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The Runaround: User-Side Subsidies for Fixed-Route Transit in Danville, Illinois

PAMELA BLOOMFIELD, DAVID KOFFMAN, AND LARRY A. BRUNO

A two-year Urban Mass Transportation Administration Service and Methods Demonstration (SMD) project in Danville, Illinois, tested the first application of the concept of the user-side subsidy to fixed-route transit for the general population. The Transportation Systems Center was responsible for evaluating the demonstration and contracted with Crain and Associates for this purpose. Service was provided by private contractors, who were selected on a competitive basis every four months. Payment to providers, which was based on the number of prepurchased tickets used by passengers to pay for rides and then turned over to the city, was intended to create an incentive for designing and providing good, efficient service tailored to the existing demand. The system, called the Runaround, proved workable but administratively expensive. Only two providers participated, which indicated a lack of effective competition, although on most routes good service appears to have been supplied at a reasonable cost. The major provider adopted a very conservative negotiating position; the result was that payment was effectively on a fixed-price rather than per-passenger basis. Although unproductive service was dropped under the user-side subsidy arrangement, a full test of the concept's effectiveness has yet to be considered.

In August 1977, the city of Danville in Illinois was awarded a two-year grant, under an amendment to a Service and Methods Demonstration (SMD) grant from the Urban Mass Transportation Administration, to test a user-side subsidy scheme for supporting fixed-route transit to be provided by private transportation companies.

The distinguishing feature of a user-side subsidy is that providers of a service receive the subsidy only in amounts proportional to the number of people who use the service. In its purest form, potential patrons, or users, would receive the subsidy to be spent on transportation of any type, as is the case with food stamps or rent supplements. The mechanisms usually employed are (a) tickets sold at a reduced price and then redeemed by the provider for the subsidy after they are used and (b) vouchers signed by patrons and redeemed by the provider. Simple passenger or revenue counts can also be used as a basis for subsidy payments, but this type of statistic may be subject to fraud.

User-side subsidies are attracting national interest as an alternative to more-traditional forms of transit subsidy (provider-side subsidies) in which an operator receives a systemwide subsidy to provide a certain level of transit service. The most-common application to date has been in the provision of discounted taxi rides for the elderly and the handicapped. However, user-side subsidies can also be used to support more-conventional transit for the general population, as is the case in Danville. Under a user-side subsidy scheme, the revenues earned by the transit operator are not predetermined; rather, they depend on his or her ability to serve the needs of individual passengers, who, in effect, hold the power of the subsidy. There are, at least in theory, several strong advantages to a user-side subsidy arrangement:

1. By assuming that there is some form of marketlike competition or threat of competition, providers have an incentive to offer service that is as efficient as possible and tailored to the travel demands of the user population in order to maximize their profits.
2. Localities are afforded a degree of flexibility not offered by most traditional funding arrangements. For example, the need for commitment to a particular vehicle or service type can be minimized. In addition, selective application of the subsidy by type of person (e.g., elderly, handicapped, low-income, and so forth), by mode, by type of trip, or by time of day or day of week is possible. Most applications to date have been for taxi service for the elderly and the handicapped (that the user-side mechanism appears acceptable as a means to subsidize taxi service is another of its attractive features).

Danville, which covers 13 miles^2, is a city of 43 000 located in east central Illinois, about 4 miles from the Indiana border. In 1970, voters in Danville rejected a 3-cent sales tax to subsidize a bus service that had become unprofitable for the private operator the year before. From then until late 1977, Danville was virtually without regular fixed-route public transportation.

This demonstration was phase 2 of a project; in phase 1, also a two-year demonstration, the user-side subsidy concept was applied to taxi services for the elderly and the handicapped in Danville (1). Phase 2 of the Danville demonstration, the focus of this paper, was designed to be the first application of a user-side subsidy to fixed-route transit for the general population (2). Federal funds allocated to phase 2 totaled approximately $982 787; the city of Danville contributed in-kind services. The transit system, named the Runaround, began operations in November 1977.

PROJECT DESIGN

The original design of phase 2 of the project incorporated the following features. Transportation providers were selected on the basis of a competitive bidding process, repeated every four months. This short contract period was chosen, despite obvious disadvantages, to protect the city from the consequences of unrealistically low ridership predictions and to protect the providers from the consequences of unrealistically high ridership predictions. In addition, the short contract period allowed several opportunities for change over the course of the two-year demonstration.

The city established certain minimum standards (for example, air-conditioned vehicles); however, within those standards, bidders were free to propose any level or type of service they desired. In principle, multiple providers could have contracts that simultaneously operated different routes or the same routes at different times. It is important to note, however, that all transportation providers were responsible for furnishing, garaging, and maintaining the vehicles for operation of the service, as well as for hiring and training drivers.

Before each contract period, prospective providers submitted proposals, which included fares, a per-ticket reimbursement rate, and a complete service plan (or several alternative plans) that showed routes, schedules, hours of operation, and fares. The city was not required to choose the lowest bidder or to implement the exact service plan contained in any of the proposals. Since Danville had been without regular transit service for seven years, estimates of initial ridership levels were very uncertain. Therefore, to minimize risk and avoid discouraging potential bidders, providers were guaranteed a minimum payment based on vehicle mileage for the first two four-month contract periods; providers would receive the mileage payment if initial ridership estimates were not realized. Thereafter, the user-side subsidy would take effect: Providers would be reimbursed on a per-passenger basis, regardless of vehicle mileage.

Prepaid tickets constituted the primary method of fare payment as well as the determinant of the amount of subsidy. The city was responsible for selling the tickets to the public at the announced fare. On a weekly basis, the provider would redeem the used tickets for an agreed-on per-ticket price. Elderly and handicapped riders as well as students under 18 years of age could purchase special tickets at a 50 percent discount; the providers received full reimbursement for such tickets. Cash fare payments were allowed; however, the city paid no subsidy on such fares. Thus, providers were encouraged to set the cash fare at a level substantially higher than the cost of tickets in order to encourage use of tickets and to compensate for the absence of subsidy on cash fares. In the original request for proposal (RFP) issued by the city, prior to the first contract period, bidders had a fair amount of leeway in designing the fare structure: For example, zone fares, peak and off-peak fares, and transfer charges were permissible under the terms of the RFP.

The city of Danville was responsible for marketing the Runaround system in order to give the system a uniform image even in the event of multiple or changing providers. Also, in order to control the subsidy mechanism, the city had to assume responsibility for marketing the tickets, which were sold by 32 local businesses on a voluntary basis and by the project office at City Hall. Other marketing responsibilities delegated to the city included designing, printing, and distributing tickets, maps, and schedules; painting of (and possible removal of paint from) transit vehicles; designing and placing route markers, bus-stop signs, benches, or shelters; and conducting advertising and promotional activities to publicize the Runaround system. It was hoped that the user-side subsidy arrangement would create an incentive for the private operators to conduct their promotional activities (with review and approval by the city). However, the costs of provider-initiated marketing efforts were not to be considered in the negotiations of the mileage or per-ticket payments received by the providers.

This paper examines the implementation of these five features of the experimental design over the course of the five four-month contract periods during which the demonstration was conducted.

COMPETITIVE BIDDING PROCESS

Prior to each contract period, the city placed notices and advertisements that announced the RFP in national transportation journals and in newspapers in Chicago, Indianapolis, and Danville. Bidders were given one month to respond. With each bid package sent to prospective bidders, the city enclosed a copy of the Transit Development Plan (TDP). (Thus, while bidders were technically free to design any type of service, it was perhaps predictable that bidders would draw heavily on the TDP.) After the provider or providers had been selected, contract negotiations between the city and the provider (or providers) were conducted. The time that remained between the signing of the contracts and the start of the new service averaged about a month and was sometimes shorter.

