: basic and relative accessibility (including transit access time), travel time, reliability, directness of service, frequency of service, and passenger density. To use these indicators properly in an evaluation, an aggregation of factors is required. A five-point grading scale, in which each of the indicators is also weighted, is proposed below. Each community could develop its own ranking for the indicators, based on the numerous research survey techniques explored elsewhere, but it is also possible to arbitrarily develop a ranking system.

Level of Service	Points	Level of Service	Points
A	5	D	2
B	4	E	1
C	3	F	0

Indicator	Weighting Credit	Indicator	Weighting Credit
1A	2	4	2
2	3	5	1
3	2	6	1

Table 1. Transit access for one end of trip.

Level of Service	Time (min)	Distance: Walking (m)	Distance: All Automobile (km)	Distance: Park-and-Ride (km)
A	<2.0	0 to 100	<0.8	—
B	2.0 to 4.0	100 to 200	0.8 to 1.6	0.4 to 1.2
C	4.0 to 7.5	201 to 400	1.6 to 3.2	1.2 to 3.2
D	7.5 to 12.0	401 to 600	3.2 to 4.8	3.2 to 4.8
E	12.0 to 20.0	601 to 1000	4.8 to 8.0	4.8 to 8.0
F	>20.0	>1000	>8.0	>8.0

Note: 1 m = 3.3 ft; 1 km = 0.6 mi.

Table 2. Indicators of reliability (percentage of transit not more than 1 min early or 3 min late).

Level of Service	8 Min or Less[a]	9 to 12 Min	13 to 20 Min	>21 Min
A	85 to 100	90 to 100	95 to 100	98 to 100
B	75 to 84	80 to 89	90 to 94	95 to 98
C	66 to 74	70 to 79	80 to 89	90 to 94
D	55 to 65	60 to 69	65 to 79	75 to 89
E	50 to 54	50 to 59	50 to 64	50 to 74
F	<50	<50	<50	<50

[a]Double the definition of "on time"; average wait is half the headway.

Table 3. Frequency of service at varying population densities.

Level of Service	4000 People/km²: Peak Headway (min)	4000 People/km²: Off-Peak Headway (min)	3000 to 4000 People/km²: Peak Headway (min)	3000 to 4000 People/km²: Off-Peak Headway (min)	2000 to 3000 People/km²: Peak Headway (min)	2000 to 3000 People/km²: Off-Peak Headway (min)	750 to 2000 People/km²: Peak Headway (min)	750 to 2000 People/km²: Off-Peak Headway (min)	Waiting Time for Demand-Responsive Service (min)
A	<2	≤5	≤4	≤9	≤9	≤14	≤9	≤14	9
B	2 to 4	5 to 9	5 to 9	10 to 14	10 to 14	15 to 19	10 to 14	15 to 29	10 to 14
C	5 to 9	10 to 14	10 to 14	15 to 19	15 to 24	20 to 30	15 to 24	30 to 44	15 to 25
D	10 to 14	15 to 20	15 to 19	20 to 29	25 to 39	31 to 45	25 to 39	45 to 59	26 to 60
E	15 to 20	21 to 30	20 to 30	30 to 60	40 to 60	46 to 60	40 to 60	60 to 90	>60
F	>20	>30	>30	>60	>60	>60	>60	>90	Day or more

Note: 1 km² = 0.4 mi²

To determine the overall LOS, multiply the number of points for the LOS for each indicator by the weighting credits; the total number of points accumulated is divided by the total number of weighting credits (11) which then equals the aggregate LOS.

CONCLUSION

There are two key independent combinations of factors that can be directly controlled by transit policy makers: transportation hygiene factors and indicators of the level of service. Of these two, only the LOS indicators can motivate potential riders; transportation hygiene factors can only discourage. The evaluation model discussed here contains subjective values; it is a starting point for further discussion and refinement. It should be remembered, however, that any method of evaluation developed will contain some subjective concepts. Furthermore, most commonly accepted standards began as subjective concepts.

This modal evaluation methodology, then, appears to provide a useful framework for transit professionals and decision makers to evaluate public transit.

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Transit Service Evaluation: Preliminary Identification of Variables Characterizing Level of Service

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This paper is an introduction to transit service evaluation and its application to medium-sized bus transit systems. The concept of transit evaluation through the measurement of level of service is discussed in terms of usefulness, past work, theory, and the presentation of a set of characteristic attributes. The need for performance evaluation, since transit is a public service that does not operate under the profit incentive, is presented. Its usefulness for management, governmental policy formulation, and determination of subsidy levels is discussed. The state of the art and practice, including the Pennsylvania Department of Transportation system, is reviewed. A methodology of transportation system evaluation developed by the Rand Corporation is summarized for its potential application to transit service. A preliminary list of service attributes, with the method of measurement identified, is given. It is concluded that transit service can be quantified and evaluated but that considerable effort is necessary to achieve a comprehensive and equitable system.

For the past three decades and until recently, the transit industry has suffered from the spiral of a decrease in patronage leading to increased fares and decreased service leading to a further decrease in patronage and so on. This nationwide experience and the realization that transit cannot generally pay for itself out of the fare box have driven transit substantially out of the private business sector and into the public service domain. As of 1973, 185 public transit agencies (18 percent of all transit operators) accounted for 91 percent of all transit passengers and 88 percent of all gross revenues (1). After years in which survival rather than progress was their main objective, transit operators are becoming agencies intended to serve the transportation needs and interests of the public.

Public ownership is a result of government recognition of transit as a necessary public service. In this regard, there has been much recent state and federal legislation allocating funds for capital improvements and operating assistance to local public transit properties. However, even as it has solved some of the problems of transit, government subsidy has created others, especially those of incentive and management control. But if transit is not to be operated solely as a profit-making enterprise, then under what general principles should it be run? This question takes on added importance because most transit subsidy funds now originate at the federal and state level, while transit operation is inherently a local concern. To what degree can upper levels of government be expected to pay for transit services that are administered largely outside their control? Or conversely, given a level of federal and state financial participation, how much control should local operators expect to have? The possibility that any government subsidy could diminish local motivation toward efficiency (unless operations are controlled to some extent by guidelines and standards) is of immediate concern. Such guidelines, applied judiciously, could be an integral part of a program to increase transit efficiency and productivity while, at the same time, they help to safeguard the interest of the public, who now have a more or less permanent stake in the provision of mass transit services.

This study, which was sponsored by the New York State Legislature, was motivated by several observations.

1. There is no comprehensive system for transit service evaluation or data collection in New York State.
2. This leads the state to allocate funds for transit operating assistance and capital improvements with little apparent control afterward. Although transit finances are under general scrutiny, the efficiency of transit operations is not.
3. State legislative and administrative officials who have recently assumed responsibility for transit are not yet fully conversant with the subjects of level of service, efficiency, and other factors involved in transit performance.
4. The complex institutional arrangements required for effective operation of transit in the public interest are still in the formative stages. The principal levels and branches of government that interact are the state legislature, the state department of transportation, and the metropolitan transportation authorities.
5. In some cases there is need for local authorities to keep better track of their own operations.

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The objective of this paper is to provide some initial information concerning transit service evaluation by

1. Discussing the usefulness of service evaluation to various branches and levels of government,
2. Reviewing current trends in transit evaluation,
3. Discussing transportation evaluation theory as it pertains to transit level of service, and
4. Identifying and describing a set of operating characteristics to be considered in the measurement of transit performance.

It is worthwhile to briefly discuss some areas outside the scope of this work. First, it is assumed that service evaluation is necessary and desirable. Second, the cost and methodology for implementation of an evaluation system are not presented. Third, the project was conceived with the idea of applying it to conventional public bus transit systems of the medium-sized metropolitan areas of upstate New York—the Capital District (Albany-Schenectady-Troy), Central New York (Syracuse), the Genesee Region (Rochester), and the Niagara Frontier (Buffalo).

BACKGROUND

Previous Work

Several concepts of transit level of service, varying with their context, have been used over the years. Service evaluation has rarely been the sole topic of study but is usually part of a larger issue. Level of service has been variously defined as: speed (2, 3, 4), transit travel time (5), headway (6), operating ratio (7), and service envelopes (limits of economic viability and passenger capacity) (8). There have been few attempts to study or implement systems of service evaluation since the now-defunct National Committee on Urban Transportation of the Public Administration Service (PAS) published two manuals on measuring transit service in 1958 (9, 10). These manuals have been the standard references in transit evaluation since their publication. However, they were meant primarily for use by operators to monitor their own operations, and this has been the extent of much of transit service evaluation thus far. As valuable as it is, it lacks a total community view of transit performance; i.e., transit service has traditionally been viewed as a concern strictly of its providers and users. This paper attempts to broaden the involvement to include all sectors and members of the community, who are ultimately responsible for the success or failure of transit.

The major sources of information on service evaluation besides the PAS manuals are the Pennsylvania Department of Transportation (PennDOT) report, Operating Guidelines and Standards for the Mass Transportation Assistance Program (11), and a supplementary paper by Vuchic, Tennyson, and Underwood on the application of the guidelines (12). The program of guidelines and standards for transit operation described in these two reports is an organized and comprehensive method of subsidy allocation based on the monitoring, evaluation, and improvement of local transit systems. This system, which is based in part on the PAS Manual, is the only statewide transit service evaluation program known to be in operation at the time this paper was written.

The Operator's View

One of the major problems that efforts to evaluate transit encounter is the uncertainty of transit operators who are wary of external appraisal of the level of service they are providing. As part of this research, officials of all four major upstate New York regional transportation authorities were interviewed; the results seem to confirm this assessment. There was a general feeling of cooperation toward being evaluated, since the officials believed that an evaluation would cast a favorable light on their systems, but they expressed concern over the possibility of increased state involvement in local transit affairs and about the cost and administration of an evaluation program.

PURPOSES OF SERVICE EVALUATION

Policy Formulation

Measuring transit service could generate a great deal of information that would be helpful in formulating policy decisions at all levels of government. Planners could use this measuring system to assess the existing transit situation in relation to what is set forth in the regional short- and long-range mass transportation plans and to resolve controversies about increasing or decreasing transit services. However, in order to know with relative confidence that the level of service is going up or down (or remaining constant), a system that will assist in defining and measuring transit level of service is needed.

Subsidy

Another area in which performance measurement can play a significant role is that of the subsidy. (This paper is not concerned with a detailed review of subsidy mechanisms and theory but only with the relationship between financial assistance and service evaluation.) There are three categories of operating subsidy: incentive, sustenance, and innovation. In this context, incentive implies a financial reward for a high level of service. It is well recognized that incentives must be service oriented to a large degree (13) and apparent that a good system of service criteria and standards can direct the way toward increased efficiency and elimination of wasteful practices.

While it is desirable to reward good service, some provision must be made for the operator who is under severe financial burdens and requires a subsidy just to keep operations from ceasing, as is often the case when a public agency takes over a private operation. This survival subsidy could be used to sustain those systems that need it the most and can show that they will put it to the most productive use in maintaining or possibly improving a minimal level of service. If good faith and conscientious effort are put forth by a public transit agency (as reflected in the level of service), then it is entitled to its fair share of subsidy funds.

The third category is that of innovation. Agencies that want to try new ideas in transit in a responsible manner should have that opportunity. Innovation in transit has been sadly lacking over the past few decades although inventive concepts are necessary to prevent stagnation. Innovation should therefore be included when reviewing transit service.

Public Information and Involvement

When discussing level of service and evaluation, one should not forget the large group that is ultimately affected: the public, including those who use transit and those who do not. Under New York State's sunshine law, public transit agencies are obliged to make their operating records available to anyone. If there were a method for evaluation that the layman could understand, perhaps the public would become more involved in regional transit affairs.

Federal Responsibility

Another motivating force for evaluation is that of the ever-increasing federal role in public transportation. The National Mass Transportation Assistance Act explicitly mentions transit efficiency. The Urban Mass Transportation Administration (UMTA) has also published its interpretation of this act and discussed the matter of improving efficiency and level of service (14). The former administrator of UMTA, Frank C. Herringer, has said (15),

> Greater emphasis is expected in the general area of performance and productivity measurement. We need to know more about the components of efficiency at each level of transit operations. Better information and evaluative tools in these areas will provide transit managers with an increased facility for isolating problem areas and for developing solutions.

This does not indicate that UMTA will become involved in the day-to-day operating decisions of transit authorities. No one (including those at UMTA) sees this as desirable. It does seem, though, that the federal government will soon require reassurances that its (the public's) money is being used wisely at the local level as a prerequisite to distributing funds.

Transit Agency Management Information

Finally, evaluation can be seen as desirable in providing information for the transit agencies' own use. Many operators already have some kind of internal evaluation procedures and there are indications that this practice is growing. Managers have a continuous need to know what is happening in their operations; it is this feedback of information that enables sound improvements to be made and efficiency to be increased. This kind of systematically collected operating information is the basis for level-of-service measurements. Again quoting Herringer (15):

> Part of the process of development on a national basis is the use of explicit criteria to guide decision making. While these are not applied in a totally restrictive way, they do contribute to an understanding of goals and progress toward meeting objectives. In effect, they substitute for the profit motive in private industry.

A comprehensive system of uniform data reporting and record keeping would help to establish valid criteria and to facilitate system information gathering.

EVALUATION THEORY AND ISSUES

Hierarchy of Evaluation Methods

It will be helpful to review a few aspects of the theoretical concepts of evaluation, discuss the hierarchy of methodologies, and then examine evaluation in terms of goals. Various descriptions of the theory of evaluation models have been proposed in many different fields of research. Methods of evaluation can be described on the basis of their complexity, technical input, and completeness. In the context of transportation system evaluation, we have the following (16):

Method 0—an intuitive judgment of the system's attributes by one or more qualified persons,

Method 1—a checklist of all system attributes that are considered significant by all persons involved,

Method 2—the checklist of attributes plus the corresponding performance measures (performance measures are physically measurable characteristics that determine system performance with respect to each attribute and should be based on their appropriateness to the relevant policy or goal structure),

Method 3—a system for setting limits on the variation of attribute values, retaining those values that are acceptable, and eliminating those that are clearly undesirable or infeasible,

Method 4—a listing of the attributes in order of their importance; a system of priorities, and

Method 5—the complete-worth procedure of finding independent worth assessments of the different attribute values, determining a set of weights showing the relative importance of the attributes, and then computing the total worth as a linearly weighted sum of the worths over the attributes.

Each of these methods is obviously a more complex and refined procedure than the one that preceded it. Method 0 was the most commonly used approach in the past; this paper concentrates on methods 1 and 2. PennDOT has attempted to apply methods 3 through 5 (11, 12) but further study is needed. As noted in method 2, it is important to relate performance measurement to a goal structure since evaluation of any kind requires a thorough understanding of what is meant by goals, objectives, standards, and criteria.

Evaluation Goals and Objectives

Goals and objectives are generally recognized as equivalent ideas and are defined as the end toward which the action is directed (9). They are necessarily abstract concepts but should always be expressed as explicitly as possible. "To improve public transportation" is so vague as to be meaningless (17). The cooperation of state and local agencies is essential to achieve purposeful definitions of transit goals and objectives.

Criteria are more specific than goals and objectives. A criterion represents a condition or state of the system. Criteria should be clear, realistic, inclusive, and not subject to a wide range of interpretation (18). Even more specific than a criterion is the idea of standard. A standard is a defined level of performance in relation to some goal or value, a set point along the way to the achievement of an objective. Standards must be extremely specific and therefore may not generally be subject to a statewide application.

Service Standards and Criteria

Service standards must of course relate as closely as possible to service criteria and to transit goals and objectives. "They should represent public policy objectives in regard to maximum service goals, and not just be related to the economics of transit operations" (19). The judicious use of accepted service standards is the only way to evaluate a single transit system on an absolute basis. The key word here is accepted; since evaluation has not been seen as necessary in past years, industry-wide transit service standards have not been formally adopted. This arises from the previously identified problem that standards must be localized to a high degree since the definition of good bus service can vary widely in different places.

Quantifying Transit Evaluation

Adherence to service standards is being used by PennDOT as a basis for evaluating transit systems in Pennsylvania to give a numerical rating for each system. However, even if the idea is accepted, that evaluation of the level of service must be quantified to a substantial degree, the usefulness of a numerical transit grade may still be

Figure 1. Transit service characteristics: quantity of service.

	METHOD OF MEASUREMENT[a]
USER RELATED	
Routes:	
Route density = $\frac{\text{route-kilometers}}{\text{square kilometers in service area}}$	A, B
route-kilometers = kilometers of round-trip bus routes	
Route distribution = $\frac{\text{vehicle-kilometers}}{\text{service area population}}$	A, B
Route coverage (area) = $\frac{\text{route-kilometers x (0.4 kilometer)}}{\text{square kilometers}}$	A, B
Route coverage (population) = $\frac{\text{route-kilometers x (0.4 kilometer)}}{\text{population}}$	A, B
Vehicle use = $\frac{\text{daily vehicle-kilometers}}{\text{scheduled number of vehicles}}$ or $\frac{\text{daily vehicle-hours}}{\text{scheduled number of vehicles}}$	A, B
Frequency:	
Headway = average time between buses (minutes)	A
Capacity:	
Vehicle seat capacity = $\frac{\text{population}}{\text{total transit seats}}$	A, B
Route capacity = $\frac{\text{maximum number of passengers}}{\text{hour}}$ (average overall routes)	A
NON-USER RELATED	
Routes:	
Route congestion = $\frac{\text{maximum number of buses on any street segment}}{\text{hour}}$	A, C

Note: 1 km = 0.62 mile.

[a]A is measured directly from transit authority operating records;
B is obtained from census or metropolitan planning bureau data;
C is measured in the field by trained observers;
D is obtained from data and specifications provided by bus manufacturers; and
E is subjective judgment on the part of the examining agency.

questioned. Although the purpose of evaluation is to objectively assess the performance of a transit system, the use of strictly numerical results must be approached with caution and foresight. Transit operators are understandably concerned about level-of-service measurements, since a poor rating could cause the (possibly) unjustified or misdirected wrath of elected officials and the public. On the other hand, good ratings might be equally deceptive. An alternative to the strictly numerical approach is the use of community value-factor profiles or the goals-achievement matrix described by Wegmann and Carter (20).

One argument in favor of using a single number to rate a transit system is that it facilitates subsidy calculations. Obviously, if level-of-service measurements are to be used to determine operating subsidy payments, then such measurements must be specific, accurate, and readily converted into dollars and cents. A prime example of this is the PennDOT evaluation system, in which transit operators receive an operating subsidy directly proportional to the number of points they score on the rating scale. In addition to the base subsidy for present level of service, there is a bonus or penalty that depends on the change in level of service from the preceding year.

Subsidy and Service Evaluation

It is reasonable to expect that a subsidy mechanism based on all facets of level of service would result in a more equitable and efficient allocation of funds than does the current method of determining transit operating assistance in New York. The formula now in use involves a subsidy based on vehicle-kilometers operated and passengers carried (and, in some cases, on population of the service area). This formula works reasonably well as far as it goes but does not take into account the total level of service provided to the community and is not a particularly effective measure of total performance. In their attempts to increase vehicle-kilometers or even passengers, operators could change their service in a manner that would run counter to the transit needs and objectives of the community.

Another factor in the subsidy issue is the role of politics in determining the allocation of funds. Even though legislatures make the decisions on subsidy policy, politics should not intrude into the daily operations of transit agencies. If subsidies are based mainly on need and incentive as determined by a technical evaluation process, then the benefits of an improved distribution of funds will accrue to all.

If an issue as important as transit operating assistance is to be inextricably related to the evaluation of performance and service standards, these standards and their measurement must be as independent as possible. The guidelines should be agreed upon by the legislature, the transportation agencies, and the citizens' groups, however difficult this may be. Transit standards will be less arbitrary if expertise, coordination, and cooperation are employed in their development, although there may still be valid differences of opinion. The key is to effectively combine the operator's experience, the state's research and planning capabilities, the legislature's policy-making process, and the local citizens' needs and desires. (This does not neglect the role of local government, which also participates in transit funding and acts as a representative of the populace.)