At the outset of the demonstration, before the first contract period, 10 firms requested RFPs; however, only 2 submitted bids. One of them, St. Louis-based American Transit Corporation (ATC), was well known to the city of Danville and its residents: The bus service that operated in Danville until 1970 was operated by the Bee Line Transit Company, a division of ATC. Bee Line continued to operate Danville's school bus service until the summer of 1979 by using a large fleet of buses based at Bee Line's extensive maintenance facility in Danville. The other bidder was unfamiliar to the city and owned no facilities near Danville.

Although the unit and total costs proposed by ATC were considerably higher than those contained in the other firm's bid, the latter took exception to many details of the RFP--specifically, the concept of multiple providers, the use of prepaid tickets, and the city's role in marketing the tickets and publicizing the transit system. The bid was therefore determined to be unresponsive to the RFP; a single contract was awarded to ATC, which offered the advantages of an established reputation and a large existing facility in Danville.

Prior to the second contract period, the city again attempted to induce prospective operators to bid on the Runaround service; however, only the same two firms submitted bids. The possibility of having the other firm provide small-bus service on lightly patronized routes was closely examined. However, after an investigation into this firm's past performance, the contract was again awarded to ATC. The other firm submitted no further bids.

Throughout the remainder of the demonstration, which consisted of three more contract periods, ATC had virtually no competition, although Red Top Cab, a local company, did provide service on routes that ATC could not serve at a reasonable price after the user-side subsidy arrangement came into force in the third contract period. Considerable effort was spent encouraging Red Top to bid. Although 25 firms were sent copies of the RFP to provide service for the third contract period under the user-side subsidy arrangement, only ATC and Red Top Cab submitted bids. Red Top Cab had 18 licensed vehicles in early 1978. During phase 1 of the Danville demonstration, Red Top Cab had provided the majority of subsidized taxi trips to elderly and handicapped persons registered with the project. Thus, the cab company was well known to the federal monitors as well as to the city and community of Danville. Contracts for the third period were awarded to both ATC and Red Top; the latter was to operate a 21-passenger minibus along two routes that could not be profitably served by ATC's large 45-passenger buses, as well as a demand-responsive, fixed-route taxi service along two other low-volume routes. This arrangement remained essentially unchanged throughout the two final contract periods: ATC and Red Top Cab were the sole bidders; both were awarded contracts. Clearly, then, the competitive environment envisioned in the experimental design of the project never materialized.

At the end of the demonstration, a mail-back survey of nonbidding firms was conducted. The majority of the 15 firms that responded indicated that the four-month contract period constituted the primary obstacle to bidding. In addition, several respondents wrote in comments about ATC; one wrote, "Incumbent or local operator has an unrealistic advantage due to short [lead] time and size of system; the cost to an outside firm to set up and operate the system under the program is too high. It is an ideal arrangement for keeping outsiders out."

SERVICE DESIGN

The route structure proposed in ATC's initial bid (submitted prior to the first contract period) conformed closely to the TDP developed for Danville by De Leuw Cather and Company in 1976 and also to the routes served by Bee Line Transit (operated by ATC) prior to 1970. ATC proposed a flat $0.40 ticket fare and a $1.00 cash fare; transfers were to be free. In response to this fare structure, the city decided to sell tickets in books of 5 and 20 full-fare tickets and 10 half-fare tickets. ATC's initial bid also proposed three alternative levels of transit service; the city chose to implement the highest of the three service levels. Thus, in December 1977, having had no public transit service at all for seven years, the Danville community suddenly had service 12 h/day, 6 days/week, that consisted of 11 routes, 5 of which operated on 30-min headways. The rest operated on 60-min headways. These routes were served by seven regular 45-passenger buses and two spares; each bus served at least two routes. In hindsight, this level of service proved to be unnecessarily and unmanageably high. The need for rerouting, unforeseen delays in obtaining two-way radios, and other reliability problems all contributed to uneven service quality in the initial months of service.

A number of schedule and level-of-service changes were instituted during the second contract period. The schedules were altered to permit "pulsing" of the buses at the central downtown transfer zone, and weekday service headways were decreased to 30 min on all but two routes, which thus raised the weekly vehicle mileage from 6923 to 8090. Note that the user-side subsidy arrangement had not yet been implemented; the mileage guarantee was still in effect. The decision to increase service was made by the city, not by ATC, in response to disappointingly low ridership. City officials felt strongly that only by increasing system coverage could the Runaround receive a fair test.

As stated earlier, the remaining three contract periods incorporated two major changes to existing arrangements: The guaranteed per-mile reimbursement was dropped, and service on four low-demand routes was contracted to Red Top Cab due to the prohibitively high per-passenger cost of having ATC continue to serve those routes. A plan was devised by which a van or minibus would serve two of the unproductive routes and taxis would serve the other two. Red Top Cab purchased a 21-passenger minibus, which operated for the duration of the project.

In summary, the implementation of the user-side subsidy appears to have had two beneficial impacts on the design of the Runaround: It created an incentive for ATC to eliminate unproductive service and, by focusing attention on the per-passenger cost of serving various routes, it provided the city with justification for service cutbacks. Without this justification, the city might have been more susceptible to fair-share arguments against service cutbacks. The decision to serve the unproductive routes with minibus and taxi service was not a product of free-market forces at work, however. Rather, the multiple-provider arrangement was devised by the federal monitors and the city; intense negotiations with all parties were required to design an arrangement that was workable and satisfactory to both ATC and Red Top.

SUBSIDY MECHANISM AND PROJECT RIDERSHIP

As discussed earlier, providers were guaranteed a minimum payment based on vehicle mileage for the first two contract periods. Thus, ATC received a per-mile reimbursement of $1.35 for the first contract period; this figure was renegotiated and lowered to $1.26 for the second contract period to compensate for the addition of 1167 vehicle miles of service. In addition, ATC was reimbursed for start-up activities: These included training and relocating transit employees, repainting ATC's vehicles, and installing two-way radios in the vehicles.

For both initial contract periods, the contracts negotiated with ATC specified that ATC would receive either the per-mile reimbursement or $1.20/ticket collected, whichever amount proved higher. For the latter, in which the user-side subsidy payment was to exceed the mileage payment, ridership on the Runaround would have had to exceed 1327/day during the first contract period and 1415/day during the second contract period. In fact, ridership did not reach either level at any time during the demonstration. Figure 1 shows average daily project ridership by month and the levels at which the user-side subsidy would equal the mileage guarantee payment.

By the eighth month of the project, it had become clear that initial forecasts of rapid ridership increases had been unrealistic. Thus, in negotiating the per-passenger (or user-side subsidy) payment to be instituted at the start of the third contract period, ATC took a very conservative stance, but, since the city received no other bids to provide service on most routes, ATC was in a very favorable bargaining position. The resulting contract with ATC specified a subsidy of $2.00/ticket collected; Red Top received $1.50/ticket. To compensate for the high per-ticket payment, the contracts also specified a maximum payment to each contractor; trips provided beyond the specified limit were not reimbursed. The per-ticket or user-side subsidy payment received by each operator was designed to cover the cost of providing service and to furnish a reasonable profit to each operator; thus, the contract maximum was designed to allow for the possibility that the providers' profits would be far higher than anticipated. In theory, the maximum payment should be very high and thus almost impossible to attain at projected ridership levels and a projected operator profit margin of, for example, 10-15 percent. Thus, on the one hand, the high maximum should serve as an incentive for the operator to increase ridership by furnishing efficient high-quality service, and, on the other hand, it is designed to function as a safety mechanism in that it limits the city's liability in case of unusual ridership growth. It also offers potential advantages to the city in conducting contract negotiations with transit providers: If an operator furnishes a conservative ridership estimate and thus negotiates a high per-ticket payment, the city can lower the maximum payment, which thus reduces potential profits to the operator. The reverse may also hold: The city may offer to increase the maximum in order to negotiate a lower per-ticket payment. Finally, most public bodies (which include the federal government) cannot legally enter into open-ended contracts; the maximum payment was therefore an administrative necessity.