SERVICE CHARACTERISTICS

Identification of Transit Service Characteristics

In the discussion of the theory of evaluation models, method 2 was said to involve the enumeration of attributes and performance measures that contribute to transit level of service. Attributes and performance measures (collectively referred to as characteristics or variables) must be selected by cooperative processes. They must also be chosen so that data collection and manipulation are facilitated. Of utmost importance, however, is that they best reflect the mass transportation objectives of the community. Several of the characteristics that will be presented later in this chapter have been documented in past studies.

Obviously, the identification of such characteristics

Figure 2. Transit service characteristics: quality of service.

	METHOD OF MEASUREMENT[a]
USER RELATED	
Speed:	
Speed = $\frac{\text{kilometers}}{\text{hour}}$, scheduled or actual, over the whole system	A
Speed ratio = $\frac{\text{average transit speed}}{\text{average auto speed}}$ for selected routes	A, C
Reliability:	
On-time performance = percentage of buses one minute early to four minutes late	C
Comfort:	
Interior noise levels = average dbA inside the vehicle	C, D
Loading factor = $\frac{\text{maximum number of passengers}}{\text{total seats available}}$ averaged over each route at the maximum load input	A, C
Floor area = $\frac{\text{peak hour floor area}}{\text{passengers}}$ averaged over each route at the minimum load point	A, C, D
Percentage of fleet with air conditioning = $\frac{\text{number of air conditioned buses}}{\text{total number of buses}}$	A
Vehicle jerk = $\frac{\text{kilometers per hour/second}}{\text{second}}$	C, D
Convenience:	
Route directness = $\frac{\text{number of transferring passengers}}{\text{total number of passengers}}$	A
Hours of service = daily hours of operation	A
Stop spacing = average distance between bus stops in meters	C
Loading zone quality = subjective measure of bus stop adequacy (e.g., shelters, benches, illumination, bus stop marking, curb length)	A, C, E
Step height = average curb-to-vehicle step height in centimeters	C
Information services = subjective measure of communication between transit agency and public (e.g., schedule coherence, route identification, telephone information, marketing)	A, C, E
Safety and Security:	
Accidents and crimes = $\frac{\text{transit accidents}}{\text{million vehicle-kilometers}}$ and $\frac{\text{transit crimes}}{\text{million vehicle-kilometers}}$	A
Special Services and Innovations	
Subjective measures of the implementation of innovative concepts to benefit the transit related community (e.g., preferential treatment for buses on roads, special service to handicapped, etc.)	A, E
NON-USER RELATED	
System Efficiency:	
Equipment utilization = $\frac{\text{scheduled vehicle-hours}}{\text{available vehicle-hours}}$	A
Peaking factor = $\frac{\text{number of peak hour buses scheduled}}{\text{number of base hour buses scheduled}}$	A
Energy efficiency = $\frac{\text{passenger-kilometers}^*}{\text{liter of fuel}}$	A, C
Pollution:	
Air Pollution = $\frac{\text{grams of pollutant}}{\text{brake horsepower-hour}}$ for chemical pollutants such as CO, oxides of nitrogen, and hydrocarbons; = Ringlemann number for smoke and other particulates	C
Noise Pollution = average dbA outside the vehicle, usually measured at a distance of 7.8 or 15.6 meters (25 or 50 ft)	C
Productivity = $\frac{\text{platform hours}}{\text{pay hours}}$ or $\frac{\text{number of annual passengers}}{\text{transit employee}}$; platform hours = hours that the bus driver is on duty; pay hours = hours for which the driver is paid	A
Demand:	
Modal split (for work trips) = $\frac{\text{work trips by transit}}{\text{total number of work trips}}$	A, B
Service usage = $\frac{\text{number of annual passengers}}{\text{population}}$	A, B
Passenger density = $\frac{\text{number of annual passengers}}{\text{square kilometer}}$	A, C
Density of usage = $\frac{\text{passenger-kilometers}}{\text{route-kilometers}}$	A, C
Vehicle occupancy = $\frac{\text{average number of passengers per vehicle}}{\text{hour}}$	A, C
Seat turnover = $\frac{\text{number of annual passengers}}{\text{annual seat-kilometers}}$; seat kilometers = average number of seats per vehicle x vehicle-kilometers	A, C
Desire coincidence = subjective measure of how well bus routes coincide with travel desire lines (i.e., origin-destination patterns)	A, B, E

Note: 1 liter = 0.26 gal.
[a]See Figure 1.

Figure 3. Transit service characteristics: cost/revenue.

	METHOD OF MEASUREMENT[a]
USER RELATED	
Fare:	
Base fare = normal transit fare or $\frac{\text{auto user cost per kilometer}}{\text{transit user cost per kilometer}}$	A
Transfer, zone, and reduced fares = subjective consideration of their usefulness and necessity	A
Fare collection methods = subjective balancing of information gained versus cost of collecting fares	A, E
NON-USER RELATED	
Operating economy:	
Operating ratio = $\frac{\text{operating costs}}{\text{operating revenues}}$	A
Route economy = $\frac{\text{operating costs}}{\text{vehicle-kilometers}}$ and $\frac{\text{operating revenues}}{\text{vehicle-kilometers}}$	A
Average fare = $\frac{\text{passenger revenue}}{\text{total passengers}}$ and $\frac{\text{operating cost}}{\text{total passengers}}$	A
Maintenance costs = $\frac{\text{maintenance costs}}{\text{vehicle-kilometers}}$	A

[a]See Figure 1.

in this paper is only the first step toward establishing a complete evaluation system, but it is an important procedure. The steps that come later—the setting of priorities and service standards and the ultimate evaluation of existing performance with respect to those standards—depend heavily on the use of thoughtfully considered characteristics of service.

For the purposes of this paper, level of transit service is divided into three major components: quantity, quality, and cost/revenue. (These categories should not be regarded too strictly, since several characteristics could be listed in more than one category. Attempts are made to follow existing conventions whenever possible.) Quantity describes how much transit service exists—in other words, the supply. Quality deals with the abstract question of how good the service is. The distinction between quantity and quality is important because more (or less) transit does not necessarily imply better (or worse) transit. Cost/revenue is considered because it deals with economic factors that, although they are dependent on quantity and quality, need to be evaluated separately.

Listing and Explanation of Characteristics

The service characteristics recommended in this paper as important to the measurement of transit service are shown in Figures 1, 2, and 3. These service characteristics were selected on the basis of their contribution toward the evaluation of transit performance; this does not purport to be a complete listing of every characteristic that could conceivably influence service levels. On the other hand, some of the variables included could be considered partially or totally irrelevant in certain situations and the many interrelationships among the various categories and variables may give different perspectives on the same attribute.

The categorization or disaggregation of these characteristics takes two forms. First, in setting up a system to measure service, the service viewpoints of passengers, operators (management and labor), all levels of government, and the non-transit-patronizing public must be considered. For simplicity, this report divides these groups into users (passengers) and nonusers (everyone else). (This classification sacrifices some accuracy, since the operator is usually considered separately from those who use transit and those who pay for it, but here the operator's interest will be represented in both categories.) Second, the variables must be disaggregated by areas of the metropolitan region. That is, in monitoring service variables, reference must be made to a specific part of the city. The extent of this geographical breakdown depends on the particular circumstances of the evaluation but should at least distinguish between transit service in the central city and in suburban areas.

Factors Outside Control of Transit Agency

Some of these characteristics may be partially or totally out of the control of the regional operating authority or planning commission. Examples of this are stipulations of labor contracts, traffic control and traffic regulation enforcement, service boundaries defined by political divisions, and differences in urban environment. One of the problems of comparing transit operations in various cities is that the evaluation must consider differences in urban form and land use, population and employment distribution, topography, and climate. An attempt was made to structure the variables so as to minimize these effects.

Data Collection and Costs

Data collection is another major problem facing an evaluation effort, since it is mandatory that all transit operations being monitored use the same methods and express the results in the same format. The concern of the agencies involved is always directed toward the costs and responsibilities of such a system: who is to pay for it and who is to administer it. The state government, with the advice and guidance of all directly affected parties, is the proper agency to carry out the evaluation. The question of evaluation costs should be related to the amount of subsidy: Evaluation costs would probably be small compared with the operating subsidies now being used in many cities. Furthermore, evaluation costs could probably be borne initially by UMTA and possibly later by state governments and regional transportation authorities since UMTA has begun to develop a data collection system of Financial Accounting and Reporting Elements (FARE) that will be implemented in 1977, when its use will be made a mandatory precondition for the granting of UMTA section 5 funds.

CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. Aside from the PAS manuals (9, 10) published in 1958 and the recent extension of that work by PennDOT (11, 12), there has been little work done on comprehensive evaluation of transit level of service.
2. Since transit is a public service, not operating under the profit incentive, there exists a need for per-

formance evaluation. This need exists for management at the operating level, for policy formulation at several levels of government, and possibly for determination of subsidy levels. (The issue of basing subsidy in part on performance rather than solely on a demographically based formula is not discussed here.)

3. Transit service can be quantified and evaluated in terms of a finite set of operating characteristics. This assertion is based on the existence of at least one prominent evaluation methodology (16) applicable to public transit service and the present identification and presentation of a preliminary list of transit service attributes.

4. It will require a considerable commitment and effort of government, the transit industry, and the research community to devise and implement a comprehensive transit service evaluation system.

Recommendations

1. A framework for performance evaluation should be developed. This should include establishing goals and relating those goals to the measures of level of service.

2. The techniques and economics of data collection should be studied.

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Bus and Shared-Ride Taxi Use in Two Small Urban Areas

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The demand for publicly owned fixed-route, fixed-schedule bus service was compared with the demand for privately owned shared-ride taxi service in Davenport, Iowa, and Hicksville, New York, through on-board surveys and cab company dispatch records and driver logs. The bus and shared-ride taxi systems in Davenport competed for the off-peak-period travel market. During off-peak hours, the taxis tended to attract social-recreation, medical, and personal business trips between widely scattered origins and destinations, while the buses tended to attract shopping and personal business trips to the CBD. The shared-ride taxi system in Hicksville, in addition to providing many-to-many service, competed with the countywide bus system as a feeder system to the Long Island commuter railroad network. In each study area, the markets of each mode of public transportation were similar. There were no statistically significant differences between bus and shared-ride taxi users in Davenport relative to ability to drive, household income, employment status, number of automobiles available to the household, and physical capabilities. Bus and shared-ride taxi users in Hicksville differed slightly in age, household income, number of automobiles available to the household, and distance from home to bus stop. In general, a major portion of the market of both shared-ride and taxi systems were of people likely to be dependent on some form of public transportation for some of their trips.

Although the concept of demand-responsive transportation has been studied extensively, its most common form, the taxicab, has received little attention. Most of the research and development in demand-responsive transportation has been concerned with the publicly owned fleets of small buses and vans known as dial-a-bus or dial-a-ride systems, and the taxicab has been regarded as a relatively expensive, premium service that transports only one fare at a time. This image may be partially to blame for the fact that the taxicab is largely ignored in transportation planning.

The relatively few studies of taxicab operations have shown that taxis serve many markets (1, 2, 3, 4, 5, 6) and transport large numbers of housewives, senior citizens, nondrivers, the poor, the unemployed, and the handicapped as well as wealthier residents, male white-collar workers, tourists, and nonresident businessmen. They are used for work and business-related trips to and within CBDs and for short social, shopping, medical, and personal business trips.

In many small cities and in many suburbs of large metropolises, buses and taxicabs operate within the same jurisdictions and may compete for the same public transportation market. Two examples of small communities in which buses and taxis coexist are Davenport, Iowa, and Hicksville, New York. The markets, economic characteristics, organization, management, and operation of the taxicab systems serving these communities were analyzed in a recent study (7). This paper analyzes the demand for bus and taxicab service in these cities to provide an insight into the roles and potential of privately owned demand-responsive transportation in such areas.

DISTINCTIVE FEATURES OF PROJECT

Several features of this project distinguish it from much of the previous research on demand-responsive transportation and taxicab use. First, the project was concerned with two taxicab systems that operated in a manner more like a dial-a-ride service than like a typical taxicab service. Both cab companies used the ride-sharing method of operation in which, in scheduling and routing the cabs, the dispatcher attempts to pool passengers traveling in the same direction into the same cab. Additional riders are accommodated in a cab only when the passengers already in the cab are not unduly inconvenienced. Accordingly, cabs are seldom diverted more than four blocks and are never required to backtrack to serve additional passengers. One of the principal advantages of this method of operation is higher vehicle productivity. At present, ride sharing is not widely practiced by the taxicab industry. In many cities it is either specifically prohibited by ordinance or is permitted only on the consent of the first passenger. It is also precluded in cities where taxi operators are required to use meters. Although the shared-ride taxi systems of Davenport and Hicksville are not the only operations of this type in the United States, the actual number appears to be small. There are, however, indications that the number is increasing. Second, this project involved a study of

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demand-responsive transportation services that competed with conventional fixed-route, fixed-schedule bus services for some of its market. Most of the publicly owned demand-responsive transportation systems currently operating have been implemented to provide public transportation where none previously existed, to replace lightly used bus routes, or to augment available bus and rapid-rail transit service. Finally, unlike most previous studies of actual demand-responsive transportation systems, this project was not a demonstration project, nor was it concerned with new or experimental services. The cab company in Hicksville had been offering shared-ride taxi service since 1961, while the cab company in Davenport had initiated it in 1967. Both systems were therefore well established.

BACKGROUND

Study Areas

The study areas of Davenport, Iowa, and Hicksville, New York, are dissimilar in location, size, population characteristics, and other respects. Davenport is one of four incorporated communities in a cluster known as the Quad Cities, a metropolitan area having a population of approximately 300 000. It is the largest of the four communities, with a 1970 population of nearly 98 500, almost 11 percent higher than in 1960. Situated along the Mississippi River, the Quad Cities are an important midwestern trade and industrial center. Hicksville, however, is an unincorporated community in Nassau County on Long Island. It is the smaller of the two study areas in terms of population, with a 1970 population of 48 100, 4.6 percent lower than in 1960. Although it, too, is the site of a large number of diverse industries, it is also a major transportation hub, with the local Long Island Railroad station handling the largest number of commuter rail passengers of any station on the island. Household incomes and the number of automobiles per household are much higher in Hicksville than in Davenport, while the population of Davenport contains a higher percentage of persons over 65 years old. These differences in the characteristics of the two areas enabled the researchers to determine the markets for shared-ride taxi service in dissimilar communities.

Bus Services

The bus systems serving Davenport and Hicksville are typical of many interurban bus systems throughout the United States. Both operate on fixed headways along established routes that converge in the CBD. Both have had the same ruinous problems of rising costs and declining patronage that have plagued much of the transit industry. Consequently, at the beginning of this study, both were making the transition from private to public ownership and operation.

Shared-Ride Taxi Services

Although both taxi systems provide shared-ride service, the two differ in several important respects. The Davenport firm maintains a smaller fleet—approximately 20 Checker cabs, compared to approximately 30 Dodge passenger cars in Hicksville—to cover a much larger service area. Although the fare schedule in each community is based on a network of zones, that of the Davenport system is considerably lower. [For the shared-ride level of service, the base fare in Davenport is 75 cents with an incremental charge of 25 cents/zone, while in Hicksville the minimum fare is $1.00 with an incremental charge of $0.32/km ($0.50/mile).] This disparity in the fare levels reflects the different market strategy of each firm. The management of the system in Davenport is more interested in increasing its share of the market and maintaining high volumes through relatively low fares but the Hicksville strategy involves higher rates and a carefully controlled fleet size in order to maintain a wide profit margin. These differences may affect the level of performance and the market composition of each system.

Data Collection

The primary sources of information for this study were the dispatching records maintained by the shared-ride taxi companies, and the reports of the bus and taxi users themselves. A special form, the customer data record, designed to record the information on cab dispatch tickets and driver logs, was completed for each request for cab service. The data obtained from this form included the time at which the request for service was received, the time at which a cab was dispatched to handle the request, the origin and destination of the trip, arrival times of the cab at the origin and destination, the number of passengers involved, and the level of service (shared- or exclusive-ride) requested. Between April 1973 and January 1974, information on the operation of the shared-ride taxi systems was collected for 20 days in Davenport and 17 days in Hicksville.

Two surveys using a dual questionnaire that consisted of a form to be completed while traveling in the bus or cab and a form to be completed later and returned by mail were conducted in each study area. Additional information was obtained from a home interview survey of the general public in each study area.

LEVELS OF RIDERSHIP

During the study period the demand for shared-ride taxi service in Davenport averaged 1040 (from 750 to 1530) passengers/weekday, 1100 passengers/Saturday, and 650 passengers/Sunday. During the same period, the demand for shared-ride taxi service in Hicksville averaged 700 (from 380 to 970) passengers/weekday, 440 passengers/Saturday, and 250 passengers/Sunday. Both cab companies also offered regular taxi service that assured the passenger the exclusive use of the cab. However, this service was provided only upon request and for a much higher fare, and the demand for it was virtually nonexistent.

More persons traveled by bus than by shared-ride cab in Davenport; the buses usually carried 2500 to 3000 passengers on weekdays. However, between 1967 and 1972 patronage of the bus system had declined from 1.5 million to 750 000 passengers/year, while patronage of the shared-ride taxi system had risen from 174 000 to 485 000 passengers/year. Accurate estimates of bus patronage in Hicksville were not available. Since the bus system serves all of Nassau County and has 10 of its 67 routes converging at the regional shopping center and commuter rail station located near the center of Hicksville, the number of passengers from Hicksville itself could not be determined.

COMPARISON OF ROLES AND MARKETS

One of the main objectives of this project was to determine the roles performed by the buses and taxis in Hicksville and Davenport, the markets served by each mode, and the amount of competition between the two modes through an analysis of the characteristics of bus and taxi trips, the characteristics of bus and taxi users, and the frequency of bus and taxi use. Although each type of public transportation can perform certain functions better than the other, demand-responsive transportation services can replace poorly utilized portions of a conventional bus system and at the same time complement conventional fixed-route mass transit service.

Trip Characteristics

Temporal Distribution

One of the more obvious differences in the use of the bus and shared-ride taxi services is in the percentage of daily trips made during peak hours by bus and taxi.

Place	Bus	Taxi
Davenport	39	20
Hicksville	40	28

The concentration of demand for fixed-route bus service in the peak periods shows clearly that the bus systems are used intensively for daily commuting: The bus systems carried more than half of their passengers in the off-peak hours, but these buses were usually less than half full. The cab companies attracted a majority of their riders during periods of low-density travel demand. The analysis of the time distributions of shared-ride taxi trips showed an important difference in the roles of the two systems with the Hicksville cab company transporting a higher proportion of passengers in the peak periods than the Davenport company. This difference in peak-period demand is explained by the role of the Hicksville cab system as a feeder service to the Long Island Railroad.

Spatial Distribution

The spatial pattern of bus and shared-ride taxi trip destinations showed another major distinction between the use of the bus and taxi services in Davenport. Although the CBD attracts a high percentage of both bus and taxi trips, the origins and destinations of cab trips are more widely scattered: Sixty-eight percent of the bus trips originate or terminate in the CBD but 62 percent of the shared-ride taxi trips begin and end at places outside it. The bus system in Davenport does not compete effectively with the shared-ride taxi system for trips that are not oriented toward the CBD because all of the routes radiate from the CBD, making trips between two noncentral locations lengthy and circuitous unless both trip ends are near the same bus route.

The shared-ride taxi service, however, does compete with the bus system for short trips to and from the CBD during off-peak hours. The individual choice between bus or cab involves a trade-off between the low bus fare and the more personalized door-to-door service of a taxi, and persons who travel frequently by public transportation tend to choose the bus while others tend to choose the taxi.

Taxi trips in the Hicksville area are much more highly centralized. On a typical weekday, approximately 65 percent of the taxi passengers travel to or from the CBD. The local commuter rail station and the Mid Island Plaza regional shopping center, both of which are located in the CBD, are the most frequent origins and destinations of shared-ride taxi trips.