The per-ticket payment and maximum payment received by ATC were renegotiated prior to the fourth and fifth contract periods; the city's financial arrangement with Red Top did not change

Figure 1. Average daily ridership.

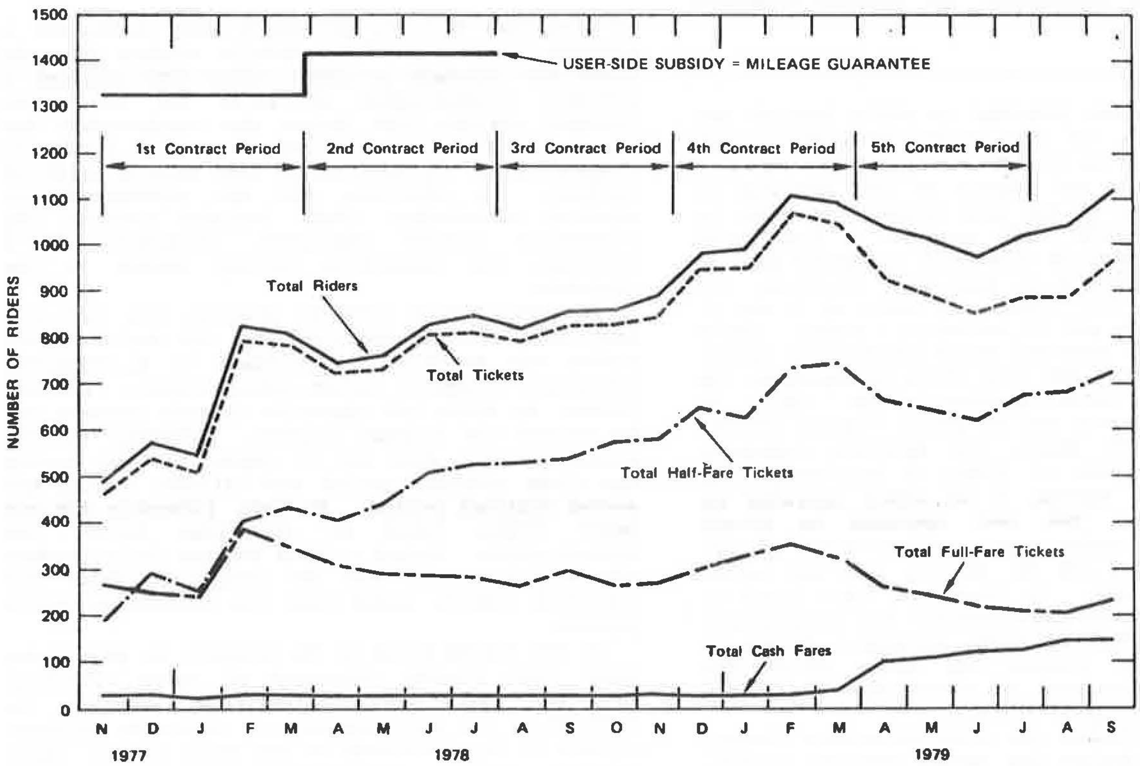

Table 1. Subsidy arrangements.

Contract Period	Contractor	Subsidy	Maximum Payment ($)
1	ATC	\$1.35/mile[a]	175 000
2	ATC	\$1.26/mile[a]	172 000
3	ATC	\$2.00/ticket	130 000
	Red Top	\$1.50/ticket	25 000
4	ATC	\$1.85/ticket	138 000
	Red Top	\$1.50/ticket	25 500
5	ATC	\$1.65/ticket \$1.15/cash fare[b]	142 000
	Red Top	\$1.50/ticket \$1.00/cash fare[b]	25 500
Post-demonstration	ATC	\$1.65/ticket \$1.15/cash fare[b]	486 000
	Red Top	\$1.65/ticket \$1.15/cash fare[b]	14 000

[a]Or \$1.20/ticket collected, whichever amount proved higher. During both contract periods, ATC received the mileage payments.
[b]Providers retained the \$0.50 cash fare; thus, the total payment (fare plus subsidy) was the same as that for tickets.

for the duration of the project. Table 1 lists the subsidy arrangements negotiated with ATC and Red Top for each contract period. In general, ATC negotiated high per-ticket payments for the three contract periods during which the user-side subsidy arrangement was in effect. Correspondingly, the city set the maximum payments at levels that were in fact attainable. Figure 2 shows ATC ridership by month and the ridership levels that corresponded to the maximum payments for the last three contract periods. Note that for the last three contract periods, ATC's ridership was more than that needed to reach the contract maximum. Thus, due to the difficulty of accurately predicting ridership levels of the new transit system, the user-side subsidy mechanism of reimbursement in practice had little relevance to ATC, which received (in effect) a fixed amount of money to furnish service during each contract period. The other provider, Red Top, never reached the contract maximum and thus operated under the user-side subsidy arrangement for three contract periods. However, due to many factors, the service furnished by Red Top was of inferior quality to that of ATC, and ridership on the routes served by Red Top remained low throughout the demonstration.

As noted earlier, the user-side subsidy arrangement did cause unproductive service to be dropped before the third contract period. Indeed, the flexibility to change levels of service and providers is considered to be a major advantage of the user-side subsidy concept. In the Danville case, however, an additional, unresolved issue is whether major changes in service levels, routes, schedules, and providers depressed ridership levels.

PROJECT COSTS

The costs of operating and administering the Runaround system, exclusive of federal evaluation survey and data collection costs, totaled approximately \$550 000 for one year under the user-side subsidy arrangement. Table 2 shows the breakdown by the total cost, cost per revenue mile, and cost per revenue passenger.

The most striking feature of Danville's cost breakdown concerns the figures for administrative expenses. In particular, salaries and wages appear to be very high. ATC was able to negotiate very favorable contracts with the transit drivers during both years of the demonstration; thus, the wages received by ATC drivers are low compared with those of other transit systems. Therefore, the figure for salaries and wages shown reflects high administrative costs rather than high operating

Figure 2. Average daily subsidized trips provided by ATC (contract periods 3, 4, and 5).

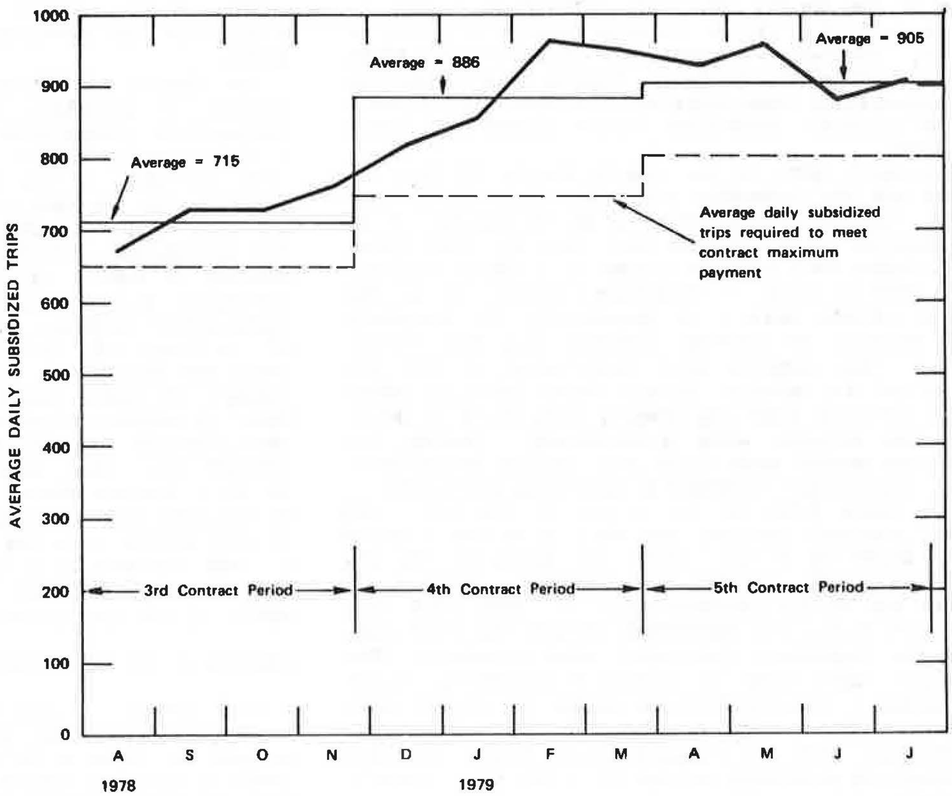

Table 2. Breakdown of Runaround costs for one year under user-side subsidy.

Category	Costs ($) Total	Per Revenue Mile	Per Revenue Passenger
Transit services			
Vehicles	68 700	0.21	0.23
Drivers' wages	111 457	0.34	0.38
Maintenance (wages and other)	57 573	0.18	0.20
Other (including fuel)	53 317	0.16	0.18
Administration			
Salaries and wages	95 141	0.29	0.32
Other (tickets, maps, office supplies, etc.)	19 622	0.06	0.07
Garage and office rent	18 410	0.06	0.06
Marketing	13 194	0.04	0.04
Insurance and bonding	23 060	0.07	0.08
ATC back-up service on Red Top routes 4 and 7	1 190	0.00	0.00
ATC profit[a]	37 659	0.11	0.13
Red Top costs and profit[b]	51 884	0.16	0.18
Subtotal	551 207	1.68	1.87
Less			
Cash fares	11 411	0.03	0.04
Ticket revenues	71 207	0.22	0.24
Total subsidy costs	468 589	1.43	1.59

[a]Based on costs reported by ATC.
[b]A full cost breakdown for Red Top Cab is not available.

costs. The user-side subsidy arrangement does in fact require a large administrative effort to handle the ticket program, prepare RFPs, conduct contract negotiations, monitor the subsidy arrangement, and publicize changes in service features.

Although ATC adopted a very conservative posture in each round of contract negotiations, analysis of the estimated costs submitted by ATC with each proposal does not indicate that their overall profit margin was unreasonably high. For the third contract period, in which the user-side subsidy was first implemented, their estimated profit margin was close to 13 percent; however, this dropped to 9.8 percent for the fourth period and to 7.7 percent for the fifth period.

When the revenue mileage and ridership for the third through fifth contract periods were compared, the project costs were as follows:

Cost Category	Contract Period Third	Fourth	Fifth
Per revenue mile ($)	1.61	1.70	1.71
Per revenue passenger ($)	2.08	1.84	1.74

The high cost per revenue passenger is corroborated by the low productivity statistics for those periods:

Productivity Category	Contract Period Third	Fourth	Fifth
Passengers per revenue mile	0.78	0.93	0.99
Passengers per revenue hour	11.46	14.44	14.53

Overall, project ridership was disappointingly low. Although the costs of ATC's operations appear to have been reasonable and the total project costs do not appear to have been extraordinarily high, the low ridership levels did call into question Danville's ability to support a fixed-route transit system.

PREPAID TICKETS

On the whole, the system of selling books of prepaid half-fare and full-fare tickets worked well. When the bus service began, 32 local businesses enthusiastically agreed to sell the ticket books on a volunteer basis, despite the staff time required to order consignments from the city, sell the tickets, and maintain records of all transactions. Full-fare tickets were sold in books of 5 for $2.00

and 20 for $8.00; half-fare tickets were sold in books of 10 for $2.00. Elderly persons 65 years or older, handicapped persons, and students aged 18 or less qualified for half-fare tickets on presentation of appropriate identification. In addition, parents could purchase half-fare ticket books for their children.

In April 1978, in response to complaints from the press and the community about the steep $1.00 cash fare, the city introduced a $0.50 coupon to be distributed to all riders that paid the cash fare. The coupon entitled the bearer to a $0.50 discount on a book of half- or full-fare tickets. Thus, the sales outlets were also responsible for accepting the coupons as partial payment for the ticket books. The coupons were distributed on the ATC buses and the minibus through March 1979, at which time the cash fare was lowered from $1.00 to $0.50 and the coupons were discontinued. During the one-year period from April 1978 through March 1979, 3999 coupons were redeemed by Runaround passengers.

In March 1979, at the outset of the fifth and final contract period, the cash fare was lowered from $1.00 to $0.50. Under the terms of the new contracts, ATC and Red Top received subsidies of $1.15 and $1.00, respectively, for each cash fare received (i.e., the difference between the cash fare and the negotiated per-ticket reimbursement). The ensuing rapid rise in cash-fare ridership, which included a disproportionate number of new transit riders, offers some evidence in support of the hypothesis that the prepaid ticket system may have discouraged ridership during the first four contract periods.

Although the sales outlets performed the various functions associated with selling the tickets at no charge to the city, the ticket system proved quite time consuming (and thus costly) to administer. During the first year or so of operations, two project staff members spent at least eight person days per month on ticket-related activities, e.g., resupplying the outlets with tickets, taking inventory and counting cash at each location, and keeping detailed records of all transactions. Various procedural changes designed to reduce the burden on city staff were introduced midway through the demonstration; for example, outlets were asked to order larger ticket consignments less frequently and to pay by check rather than cash for tickets sold. However, the ticket system continued to absorb a relatively large amount of staff time--about five person days per month.

MARKETING

The city of Danville conducted a number of advertising campaigns and promotional activities designed to publicize the Runaround over the course of the demonstration. These included radio and newspaper advertisements, displays at various locations in Danville that showed the bus schedule and listed the ticket sales outlets, discount coupons in the newspaper good toward the purchase of ticket books, distribution of free Runaround tickets at special events, and free-ride days on which Danville residents could ride the bus all day at no charge. The payment received by ATC was based on an average of normal ridership levels; Red Top Cab's payment was based on actual ridership on the free-ride days. The first two free-ride days were held on two consecutive Saturdays just before the Christmas holidays in December 1978; ridership skyrocketed to four times the average Saturday ridership. The third free-ride day was held on a Monday in late May 1979; 2500 riders took advantage of the event. However, these days did not seem to induce large numbers of first-time riders to substitute the Runaround for their transportation needs.

In theory, the user-side subsidy arrangement creates an incentive to the provider to finance independent promotional activities in order to attract new ridership and thus increase profits. Under the terms of the contracts between the city of Danville and the two transit operators, ATC and Red Top Cab, these providers received no reimbursement for promotional activities. Nevertheless, ATC did conduct a number of low-cost transit events to publicize the Runaround service; these included distributing balloons and candy on the anniversary of the Runaround, distributing prizes and flowers on board the buses on special days, and outfitting the drivers in Santa Claus costumes on the free-ride Saturday before Christmas. Thus, although ATC's net out-of-pocket expenditures on Runaround publicity totaled less than about $1000, the company did devote a certain amount of staff time and resources to planning and coordinating promotional activities in conjunction with the city of Danville. Red Top Cab was included in a few such activities, but the cab company did not initiate or finance any publicity for the system.

LESSONS OF THE DEMONSTRATION

A full test of the user-side subsidy for fixed-route transit service has yet to be conducted. The lessons of phase 2 in Danville carry a number of implications with regard to the optimal location and set of circumstances in which to implement a user-side subsidy arrangement. Specifically, they are as follows.

1. The bidding environment should favor open entry of transportation providers. This implies the existence of no single, well-entrenched local operator who would impair the bidding process, as in Danville. The user-side subsidy scheme assumes some form of marketlike competition or threat of competition in order to create an incentive to the existing provider or providers to offer efficient service tailored to the travel demands of the user population.