The bus and shared-ride taxi systems in Hicksville compete for the trips to and from the CBD, particularly those trips to and from the commuter rail station. Approximately 52 percent of the bus and 65 percent of the taxi trips beginning and ending in Hicksville on a typical weekday are oriented toward the CBD. Residents often chose the taxi service instead of the bus service for trips to the commuter rail station because, at the time of this study, the bus schedule was not well coordinated with the train schedule. To many other residents, the taxi is the only form of public transportation available because their homes are located a long distance from a bus stop.

Since the bus system serving Hicksville links many of the communities in Nassau County, another possible role for the local shared-ride taxi system would be to provide a feeder service to the bus system for long trips within the county, but the bus and taxi systems were not as well integrated as the taxi and commuter rail systems at the time of this study.

Trip Purpose

The percentage distribution of bus and taxi trips by purpose is shown below:

	Davenport		Hicksville	
Trip Purpose	Bus	Taxi	Bus	Taxi
Work	59	47	62	55
School	5	3	7	3
Shopping	18	9	23	18
Social-recreation	5	11	2	7
Medical	4	18	2	6
Personal business	9	12	4	11

Both the bus and taxi services in Davenport are most frequently used for traveling to and from work. The bus system, however, carries a significantly higher proportion of the work trips. These trips are normally made during the peak periods to work locations in the CBD: taxi work trips are usually those made to noncentral work locations or at irregular times or both, such as after the bus system has ceased operation for the night.

The distribution of nonwork trips shows several other differences in the roles of the bus and shared-ride taxi services in Davenport. The bus system is used more frequently (over 40 percent of its nonwork trips) for shopping. The shared-ride taxi service is used to a lesser degree for shopping and to a greater degree (over 80 percent of the nonwork trips) for social-recreation, medical, and personal business purposes. These infrequent trips, which are normally made during periods of low-density travel demand and between widely scattered locations, are served well by regular or shared-ride taxi services.

Both the bus and shared-ride taxi systems in Hicksville are used primarily for work and shopping trips. The taxis are commonly used by commuters for transportation to and from the commuter rail station rather than directly to and from work location. As in Davenport, the taxis carry a higher percentage of social-recreation, personal business, and medical trips than the buses.

Because of its role as a feeder system, the Hicksville shared-ride taxi system carries a significantly higher percentage of work trips than does its counterpart in Davenport. There is also a significantly higher demand for shared-ride taxi service to shopping facilities in Hicksville. Other differences and similarities in the demand for shared-ride taxi service in the two study areas are shown in Table 1, which lists the most common unidirectional taxicab movements in the order of their frequency of occurrence.

One important similarity between the two shared-taxi systems is the strong orientation of taxi trips toward residences. In each study area, most taxi trips were home-based: Trips directed to or from residences account for 83 percent of the total on the average weekday

Table 1. Principal shared-ride taxi movements on weekdays.

Origin	Destination	Average No. Trips/Day	Percentage of Trips
Davenport			
Residence	Residence	203	19.7
Residence	Business	189	18.3
Business	Residence	125	12.1
Cab terminal	Residence	78	7.6
Residence	Medical facility	50	4.9
Tavern	Residence	45	4.4
Medical facility	Residence	39	3.8
Business	Business	35	3.4
Hotel-motel	Business	21	2.0
Hicksville			
Rail station	Residence	135	19.4
Residence	Rail station	88	12.7
Shopping center	Residence	69	9.9
Residence	Shopping center	50	7.2
Residence	Residence	49	7.0
Residence	Business	41	5.9
Business	Residence	31	4.5
Residence	Public facility	26	3.7
Rail station	Business	21	3.0
Public facility	Residence	19	2.7
Residence	Medical facility	14	2.0

Table 2. Characteristics of bus and shared-ride taxi users (percent distribution).

	Davenport		Hicksville	
Characteristic	Bus Users	Taxi Users	Bus Users	Taxi Users
Sex				
Male	21	31	28	31
Female	79	69	72	69
Age (years)				
Under 16	4	3	7	1
16 to 21	13	12	19	12
22 to 44	23	41	29	42
45 to 64	38	29	39	41
Over 64	23	14	7	4
Household income ($)				
Under 5000	32	31	20	5
5000 to 9999	33	33	23	20
10 000 to 14 999	18	19	26	33
15 000 to 19 999	11	11	20	23
20 000 and over	5	6	11	18
Employed	67	63	70	70
Retired	15	11	5	3
Housewives	13	23	11	24
Students	12	7	21	5
Handicapped	5	9	3	4
Nondrivers	62	61	66	58
Automobiles/household				
None	38	41	20	10
One	40	37	42	47
Two	16	18	28	33
Three or more	5	5	10	10
Distance from home to bus stop (blocks)				
0 to 1	60	46	31	15
1 to 2	20	18	21	21
2 to 4	15	18	25	20
4 or more	5	18	22	44

in Davenport and 84 percent in Hicksville. Relatively few trips originate or terminate at hotels and motels, indicating that local residents, rather than tourists, visiting businessmen, and other transients, constitute the major share of the market for shared-ride taxi service in both study areas.

The two shared-ride taxi systems were also alike in the kinds of markets that they did not serve: Industrial workers are a weak market for both systems. Neither fleet is used to any considerable extent to connect to other transportation facilities such as airports and intercity bus depots, or for trips to educational facilities.

Both cab companies provide many-to-many service, but the Hicksville taxi service tends to operate as a many-to-few system. The most frequent cab trips in Davenport are those between two residences and those between residences and myriad private business establishments. In Hicksville, however, approximately 42 percent of the trips made on an average weekday are to the commuter rail station and 17 percent are between residences and shopping centers, principally the Mid Island Plaza regional shopping center.

User Characteristics

Because of the disparity in the fare charged by each mode, differences in the patterns of bus and shared-ride taxi use will also be determined by the personal characteristics of the users. Table 2 summarizes the socioeconomic characteristics of the bus and shared-ride taxi users in Hicksville and Davenport.

Comparison of Bus and Shared-Ride Taxi Users

Davenport

Sex, age, and distance from home to bus stop are the only characteristics for which there were statistically significant differences between bus and shared-ride taxi users. Women are the predominant users of both modes, but the shared-ride taxi system carries a higher percentage of male passengers than does the bus. The taxis, on the other hand, transport a much higher percentage of housewives. The bus patrons tend to be older than the taxi users; in particular, senior citizens are a much larger fraction of the bus riders, possibly because of the reduced bus fare for such persons. During the school year, the buses also transport a higher percentage of students. Bus users are more likely to reside within a block of a bus stop, whereas taxi users are more likely to live more than 4 blocks away; however, a large majority of the passengers in both groups live within reasonable walking distance to a bus route.

With the exception of the differences noted above, the markets of each form of public transportation in Davenport are remarkably similar. There are no statistically significant differences relative to ability to drive, household income, employment status, number of automobiles available to the household, or physical capabilities. Nondrivers are a major portion of the market for each system. Most bus and shared-ride taxi users belong to households having a total annual income under $10 000. Approximately one-third of the customers of each mode are unemployed. Well over one-third of the passengers of each mode live in households without an automobile. In general, both modes attracted people who are likely to be dependent on some form of public transportation for many of their trips.

Hicksville

Bus and shared-ride taxi users in Hicksville differ slightly in age, household income, number of automobiles available to the household, and distance from home to bus stop. The buses transport a significantly higher percentage of students and other persons under 21 years old. Bus users tend to have lower household incomes; they are much more likely to come from households with incomes under $5000 and from households without an automobile. As in Davenport, the bus users tend to live closer to a bus route; in particular, they are more likely to live within a block of a bus stop, while taxi users are more likely to live more than 4 blocks away. The distances from home to bus stop, however, tend to be longer in Hicksville than in Davenport for both groups.

In many other respects, bus and shared-ride taxi users in Hicksville are alike: More than two-thirds of the passengers of both are women; more than two-thirds are employed; less than 10 percent are over 65 years old; a majority do not possess a driver's license. In general, both markets are of a mixture of commuters and persons dependent on some form of public transportation.

Comparison of Shared-Ride Taxi Passengers

The markets of the two shared-ride taxi systems differ in several respects because of the differences in the compositions of the study area populations. The Davenport system, for example, carries a higher percentage of elderly persons, reflecting the higher proportion of elderly people in the population. Residents of the Hicksville area tend to have higher household incomes and belong to multi-car families, and so the relative frequency of shared-ride taxi users from households in upper income brackets and from multi-car families is greater in Hicksville. Because of the more limited coverage of the bus system in the Hicksville area, taxi users there tend to reside farther away from a bus stop. The Hicksville shared-ride taxi system transports a slightly lower percentage of unemployed persons; this is consistent with the role of the Hicksville system as a feeder service transporting workers to and from the commuter rail system.

Bus and Taxi Trip Frequency

In both study areas, bus users tend to use the bus more often than taxi users use the cab, but, in each community, the total number of weekly trips per person was virtually the same for both groups, as given below.

	Trips/Person by Transit		Total Trips/Person	
Place	Bus Users	Taxi Users	Bus Users	Taxi Users
Davenport	5.8	1.8	11.8	10.1
Hicksville	8.9	1.5	14.3	15.3

As a result of their more frequent use of their selected mode of public transportation, bus users tend to make a higher percentage of their total trips by bus than do shared-ride taxi users by the cab service. In Davenport 59 percent of the bus riders but only 32 percent of the taxi riders use their respective modes for more than half of their trips. While more than 50 percent of the taxi users make less than 30 percent of their trips by cab, a majority of the bus riders use the bus system for over 60 percent of their trips. Nearly one-third of the bus users travel solely by bus but only one-fifth of the taxi users travel solely by shared-ride taxi. Similar observations were made in Hicksville, where 59 percent of the bus users but only 22 percent of the taxi users make a majority of their trips by their respective modes of public transportation.

These findings imply that bus users are generally more dependent on public transportation. In particular, they include a higher percentage of captive riders who have no means of travel other than some form of public conveyance. In general, to most users the local bus system functions as their primary mode of transportation, whereas to most taxi users the shared-ride taxi system is a secondary or auxiliary means of travel, although for particular kinds of trips the taxi may be used as the principal mode.