2. New transit service should be introduced gradually. Not only did the initially high level of service implemented in Danville prove costly and unmanageable, but it also served to discourage small providers from bidding on the service, due to the high start-up and capital costs involved. In view of the scheduling and reliability problems experienced by any new service in its early stages, a better strategy might have been to start transit operations with only a few routes and to add service gradually as start-up problems were ironed out and ridership increased.

3. The contract period should exceed four months in order to attract prospective bidders. Long contract periods do entail the disadvantages of restricting entry of new providers and possibly locking the city, the provider, or both into an untenable financial position. One compromise arrangement, which took effect in Danville after the demonstration, is a one-year contract that permits either party to reopen the negotiations at specified intervals. (In the Danville case, this interval was three months.) Such a contract could also specify that new proposals could be entertained at any time, which allows a reasonable termination notice before another provider could take over operation of the service.

4. Prospective bidders may require some assistance from the city or other public body that

contracts for service. In particular, small paratransit operators generally lack the resources and experience necessary to prepare detailed proposals or negotiate service contracts. Therefore, a willingness on the part of the city to offer such assistance may be desirable in order to encourage operators to bid and thus increase the competition among bidders to provide the service.

5. Administrative costs of user-side subsidy arrangements are likely to be higher than average, due to the need to monitor the ticket system, conduct contract negotiations, and oversee reimbursement procedures.

6. The system for prepurchasing tickets is costly to administer and may discourage ridership; however, such a system may be a necessary safeguard against fraud.

7. The user-side subsidy arrangement does appear to create an incentive for providers to eliminate unproductive service, although the providers generally did not initiate any major service revisions during this project.

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Elasticity Measures of Behavioral Response to Off-Peak Free-Fare Transit

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Changes in transit ridership behavior in response to the elimination of off-peak transit fares are examined. Empirically, the analysis is based on data collected for a one-year free-fare demonstration sponsored by the Urban Mass Transportation Administration in Trenton, New Jersey. Fare elasticity of demand is used as the measure of behavioral response. Important to the analysis is the clarification of distinctions among different measures of fare elasticity. In order to both illustrate the differences among types of elasticity and demonstrate the separate impact attributable to the choice of estimating technique, several techniques are applied and their results compared. It is concluded that the demand response to fare elimination is inelastic and that variations among individuals in the extent of response cannot be associated with differences in socioeconomic characteristics. Free fare is therefore judged not to be a direct means of fulfilling the transportation needs of socioeconomically defined population groups.

Between March 1, 1978, and February 28, 1979, the Office of Service and Methods Demonstration of the Urban Mass Transportation Administration (UMTA) and the New Jersey Department of Transportation sponsored the elimination of the existing 15-cent off-peak bus fare in Trenton, New Jersey, and surrounding Mercer County. The peak fare was unchanged until December 1978, when it was increased to 40 cents.

The major objective of this study was the examination of changes in transit use behavior by the Trenton area population in response to the elimination of bus fares during off-peak periods. Two major conclusions result. There was an inelastic response to the fare elimination, and little of the variation in responsiveness among individuals could be explained by socioeconomic differences. Furthermore, elasticity estimates are shown to be sensitive to the particular elasticity definition chosen, the functional form of the demand curve, the initial conditions against which changes are measured, the estimation technique applied, and the data used.

The first part of this paper reviews the concept of demand elasticity as a measure of responsiveness to fare change. A discussion of alternative measures of elasticity is presented.

The second part of the paper presents the results of estimating elasticities from data collected in Trenton. Elasticity estimates are obtained by four different procedures.

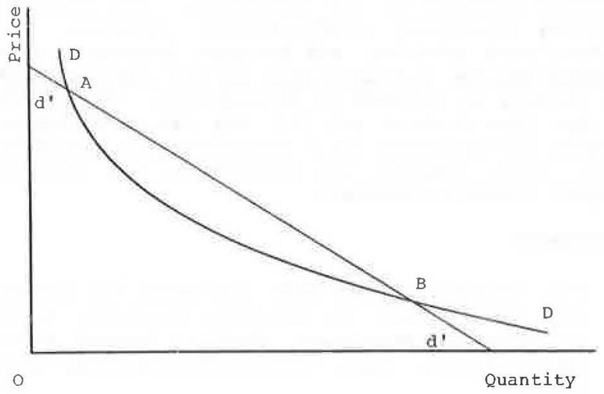
ELASTICITY MEASURES

In many studies of fare-change response, there has been inadequate recognition that there are a number of related (though nonequivalent) measures of demand elasticity. Failure to distinguish among elasticity measures results in two kinds of error. First, inferences appropriate to one type of elasticity have been drawn from estimates of another type. Second, there is a tendency for elasticities of different types to be compared directly and for conclusions to be drawn from differences or similarities in their values.

Elementary Properties of Demand Curves

To clarify the differences among alternative elasticity measures, several underlying properties

Figure 1. Linear and convex demand curves.



of demand curves should be pointed out. First, since factors other than price influence how much of a commodity people would be willing to buy, the expression of demand as a function of price alone requires either that other factors be held constant or that an explicit accounting be made of those factors.

Second, there is a distinction between the demand of an individual and that of a group of individuals. The former is a characterization of individual behavioral response; the latter is a characterization of group response and, as such, of overall market structure. While the market demand curve is simply the aggregate of individual demand curves, its shape will not in general be a scaled-up version of individual demand except in the rare circumstance where all persons in the market exhibit identical demand. Even if the individual demand curves are linear, the market demand curve is generally convex to the origin.

Finally, there is the problem of the time frame to which a particular demand curve applies. When a price is changed, individuals immediately begin adjusting to the new price level. Some adjustments can be made more quickly than others. Unless adequate time is allowed for full adjustment to take place, the measured response to a price change will be incomplete.

Definition of Elasticities

Having outlined some of the elementary properties of demand curves, we can now turn our attention to the definition of elasticities and their interpretation. The expression for an elasticity may be written

$$\begin{aligned} e &= (\text{percent } \Delta Q)/(\text{percent } \Delta P) \\ &= (dQ/dP)(P/Q) \\ &= \text{ratio of the marginal function } (dQ/dP) \text{ to the average function } (Q/P) \end{aligned} \quad (1)$$

where

- e = price or fare elasticity of demand,
- P = price or fare level, and
- Q = volume of ridership per period of time.

Strictly speaking, this is the expression for point elasticity. It provides a measure of responsiveness for very small movements along a demand curve. By comparison, for measurably large price changes an arc elasticity is calculated; the arc is the segment of the demand curve that lies between the initial and the final equilibrium points. The expression for an arc elasticity can be written $(\Delta Q/\Delta P)(P/Q)$. If the demand curve is linear, the ratio dQ/dP is constant along its length and is equal to $\Delta Q/\Delta P$. Thus, with a linear demand curve it is possible to take any pair of points, to use them to determine $\Delta Q/\Delta P$, and, by multiplying the ratio of changes by the ratio of P and Q at a selected point, to find the point elasticity for any point on the demand curve. The value of the point elasticity ranges from infinite (where Q is zero) to zero (at the point where P is zero). This observation illustrates an important compromise in the use of an arc elasticity. The arc elasticity assigns a single value for the entire arc. However, since the point (or actual) elasticity varies across the range, the arc elasticity is only an approximation. The larger the range, the greater the difference between point elasticity at its upper and lower ends and hence the greater the compromise involved in using the arc elasticity.

Now consider the case in which the demand curve is not linear. Recall the earlier discussion of aggregating individual demand curves into a market demand curve. One important result was the tendency for the market demand curve to be convex to the origin. This result was obtained when the individual curves were linear. If the individual curves are themselves convex, the curvature of the market demand curve will be accentuated.

In Figure 1, DD is the actual demand curve, A and B are the two observed points, and d'd' is the linear approximation to DD implicit in the arc elasticity formula. At point A the slope of DD is greater (in absolute value) than is that of d'd'. At B the slope of DD is less than that of d'd'. Since the ratio of P to Q is the same between DD and d'd' at each of the points and since the point elasticity is the inverse of the slope times the ratio of P to Q, the arc approximation to point elasticity at A measured along d'd' is greater than that measured along DD. The reverse ranking holds at B. The arc elasticity therefore overstates the point elasticity at A. The greater the curvature is in DD or the farther apart are A and B, the greater is the distortion.

THE DATA

Over the course of the demonstration, several types of data were collected, including self-administered on-board surveys in November 1977, May 1978, and October 1978; telephone surveys in November 1977 and October 1978; and a series of six systemwide ridership counts to document overall changes. The two sets of autumn surveys were central to the original evaluation strategy. Their timing was intended to remove the effects of seasonal fluctuations. For the two telephone surveys, some individuals were selected from listings in the telephone book and others from among those who volunteered their telephone numbers during the corresponding on-board survey. The inclusion of those from the on-board survey raised the overall proportion of bus users in the sample.

The six systemwide ridership counts were made in November 1977 and in February, March, May, July, and October 1978. For each count, observers were positioned on three downtown street corners. The corners were selected so that some observer would have access to every bus that entered the downtown area.

Each of the survey types was, in a statistical sense, drawn from a different population. This has implications for either comparisons among surveys or pools of data between surveys. The sampling for each of the on-board surveys was from all trips made on Mercer Metro during the relevant survey week.

For the telephone surveys it was from the population of households, except for the on-board follow-up subgroup. As an illustration of what these differences imply, consider the following. If we assume that all trips had equal probability of being drawn in an on-board survey, an individual's probability of being drawn was directly proportional to his or her trip frequency. A person who made four trips during the survey week had twice the chance of being surveyed as did someone who made two trips. On the other hand, trip frequency did not influence the chance of being drawn in the telephone survey. Thus, the likelihood of an individual's being sampled did not have the same relationship to sample size in one type of survey as it did in the others.

ESTIMATION

For the estimation of elasticities there are two general approaches--aggregate and disaggregate. The former requires a series of at least two observations taken over time. The latter can be estimated either for a temporal series on a given set of individuals or (if different individuals face different prices) for observations on a cross section of individuals at one time. Three possibilities result: aggregate time series, disaggregate time series, and disaggregate cross section.

Four estimation techniques were applied in order to illustrate both the diversity of the elasticity values derived for different types of elasticities and, for a single type of elasticity, the sensitivity of the results to variations in estimation technique.

Although the techniques used provide a fairly clear picture of both influences, they do not exhaust the estimation possibilities. Data limitations of two kinds precluded the application of further alternatives. The first involves omissions in the data as collected, which includes incomplete responses and survey questions phrased or coded in ways that prevented the retrieval of more than minimal information. There is, however, a more fundamental type of fault. In order to measure the impact of a fare change on a population, rather comprehensive information is needed on how a large number of individuals responded. Ultimately one would like to arrive at causal statements on the linkage between the fare reduction and changes in transit use. To do so requires disaggregate data, not only on descriptive characteristics and on changes in individual behavior, but also on all factors other than fare that could have contributed to the changes in travel behavior. In contrast, the existing data show travel-behavior changes only for off-peak bus use and only as individuals recall their behavior before the free fare. Furthermore, information on factors other than fare is severely limited. However, it should be pointed out that the collection of data was far richer than that generally available and that it adequately serves the set of questions for which it was originally designed.

Of the four estimation procedures used in this study, two use aggregate data. The first uses fully aggregate data and the second uses data aggregated into various population subgroups within the total market. The third procedure applies regression techniques to a disaggregate time series. The fourth procedure is a binomial logit mode-choice model that uses disaggregate data but implicitly constrains the price-change response to be reflected only in a shift of modes.

NONEMPIRICAL FACTORS THAT AFFECT ESTIMATES

This section outlines four factors, each of which tends to bias the elasticity estimates. While all can, in principle, be corrected for, it was feasible to correct only for the third in this study.

The demand for bus travel is influenced by the levels of various service characteristics as well as by fare. When the fare is reduced, ridership increases. When there is no increase in the number of bus runs, fare reductions may increase the degree of crowding. Also, especially when bus stops are close together (as they are in Trenton), the increase in ridership tends to increase the number of stops that a bus makes on a run as well as the number of people who board, which reduces the level of schedule adherence. The additional crowding and reduced reliability, even if slight, may deter some riders and thereby partly offset the rider response to the fare decrease. This results in a downward bias to the elasticities estimated as a function of price alone. The bias is large either if the change in the service characteristics is great or if the responsiveness of the market to service characteristics is high. Because of difficulties in quantifying relevant service characteristics, no attempt has been made to approach the problem with a simultaneous-equations model. There are indications that Mercer Metro's off-peak schedule adherence was less regular with the free-fare transit than it had previously been and that a greater proportion of the buses arrived downtown with all seats taken--an indication of increased crowding (1).

Second, the estimated elasticities can be interpreted only as fare elasticities, not as price elasticities. If the full price of a transit trip is taken to be the sum of the fare paid and the value of the time spent in travel, a given percentage reduction in fare is reflected as a lesser reduction in price. Thus, fare elasticities are smaller than are the associated price elasticities.

Third, when before-and-after comparisons are made, it is necessary to restrict attention in the after comparisons to those who were off-peak transit users in the before period. The total change in trip making between the before and after periods is composed of additional trips by old users and trips by new users. The result of calculating the ratio of the total percentage ridership change (inclusive of trips by new users) to the percentage fare change can be defined as a shrinkage ratio. Although the shrinkage ratio validly indicates the total impact of a fare change on the transit operator, it is not a good measure of behavioral response, since two nonequivalent groups are compared.

Finally, a problem results from having measured individual bus trip frequency but not total trip frequency. It is likely that, in response to the free-fare program, many increased both their total number of trips made and their share of total trips taken by bus. Either of these responses would increase bus trip frequency. When they occur together, the combined effect cannot be partitioned into the separate effect of each unless there is information on both the individual's total frequency and the bus modal share. It is thus impossible to determine whether a given change in bus trip frequency is largely the consequence of a mode shift with a given number of trips, an increase in total trip making with a given mode split, or a combination of the two. Since an increase in trip making and a change in mode split are different types of behavioral response, the inability to distinguish between them implies a loss of information. In the abstract, the change in bus frequency can be regarded as the combined result of two separately determined behavioral responses. Ideally, one would make separate estimates for mode split and total trip frequency. Because the data do not allow us to do so, the estimations cannot fully identify the behavioral mechanisms.

ESTIMATION PROCEDURES AND RESULTS

The first of the four estimation procedures uses only the data from the six ridership counts made from street corners. Because trips by old users are indistinguishable from those by new users, the procedure estimates a shrinkage ratio. The total ridership level from each of the counts was regressed on time and on a dummy variable that takes the value of 1 for the free-fare period and 0 for the 15-cent fare period. The time variable isolates trend effects. There were too few observations to attempt seasonal adjustment. Two equations were estimated, one for the peak period and one for the off-peak period. For each, the coefficient on the dummy variable represents the effect of free fare. The results are reported below (the t-statistics are in brackets after each coefficient; ridership is expressed in thousands of trips per week and time is measured in months):

$$\text{Trips} = 85.25\ [10.92] + 1.22\ [0.72] * \text{time} - 7.58\ [-0.60] * \text{dummy}\ (R^2 = 0.15).$$

$$\text{Trips} = 45.22\ [10.95] - 0.73\ [-0.82] * \text{time} + 29.04\ [4.37] * \text{dummy}\ (R^2 = 0.92).$$

The coefficients on the time variables reflect the changes that would have occurred without free fare. The estimated impact of fare removal can be read from the coefficients on the dummy variables. The coefficient on the dummy in the second equation (off-peak period) indicates an increase of 29 000 weekly off-peak trips as a result of the free fare. This coefficient is statistically significant at a 95 percent level. The constant term is an estimate of the base level of ridership. A shrinkage ratio of 0.64 obtains by taking the change in ridership due to free fare (29 000) as a percentage of the base ridership (45 000) and dividing by the percentage change in fare (100 percent); a 90 percent confidence interval places it between 0.24 and 1.26.