SUMMARY

Together, the two shared-ride taxi systems studied perform most of the roles that have been theoretically envisioned for demand-responsive transportation systems. The system in Davenport is an excellent example of a many-to-many demand-responsive service. It is especially useful for transporting residents between widely scattered origins and destinations during periods of low-density travel demand. Although the system in Hicksville also provides many-to-many service, it more closely resembles a many-to-few system because of the characteristics of its service area and the nature of the demand for its services (especially as a feeder system to the Long Island commuter railroad network).

The bus and shared-ride taxi systems in Davenport compete for the off-peak-period travel market. The taxis tend to attract social-recreational, medical, and personal business trips between widely scattered places not easily reached by bus, while the buses tend to attract shopping and personal business trips to the CBD. There is less competition between bus and shared-ride taxi services in Hicksville because the bus system is designed to serve all of Nassau County and not to provide particularly for circulation within Hicksville itself. The two modes, nevertheless, do compete for trips to the CBD and the commuter rail station there.

A major portion of the market for each shared-ride taxi system are people who are likely to be dependent on some form of public transportation for at least some of their trips. This is especially true in Davenport where bus and shared-ride taxi users are alike in ability to drive, household income, employment status, number of automobiles available to the household, and physical capabilities. There is therefore no reason to believe that shared-ride taxi services are unacceptable to the transportation disadvantaged such as the poor, the elderly, and the handicapped. Local elected officials and transportation planners in smaller urban areas should consider the alternative of subsidizing the transportation disadvantaged rather than subsidizing publicly owned transportation systems that may not always adequately serve the needs of these people. Designated groups can be subsidized by issuing transportation stamps as in West Virginia or by entering into contracts with private carriers to offer their services to these groups at a reduced fare. The latter approach is now being used or considered in at least eight small to medium-sized urban areas (8).

Additional research in taxicab use in small urban areas is needed to clarify the roles this mode could play in such communities. This research should also include other privately owned public carriers such as jitney, livery, and public limousine services.

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An Innovative Public Transportation System for a Small City: The Merrill, Wisconsin, Case Study

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This paper describes a recently implemented innovative transportation system which can serve as a prototype for similar systems in other areas. The system was implemented in Merrill, Wisconsin, a city of 9500 persons that has had a long history of public transportation, but has been unable to maintain high-quality transit service in recent years. A point deviation bus system, a form of demand-responsive transportation that has seen little experimentation, has been introduced in Merrill with the help of a state demonstration grant. The system uses two vehicles which make scheduled stops at checkpoints located around the city, but also respond to requests for doorstep pickups or drop-offs between checkpoints. A higher fare is charged for the premium doorstep service. With operating data for the first 7 months of service available, it appears that the point deviation concept is operationally valid. The service has been of high enough quality to attract a significantly greater number of passengers then had been using the transportation services that previously existed in Merrill. The higher cost, doorstep service option has been chosen by almost 40 percent of the adult ridership. Cost per hour has been below the cost of many other demand-responsive transportation systems. The system has demonstrated how high-quality transportation service can be provided in a small city.

Small cities in the United States, like their larger counterparts, have witnessed a deterioration in public transportation service during the past few decades. With few parking or congestion problems, these cities have not had strong community support for transit; as a result, the failure of private bus companies has often meant an end to public transit service. It was recently estimated that, of all urban areas with populations between 10 000 and 50 000, only 313 are served by public transportation systems (1).

The recently awakened interest in public transportation has been experienced in small cities as well as in larger cities, and numerous public transit services have been introduced in smaller cities during the past few years. Unfortunately, a lack of financial resources limits the potential of public transportation systems in these cities. Federal operating assistance is not at present available to cities with populations below 50 000, and local resources are rarely sufficient to subsidize a high-quality public transit system. Recently state governments have begun to play a more important role in developing public transit services in small communities. The state of Wisconsin is one of the first states to go beyond the provision of operating assistance by introducing a Transit Demonstration Program. Programs of this sort make it possible for small cities to develop and operate innovative, high-quality public transportation services and demonstrations such as these may lead to the next generation of public transportation systems in small cities, and perhaps larger cities as well.

This paper presents the experience of the Merrill-Go-Round, an innovative transit system recently implemented in Merrill, Wisconsin, under the Wisconsin Transit Demonstration Program. This system, which has combined the characteristics of fixed-route and demand-responsive transportation service, has performed extremely well thus far and may serve as a prototype for other cities.

BACKGROUND OF TRANSIT IN MERRILL, WISCONSIN

Merrill, Wisconsin, is a city of some 9500 persons located in the central part of the state. Although agriculture is no longer the dominant industry, small farms dot the gently rolling countryside that surrounds the city. The setting is not one that would be expected to serve as a test area for numerous transit innovations.

Yet Merrill has been a harbinger of urban transportation trends since 1891, when it became the first city in Wisconsin to be served by an electric street railway system. Trolley service, augmented for a short period of time by one of the nation's first trackless trolleys, continued until it was replaced by bus service in the 1920s. In 1955, when the bus service was experiencing significant losses, Merrill became one of the few small cities in the nation to take over the operation of public transit service. The city ran the service until 1970, by which time annual ridership had decreased to 29 000 from a 1956 high of 78 000 and the deficit had increased to $25 000. After a citywide referendum, the bus service was discontinued. However, city officials were unwilling

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to eliminate public transportation entirely, and therefore agreed to provide a local charter bus operator with a modest subsidy, in order for him to operate in-city school bus service and taxi service. Merrill then became one of the first cities in the country to subsidize a taxi operator, predating the recently awakened interest in utilizing taxi companies to provide mass transportation services.

Despite the subsidy the taxi operator soon ran into financial difficulties. While debating the merits of an eventually granted rate increase, city officials conferred with representatives of the state Division on Aging, to determine whether transit subsidies could be obtained for senior citizens. Instead, the city applied for and received a grant to purchase a vehicle and operate a free transportation service for the elderly and handicapped. At the urging of the Division on Aging, the city purchased the first battery-powered vehicle to be used for transit service in the United States since the early part of the century. In what was termed dial-a-bus service, the bus followed a designated route, but would deviate to provide doorstep service for the handicapped. Unfortunately, the bus was completely unreliable, and the service never attracted more than 30 passengers/day.

With the prospect for continued state funding of the dial-a-bus system reduced and with the taxi company experiencing increasing costs, Merrill officials next approached the Wisconsin Department of Transportation (WISDOT) in October 1973 to request state transit operating assistance but were informed that only common carrier operations were eligible for transit operating assistance. Although the in-city school bus service was eligible, the taxi company was not. However, the city was eligible for funds under a Transit Demonstration Program. At that time, WISDOT was interested in testing the concept of demand-responsive transportation. Since Merrill had already briefly experimented with the concept, it seemed to be a logical location to attempt the integration of various transportation subsystems into a cohesive demand-responsive transportation system. WISDOT hired the transportation consulting firm of Multisystems, Inc. (formerly ECI Systems, Inc.), to perform a transit feasibility study, apply for the funds, and design the Merrill system (2).

DEMAND-RESPONSIVE TRANSPORTATION IN MERRILL

The feasibility study focused on the generation and evaluation of transit alternatives for Merrill. A fixed-route alternative was considered, but rejected because significant improvements over the previous fixed-route service would not be possible within the budget constraints. Three other alternatives, all characterized as demand-responsive services, were also evaluated.

Demand-responsive transportation (DRT) is a concept that has received increasing interest during the past decade in response to the shift in development patterns to lower density development that is not readily (or economically) served by conventional fixed-route transit systems. There are many types of DRT systems; what they share is a degree of flexibility not found in conventional transit systems. They respond in some degree to the spatial or temporal demands of the passengers. Unlike taxis, however, which generally are constrained to serve only one passenger group at a time, DRT systems can transport many persons simultaneously, providing high-quality, door-to-door transportation (3). The cost per passenger of providing DRT service is typically between the costs of taxi and fixed-route bus service.

The three DRT alternatives considered, in order of increasing demand-responsiveness, were: route deviation service; zonal dial-a-ride service, and areawide dial-a-ride service. In a route deviation system vehicles travel along a fixed route, but may deviate from the route on demand to pick up or drop off passengers. In a zonal dial-a-ride system point-to-point service is provided anywhere within a single zone, but transfers are required for trips between zones. An areawide dial-a-ride system is perhaps the most fully demand-responsive service; point-to-point service is provided anywhere within a given service area. These three systems have different operating characteristics; the evaluation of these options was based on a comparison of such factors as cost, capacity, expected patronage, level of service, and vehicle fleet requirements.

The evaluation of the alternatives led to a recommendation to implement a route deviation system in Merrill (2). As the implementation proceeded, and for reasons that will be discussed later, it was decided to modify the system into what has been called a point deviation system. The relationship between point and route deviation, and the characteristics of these systems, are described below.

CONCEPTS OF ROUTE AND POINT DEVIATION

A route deviation system attempts to offer the best of all possible worlds by providing the best service to the most people. In a highly developed travel corridor many persons can easily reach a bus stop and do not require a door-to-door service. Even in such a corridor, however, there will be persons, in many cases senior citizens, whose origins or destinations are not within easy walking distance of a bus stop. A route deviation service can provide low-cost, scheduled service for those persons who can use the fixed-route option, and higher cost (if a higher fare is charged for premium service), more personalized service for those who request it. This type of service makes most sense in an area with a well defined travel corridor, but with a demand density too low to support an exclusively fixed-route service. It is not feasible in an area in which fixed-route service can operate at capacity, or in long travel corridors where scheduling would be difficult and travel times unreliable.

A point deviation system differs from a route deviation system in that the vehicles are scheduled to make stops at fixed checkpoints, but are free to respond to demands for doorstep service between checkpoints. In a point deviation system vehicles are not required to follow a specific path when not responding to a doorstep service request. This type of service is better suited to areas with less well defined travel corridors and more diffuse origin-destination patterns.