The second estimation procedure combines data from the two autumn on-board surveys with the data from the corner counts. From these, total before-and-after ridership estimates were calculated for each socioeconomic group into which the respondents could be divided. The elasticity estimates were determined by algebraically fitting a demand curve through the observed before-and-after pair of demand points. To illustrate the importance of the demand curve's functional form, each of two specifications was fitted. In order to base the before-and-after comparisons on a common set of individuals, respondents who reported a prior off-peak trip rate of 0 were eliminated from the after survey when the elasticities were calculated. However, to compare the influence on the specification of including new users, the calculations were repeated by using the entire after sample. These last calculations can be thought of as population-group-specific shrinkage ratios, since they include the impact not only of the changes in ridership by old users, but also of the ridership of new users.

Table 1 contains the results of the estimations. The first four columns show the results of fitting a linear demand curve by the arc elasticity formula. Of these four, the first two columns present the elasticities calculated at the demand curve's midpoint between 15 and 0 cents. The third and fourth columns have results computed at 15 cents. The estimates in the fifth and sixth columns are the result of fitting an exponential demand function, as explained below. The elasticities in these columns are calculated at 15 cents. To illustrate the importance of restricting before-and-after comparisons to a common group, the first, third, and fifth columns use the data from all respondents to the second survey. The second, fourth, and sixth columns include only those respondents to the second survey who reported positive prior frequency. The elasticities are for the group aggregates, not for individuals or even typical individuals within each group. That is, they apply to the entire group of, say, elderly people and lend no insight into the behavior of a typical elderly person.

The linear demand function can be written $Q = a - bP$, where a = constant and b = slope of the demand curve. The price elasticity can be written $e = (\Delta Q/\Delta P)\ (P/Q) = -b(P/Q)$, where b = inverse of the slope of the demand curve. Given b, an elasticity can be estimated for any P,Q-pair.

Although the linear demand curve is simple and commonly used, many alternative specifications are possible, and often another is more suitable. As pointed out earlier, the elasticity estimates may be quite sensitive to the particular form chosen. An exponential demand curve underlies the fifth and sixth columns in Table 1. It is written $Q = Q_0 \exp[b(P_0 - P)]$, where Q_0 = initial quantity level and P_0 = initial price level. The elasticity is again computed as $(dQ/dP)(P/Q)$. In this instance it equals $-bP$. Thus, the elasticity is linear in P, whereas with the linear form the quantity demanded is linear in P/Q.

Table 1 allows comparisons both between columns that show estimation differences and among groups within a category. With regard to the former, the following discussion suggests the more-important comparisons.

Comparisons Between Columns 1 and 2, 3 and 4, or 5 and 6

These comparisons illustrate the differences between shrinkage ratios (columns 1, 3, and 5) and elasticities (columns 2, 4, and 6). The shrinkage ratios, since they include new users, have smaller values than the elasticities. Since all columns are calculated with the same base values, comparison also shows the variation among groups in the contribution made to the total change by increases on the part of old users and the addition of new users. When the second column is small in relation to the first (or the fourth in relation to the third or the sixth in relation to the fifth), the major contribution is from new users; when it is relatively large, most of the change is attributable to old users. For instance, for the groupings by trip purpose, new users are responsible for all the additional recreation trips and most of the new shopping trips but few of the new medical trips.

Comparisons Between Columns 3 and 5 or 4 and 6

Here the differences due to the choice of functional form are evident. With the two functional forms chosen, the differences are most noticeable for elasticities of higher absolute value. It should again be noted that the underlying data are identical and that all differences in results are due to the functional form. Without grounds for believing one form to be correct, the lesson is to

Table 1. Algebraic elasticity estimates.

Data Type	Linear Demand Function				Exponential Demand Function	
	At Midpoint		At 15 Cents			
	All Users	Old Users	All Users	Old Users	All Users	Old Users
Aggregate	0.17	0.10	0.41	0.24	0.34	0.21
Group aggregate						
Household size						
1	0.16	0.08	0.37	0.17	0.32	0.16
2	0.14	0.06	0.32	0.12	0.28	0.11
3	0.11	0.07	0.26	0.15	0.23	0.14
4	0.19	0.12	0.48	0.28	0.39	0.25
5	0.13	0.08	0.30	0.16	0.26	0.15
6+	0.24	0.19	0.63	0.47	0.49	0.39
Automobiles						
0	0.14	0.03	0.33	0.06	0.28	0.06
1	0.16	0.13	0.37	0.30	0.31	0.26
2	0.21	0.16	0.52	0.40	0.42	0.33
3+	0.24	0.20	0.62	0.49	0.48	0.40
Sex						
Female	0.15	0.08	0.35	0.17	0.30	0.16
Male	0.20	0.15	0.50	0.35	0.41	0.30
Age						
Less than 17	0.16	0.09	0.38	0.21	0.32	0.19
17-24	0.19	0.14	0.46	0.33	0.38	0.28
25-44	0.22	0.15	0.55	0.35	0.44	0.30
45-64	0.10	0.02	0.22	0.04	0.22	0.04
65+	0.11	0.03	0.26	0.06	0.23	0.06
Income						
$0-5000	0.05	0.01	0.10	0.01	0.10	0.01
$5000-10 000	0.14	0.09	0.32	0.19	0.28	0.17
$10 000-15 000	0.35	0.29	1.10	0.82	0.74	0.60
$15 000-25 000	0.10	0.02	0.21	0.04	0.19	0.04
$25 000+	0.31	0.23	0.91	0.60	0.65	0.47
Trip purpose						
Work	0.14	0.09	0.34	0.20	0.29	0.19
School	0.12	0.04	0.26	0.09	0.23	0.08
Shopping	0.11	0.06	0.24	0.12	0.21	0.11
Medical	0.14	0.13	0.32	0.29	0.28	0.26
Recreation	0.08	0.02	0.18	0.04	0.17	0.04
Social	0.09	0.04	0.21	0.07	0.19	0.07
Other	0.64	0.57	3.52	2.64	1.51	1.29

be cautious about accepting either as the correct elasticity.

Comparisons Between Columns 1 and 3 or 2 and 4

All four of these are for the linear demand curve. The comparison is between evaluating the elasticity at the original point and evaluating it at the midpoint. Recall that, along a linear demand curve, elasticity rises with price. Therefore elasticities calculated at the original point are higher than those calculated at the midpoint. It is evident that the selection of a point at which to compute an arc elasticity can have strong bearing on its value.

Comparison Among Population Groups Within a Category

For any categorization, groups with higher values increased their share of total trips in response to free fares. For instance, taken as a group, persons with more cars were more responsive and gained in ridership in relation to persons with fewer cars. This ranking holds both for old users and for all users. Similarly, men gained in relation to women, persons aged 25-44 gained in relation to those older and younger, and the $10 000-$15 000 income group gained in relation to other income groups.

As noted above, the on-board surveys sampled trips, not persons. A given number of trips may be composed of either a large number of individuals who each take a few trips or a small number who each take many trips. Similarly, a change in the number of trips may result from either many more trips by a few people or a few more trips by many people. The inability to distinguish between the two explanations is a consequence of the estimating group rather than the individual elasticities. In interpreting the results, it should be remembered that, since either explanation may hold, no inference can be drawn about the behavior of members of a group.

Categorizing the population by a single characteristic at a time loses much information. Even without the introduction of questions of causality, there is no way to determine whether the indicated response of, say, the high-income group would or would not vary if that group were further broken down by automobile ownership or some other variable.