The basic advantages of route and point deviation services over conventional fixed-route services are increased coverage and improved level of service for persons receiving doorstep service. Their major advantage over pure door-to-door demand-responsive services is the capacity gained because not all passengers receive personal service. This increased capacity translates directly into a lower cost per passenger. A secondary advantage over pure door-to-door service is reduced dispatching requirements, which also lowers costs.

These advantages are not achieved without any disadvantages. Passenger travel time in a route or point deviation system might be greater, and more variable, than the travel time in a fixed-route system. Furthermore, if there is a fare differential between bus stop and doorstep service, persons who do not live near a bus stop may consider the fare structure inequitable, although this would probably be less of a problem when an existing fixed route is converted to route deviation. These disadvantages, however, do not seem to offset the potential advantages of route and point deviation services.

The concept of route deviation can be traced back to the jitneys, which flourished in the United States until strong lobbying on the part of street railway companies forced them off the road before 1930. Owner operated jitneys would travel up and down main streets, stopping to pick up and drop off passengers anywhere along the route. In some cases the jitneys would deviate a few blocks from the route to drop people off, charging a premium fare for this service. While jitneys are still popular in other parts of the world, few legal jitney services operate in the United States today.

Although both route and point deviation services have been considered integral forms of demand-responsive transportation since interest in DRT reawakened, neither option has yet received much attention (3). One demonstration of route deviation service was conducted in Mansfield, Ohio, in 1971, where an underused route was converted to route deviation (4). Passengers were able to hail the bus anywhere along the route, or request to be picked up at their door. From an operational viewpoint the system worked well and, although there was no net ridership gain, about 20 percent of all passengers chose the deviation option. The experiment was abandoned in 1972 when all public transportation service in Mansfield was discontinued. A point deviation system has operated for a few years in the Model Cities area of Columbus, Ohio (5). Vehicles in the Columbus system are constrained to depart from designated checkpoints at fixed times, but are free to take any path between checkpoints. Thus, unlike the jitney, which can be considered a fixed-route, variable-schedule service, the Columbus system is a variable-route, fixed-schedule service.

In the proper setting, a route or point deviation system offers an effective means of meeting a wide range of travel demands with a relatively high level of service. Merrill appeared to be ideally suited for a demonstration of this type of concept for a number of reasons:

1. The city of Merrill is long [over 6.4 km (4 miles)] and narrow [under 2.5 km (1.5 miles)]. Its main streets, on which many of the major demand generators are located, bisect the city lengthwise. With a route or string of stops located along the main streets, a system that allowed deviations would be able to serve the entire city with reasonably short headways.
2. Preliminary demand estimates indicated that a purely demand-responsive system would require three vehicles in order to maintain an adequate level of service. A route deviation system would require that only two vehicles be in operation at one time.
3. A small number of senior citizens in the city do not have private telephones, making access to a fully demand-responsive system difficult. Furthermore, the experience of the previous dial-a-bus service suggested that many senior citizens in Merrill preferred the regularity of scheduled service.

The introduction of a point deviation system in Merrill provided an opportunity to demonstrate the concept of point deviation and to test its ability to provide service in a small city.

THE MERRILL-GO-ROUND SYSTEM

Operation

The decision to shift the emphasis from route deviation to point deviation was based on the results of preliminary community contact rather than on analysis of the physical characteristics of the city. The general public familiarity with fixed-route bus service made the concept of deviations difficult to grasp, and extensive explanations were necessary before people understood that the buses would not be constrained to a fixed route. Rather than attempt a massive reeducation program, the system was changed to a point deviation one. The word route was eliminated from all advertising material and a system map that showed only checkpoints was developed. The system, which had earlier been referred to as a route deviation system, became known as the Merrill-Go-Round. (The name was selected from the entries received in a Name the Minibus contest.)

Ten checkpoints were established at major activity centers and other locations around the city, as shown in Figure 1. A maximum distance of 0.8 km (½ mile) was maintained between successive checkpoints, which were located such that over 60 percent of the population live within 0.4 km (¼ mile) of a checkpoint. Two buses operating on 30-min headways make scheduled stops at each checkpoint. Passengers can board at any checkpoint and be taken to any other checkpoint for a base fare of 25 cents; or they can ask to be taken to any other location in the city (checkpoint to doorstep) for 40 cents. Persons not within an easy walk of a checkpoint can request doorstep pickup. Doorstep to checkpoint service costs 40 cents; doorstep to doorstep service costs 50 cents. The extra charge for doorstep service is charged only once per pickup, whether one or more persons are traveling.

When no requests for doorstep service are received, the buses follow the most direct route between checkpoints. Buses responding to doorstep service requests need not return to the route, but can proceed directly to the next checkpoint; unlike the route deviation system that operated in Mansfield there is no guarantee that a vehicle will always follow the same path. This feature of the Merrill system increases its ability to serve doorstep requests but severely limits the potential for hailing a vehicle.

Merrill-Go-Round service is provided seven days a week: 6:30 a.m. to 6:00 p.m. Monday through Thursday; 6:30 a.m. to 9:30 p.m. on Fridays (to accommodate shoppers); and 8:00 a.m. to 5:00 p.m. on Saturday and Sunday. In addition to the basic service, direct service is provided to and from each school in the city once in the morning and once in the afternoon; at those times the 30-min headways are adjusted slightly. Fares are 15 cents per trip for checkpoint to school (or return) and 30 cents per trip or $2.50 per week for doorstep to school (6).

The system uses three 21-passenger Flexible Flxettes, with one of the vehicles serving primarily as a spare but also available for charter service. To improve their accessibility to the elderly and handicapped, the vehicles are equipped with retractable first steps housed under the entranceway to the vehicle, which reduce the height of the first step from 35 to 20 cm, and extra entranceway handrails.

Dispatching

In most taxi or dial-a-ride systems a central dispatching staff receives all service requests, decides which vehicle to assign to each request, and contacts the vehicle with the necessary information, usually by means of a mobile radio system. In a route or point deviation system, where only a portion of the passengers request doorstep service and where the assignment of passengers to a vehicle is almost an automatic decision, the dispatching requirements are sharply reduced. To take full advantage of this characteristic, it would be desirable to eliminate the dispatcher entirely and have the drivers

Figure 1. Merrill-Go-Round checkpoints.

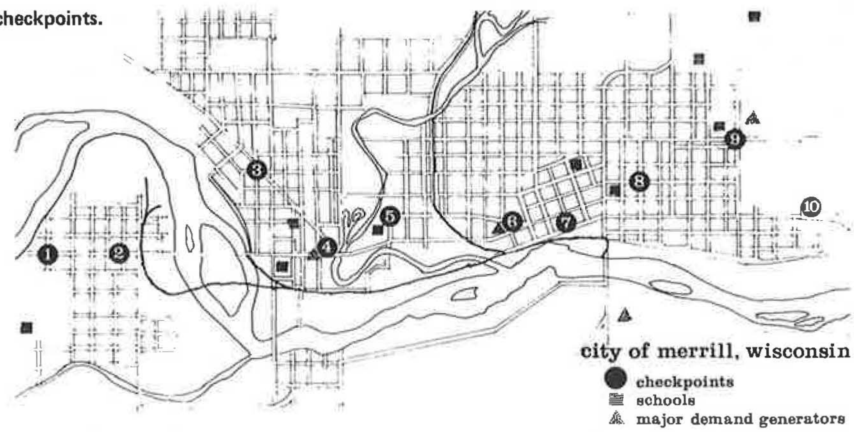


Figure 2. Average ridership.

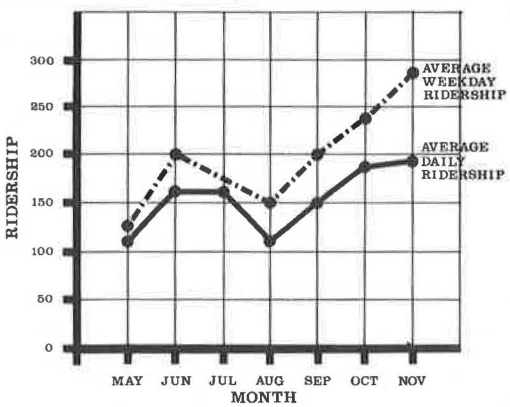
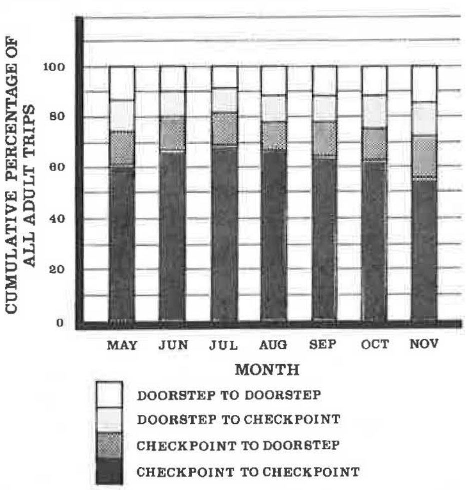


Figure 3. Use of doorstep service option.



themselves handle the dispatching task. This requires a direct passenger-to-driver communications system such as a mobile, or radio telephone. A mobile telephone was used in the Mansfield experiment (4). Unfortunately, there are two major problems associated with the use of mobile telephones in this manner: First, long telephone conversations can result in significant vehicle delays. The second and more serious problem is a result of the limited frequency spectrum allotted to mobile telephones. All mobile telephones in an urban area share a common set of one or more frequencies. For example, in Mansfield 22 subscribers shared a single frequency with the bus system and passengers were frequently unable to reach the bus by telephone. In Merrill, 34 subscribers shared two frequencies. Although there was a higher probability of successful calls in the Merrill system, there was still the possibility that passengers would have difficulty reaching the vehicles by mobile telephone.

The Merrill system presented another opportunity to test the suitability of mobile telephones for DRT dispatching, but rather than relying solely on it, a radio transmitter that had been obtained for the elderly dial-a-bus system was retained, two additional mobile radios were purchased, and a part-time dispatcher was hired to share dispatching duties with the system administrator. Plans at the beginning were to use the mobile telephones only during the periods of the lowest expected demand on the DRT system and of the lowest expected use of mobile telephones by other subscribers, and then, if the telephones were acceptable during these periods, to test them during other hours of the day.

Scheduling

Scheduling was the major concern during the system design phase. Would the vehicles be able to make doorstep pickups and drop-offs and still make scheduled stops at the checkpoints and maintain the basic headway? The limited experience this type of service has seen did not fully answer this question. The 30-min design headway allowed 15 min for deviations. Preliminary estimates suggested that this would allow an average of up to five deviations per run, which was considered to be sufficient. This estimate assumed that the average doorstep stop would be at a point midway between the route traced out by the checkpoints and the service area boundary, and hence would add to the run length twice the distance between the route and this point. The schedule of stops at the checkpoints was developed by first timing the direct run from checkpoint to checkpoint, and then adjusting the running times to incorporate sufficient time to serve the expected number of doorstep service requests between checkpoint pairs. Origin-destination data from the taxi company were used to identify potential locations of doorstep service requests. If too much time is scheduled between checkpoints, a bus may arrive at a checkpoint too early, and, since drivers in the Merrill-Go-Round system were instructed to remain at a checkpoint until the scheduled departure, the resulting delay might be unsatisfactory for passengers already on board. On the other hand, if scheduling is tight, buses may frequently arrive late at some checkpoints. The initial schedule was felt to be a reasonable compromise, but it was understood that because of the stochastic nature of doorstep service requests both situations described would, at times, occur. Operating experience would, of course, dictate schedule adjustments.

Early Operating Results

Merrill-Go-Round operations began smoothly on April 21, 1975, and no major operating problems were encountered during the early weeks of service. Ridership was slightly higher than expected at first, and rose fairly steadily. Data are now available for the first 7 months of operation.

Ridership

Average daily ridership and average weekday ridership per month are shown in Figure 2. Ridership has risen steadily, except during the summer months when school was not in session. As expected, the onset of cold weather had a significant impact on ridership, with the average weekday ridership increasing from 213 to 288 between September and November.

The most dramatic increase was in the ridership of school children. During May, when the weather was excellent, school children accounted for 30 percent of all weekday trips (average of 46 trips per day); in October, school children accounted for 45 percent of all trips (average of 145 trips per day). School trips showed a 150 percent increase between May and October, while adult passenger trips increased 32 percent during the same period.

As expected, the second major market group has been the senior citizens, who comprise 18 percent of Merrill's population and just over 20 percent of the ridership. However, according to an on-board survey conducted in early December 1976, 64 percent of the adult passengers are actually under the age of 65 and work trips account for 22 percent of all from-home trips. Thus, the system is serving the overall community, not just school children and senior citizens. In addition, according to the on-board survey, almost one-fourth of all adult passengers had been diverted from the automobile.

The average weekday ridership of 288 during the month of November 1975 is more than 2.5 times the combined daily ridership of 90 to 110 averaged by taxi and in-city school bus services that had ceased operation when Merrill-Go-Round service began. If the daily ridership were to continue at that level throughout the year, the total yearly ridership of over 80 000 would exceed the highest recorded ridership of the old fixed-route system (78 000 in 1956).

Average system productivity, or passengers per vehicle per hour, increased from six during the first month of operation to eleven during the month of November, and on some days approached twenty. Most fully demand-responsive systems, such as the one in Haddonfield, New Jersey, exhibit maximum productivities of between six and seven. Thus the Merrill experiment has already demonstrated that point deviation systems offer potentially higher capacity than other forms of demand-responsive service.

Use of the Doorstep Service Option

During the first few months of service, approximately 38 percent of all adult passengers requested doorstep service for one or both ends of their trips. This suggests that the marketing campaign had been successful in transmitting the concept of doorstep service to the community. After the introduction of a tenth checkpoint in mid-June, the percentage of doorstep service users fell to 30 percent, but as the weather turned colder the use of the doorstep service option increased again. By October 1975, 37 percent of all trips involved doorstep pickup or drop-off. In November this rose to 44 percent, and indications are that it rose even higher in December. The use of the doorstep service option over the first 7 months of service is shown in Figure 3.

The issue of the trade-off between walk time and cost made by passengers in the decision whether to request doorstep service is one for which no information is available. In the on-board survey passengers were asked how far they had walked to a checkpoint or, in the case of those persons requesting doorstep service, how far they had been from the nearest checkpoint. As might be expected, for very short walk distances (1 block or less) everyone chose checkpoint pickup. For walks beyond 6 blocks everyone chose doorstep service. For trips of intermediate length both options were chosen, with the percent choosing doorstep service increasing with increasing distance. The trade-off point occurred at about 4.5 blocks, or approximately ½ km (⅓ mile); at that distance people were equally likely to choose to walk to the nearest checkpoint or to request doorstep service. In analyzing these results, one must be careful to consider that fare differential and weather conditions are factors that will strongly influence the trade-off. [The day of the survey was a sunny winter day, with a temperature of about -3°C (25° F).] Another factor that will probably influence the trade-off point is age but insufficient data are available to test its significance on the decision.

Schedule Adherence

The concern over the ability of the vehicles to maintain schedules while serving doorstep requests dissipated quickly. The vehicles had little difficulty maintaining the headway during the early months of service. Although accurate statistics are not available, on-time performance has been estimated at 90 to 95 percent. Late arrivals at the end of a run have generally been the result of very long deviations from the direct path, rather than of too many deviations. Drivers have been able to make up time on the next trip when they were running late. Up to six requests for doorstep service have been handled during a single run without delays being incurred.

The buses do occasionally arrive as much as 4 min early or 5 to 6 min late at interim checkpoints. Thus far there have been few complaints from either passengers waiting for a late bus or those waiting on board an early bus. The schedule has been revised to minimize the problem, and no serious problem appears to exist now.

Communications System

As noted earlier, one of the subobjectives of the demonstration was to test the ability of the radio telephone to serve as the sole communications link in a point deviation system. During the first few months of service a series of tests of the system was conducted. Test calls were placed to the vehicles every 2 min during 60 to 120-min periods on a number of occasions over a 1-month period, both during the times the radio telephones were being used and during times that they were not in use. The basic results of these tests were:

1. Before 8:00 a.m. on weekdays and on Saturdays there should be no difficulty in using the mobile telephones. The success ratios, or the ratios of completed to attempted calls, for those two periods were 85 percent and 76 percent respectively.
2. After 5:00 p.m. on weekdays and on Sundays there may be difficulty in using the mobile telephones. Success ratios for these two periods were 60 percent and 50 percent respectively.

3. During the normal 8:00 a.m. to 5:00 p.m. business day it does not appear possible to use the mobile telephones; the success ratio varied between 30 and 40 percent for any 1-h time period.

4. Although there are technical difficulties when using mobile telephones, saturation of the system is the major problem. Busy signals accounted for 80 percent of all noncompleted calls.

Complaints about the mobile telephones were infrequent during the first weeks of service but increased after the summer. In October 1975, construction on a highway near Merrill was completed and the leases of about 25 percent of the mobile telephones in the area terminated. This reduced the severity of the problem, but the problem clearly remains. No formal tests of the system have been conducted since this change, but it is apparent that during normal working hours the mobile telephone cannot be used as the only communications link. Although the evidence is certainly not conclusive, radio telephones may not be generally satisfactory for demand-responsive transportation use with the present frequency allocation procedure.

The use of the telephones by the drivers in Merrill has not been a problem. The drivers have been able to answer the telephones and record the necessary information without any delay. They have not yet handled more than three telephone requests per hour, but even during peak hours when radio communications are used the number of doorstep pickups per bus per hour rarely exceeded four. Thus, although mobile telephones may not be sufficiently flexible to provide the sole communications link in a point deviation system, they are useful as an adjunct to a centralized dispatching system. They can be used during off-peak periods, and can serve as a backup in the event of failure of the regular two-way radio system to reduce labor costs and increase system reliability.

Operating Cost

Some operating cost figures for the first 6 months of operation are compared below with values projected prior to the start of service.

Indicator	First 6 Months of Service ($)	Projected First Year ($)
Operating cost/km	0.49	0.59
Operating cost/h	9.49	10.79
Operating cost/passenger	0.99	1.10
Fare box revenue/passenger	0.26	0.27
Total revenue/passenger	0.28	0.29
Net cost/passenger	0.71	0.81

Cost is running significantly below the projected level. This is due in part to the fact that the drivers were not eligible for all city benefits during their first 6 months of service, in part to low vehicle maintenance costs (with much of the maintenance covered by warranty), and in part to the lower than expected need for driver overtime. The first two costs will increase during the next few months.

Fare per passenger is running below the expected value, but has increased since October because of the increased use of doorstep service. Based on presently projected December ridership and cost figures, the operating cost per passenger should decrease during the winter months to about 85 cents and the net cost per passenger to about 56 cents. Although revenue would account for only 34 percent of cost, an 85 cents/passenger cost is significantly lower than the cost experienced by most other demand-responsive transportation services (3). While this lower cost is due partly to the low wage rate of the nonunionized labor in Merrill ($4.50/h including benefits) it is also due partly to lower dispatching costs and higher than average productivity.

CONCLUSIONS

After only 7 months service, it is difficult to report final conclusions on the results of the Merrill demonstration. However, the consistency of the results to date must be considered. Based on these results, the following tentative conclusions are offered:

1. Point deviation appears to be a viable transportation option, at the very least in a geographic setting such as Merrill. It is able to serve a variety of transit needs with a high level of service. Some of the potential advantages of point deviation over more fully demand-responsive modes, including higher capacity, more reliable service, and lower costs, have already been shown.
2. A well-marketed, high-quality transit service that combines flexibility, reliability, and comfort with high frequency and total coverage can attract new transit ridership in a small city, and divert people from the automobile.
3. With the help of a progressive state operating assistance program like the one in Wisconsin, which covers ⅔ of all operating deficits, the operation of a high-quality service is well within the financial means of most small cities. Merrill's projected share of the deficit following the demonstration period is less than $2/capita annually.

The Merrill-Go-Round system has thus far achieved or exceeded all expectations in terms of operating performance, community acceptance, and ridership. It should serve as an example of how small cities can be served by relatively inexpensive, high-quality transportation services, and has indicated that such services will be used even in areas with little or no parking or traffic congestion problems.

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