This difficulty serves to introduce the third estimation procedure. By using data in disaggregate form, multiple-regression analysis circumvents the limitations of diminishing cell size. In the regressions that follow, all data are from the autumn 1978 on-board survey. The individual's percentage change in off-peak bus trips, evaluated at the midpoint, was used as the dependent variable. The independent variables are listed below (the estimating technique was ordinary least squares):

1. Age dummies for four or five age categories,
2. Dummy for men,
3. Dummies for four or five men-age interaction categories,
4. Dummy for Trenton residence,
5. Number of automobiles in household,
6. Dummies for four or five income categories, and
7. Income per household member (an imputed income level for each income category divided by the number of household members).

Table 2. Regression estimate results.

Variable	Coefficient	Coefficient ÷ SE
Constant	0.045	1.05
Household automobiles	0.049	2.05
Dummies for age		
17-24	0.093	2.31
25-44	0.022	0.505
45-64	0.049	0.979
65+	-0.034	-0.474
Dummy for men	0.048	2.05
Dummies for men and age		
Men 17-24	-0.121	-2.17
Men 25-44	-0.029	-0.471
Men 45-64	-0.168	-2.25
Men 65+	-0.089	-0.833
Dummies for income		
\$5000-10 000	0.017	0.546
\$10 000-15 000	-0.010	-0.318
\$15 000-25 000	-0.019	-0.507
\$25 000+	0.049	1.11
Income per household members if at least \$1000	-0.0024	-0.525
Dummy for city residence	0.006	0.266

Note: R^2 = 0.020; N = 1133.

The results are presented in Table 2. Note first that only about 2 percent of the variation in responsiveness has been explained. On the other hand, a number of the individual coefficients are significantly different from zero at a 95 percent confidence level. Ignoring for the moment the fact that the remaining coefficients are not significant, we can infer that, although most of the variation in response to free fare is determined by factors not included in the equations, the contribution of the significant included variables has been determined. Thus, although the extent of differences across age groups, income groups, and so forth is indicated by the coefficient values and since some conclusions about the variations in group responsiveness can be drawn from them, the most important conclusion is that these are not the important factors in determining variations in individual responsiveness. From a policy point of view, recognition of the relative unimportance of socioeconomic and related variables argues against free fare as an instrument to reach groups defined by socioeconomic characteristics.

The elasticities used for the regressions are arc elasticities for typical individuals. A predicted value of the elasticity for an individual can be found by substituting the appropriate values for all the independent variables and by applying the estimated coefficients.

In interpreting the results it should be recalled that bus trip frequency is the product of overall trip making and bus mode share. For example, people who travel frequently but use the bus infrequently will exhibit large percentage changes in bus use by shifting a small share of their trips to the bus. Because the bus trip percentage increase is large, this shift would be interpreted as a relatively dramatic change in travel behavior. However, since there are no data to extract the two-component bus trip frequency, this case is impossible to distinguish from that of a person who travels only by bus and likewise exhibits a sharp increase in trip making. It is important to note that the inability to distinguish between these cases greatly reduces the usefulness of the estimates for identifying variations in behavioral response. It no doubt also contributes to the low R^2-values.

Aggregate elasticity estimates are derived by applying the estimated coefficient values to data on the individuals in the sample and taking a weighted average of the results. This procedure links the aggregate elasticity to the explained portion of the individual elasticities. If the explained portion had been substantial, this could be argued as a netting out of random components in individual response. However, it is difficult to argue that 98 percent of the individual variation is random. Consequently, the aggregate elasticities are subject to large error. The individual elasticities were weighted by the respondent's share of all trips collectively taken by the respondents during a typical week; the resulting value was 0.528.

The final estimation technique applies binominal logit to the choice of mode between automobile and bus. The data source is the 1977 telephone survey. Estimation was sharply constrained by data limitations: There were too few observations to include any modes but automobile and bus or to distinguish between automobile passengers and drivers. Furthermore, only estimation of mode choice was possible, due largely to the omission of variables that might contribute to distinguishing over more-complex choice dimensions. The overall explanatory power of the model indicates this less than does the statistical significance of individual coefficients.

In all, the results here are not comparable with those of the other approaches. This is especially unfortunate since the logit estimation procedure has an important inherent advantage over the other techniques. By using cross-sectional rather than time-series data, the results are influenced by exogenous interperiod changes. Use of cross-sectional data also serves to offset the simultaneous-equations bias that results when responses to fare and service changes interact over time.

The first two of the independent variables included in the estimate are travel time for automobile and for bus, both in minutes. The third variable, bus wait time, was specified as the minimum of one-half the headway plus 15 min. The results were insensitive to the assumption made. Bus cost depended on the time the trip began. If it began during the off-peak hours, the cost was 15 cents; for trips that began during the peak, it was 30 cents. Automobile cost was estimated as 9 cents/mile plus parking cost. The 9-cent figure lies between the per-mile cost of gasoline and the total per-mile vehicle operating cost. It was used on the assumption that individuals perceive fuel costs and are partially aware of additional operating costs. There is no way to determine how many persons traveled together on the automobile trips, and hence the vehicle cost is taken to be the individual's cost. However, in the results, variations in the assumption on automobile cost were reflected almost entirely in the coefficient on that variable.

Socioeconomic data included a set of dummies for age, a dummy for men, the number of household members, and the number of automobiles owned by the household.

In the estimation, since the drawing for the sample was partly random and partly based on choice, a correction was necessary. Entries from the choice-based on-board follow-up portion were weighted according to the bus trip proportion in the random section (2). The bus trip share in the random portion was thus used as an estimate of the share in the overall population. The reported version of the equation follows (the t-statistics are in brackets after each coefficient):

$$\ln[\Pr(\text{bus})/1 - \Pr(\text{bus})] = 0.0656\ [0.0319]$$
$$+\ 0.000\ 001\ 74\ [1.33]\ (\text{time}_{\text{auto}} - \text{time}_{\text{bus}})$$

- 5.44 [-1.26] (bus cost) - 0.116 [-0.122] (auto cost) - 0.247 [-0.272] (transfers)
- 1.07 [-0.189] (bus wait time)
+ 0.632 [0.887] (Trenton residence dummy)
+ 0.469 [1.249] (automobiles per household)
- 0.0262 [-0.123] (household size)
- 0.866 [-1.10] (dummy for men)
- 1.02 [-1.03] (dummy for ages 17-24)
- 0.515 [-0.557] (dummy for ages 25-44)
- 1.35 [-1.76] (dummy for age 45+).

As can be seen from the t-statistics, none of the coefficients is significant at the 95 percent level, that on the dummy for age 45+ is significant at the 90 percent level, and those on bus cost, number of family automobiles, and travel time are significant at the 75 percent level.

The summary fit statistics appear at first to be quite good. The log likelihood (with all coefficients but that on the bus constant set to zero) takes a value of -92.65. With the estimated coefficients it is -39.37. Thus, -2 log (likelihood ratio) = 106.56 and $\rho^2 = 0.58$. Although both these summary statistics are quite good, all 213 trips are predicted as automobile trips with the estimated coefficients and measured variable values. Against this, the sum of the individual choice probabilities suggests that, on an expected-value basis, 28 of the trips would be taken by bus. The aggregate point elasticity at the original fare level for off-peak trips alone is 0.58.

Since the approach does not allow either for a shift according to the time of day (i.e., drawing riders from the peak period to the off-peak period) or for an increase in total trip making, the value as estimated is high in comparison with those of the other estimation procedures.

SUMMARY OF ESTIMATION RESULTS

A summary of the estimates is shown below. All values are for elasticities calculated at 15 cents. Since all estimates are substantially below 1, the conclusion that the demand is inelastic is a firm one. This conclusion holds for the shrinkage ratio estimates as well.

Type of Estimate	Aggregate Elasticity Value	Shrinkage Ratio	Data Used
Regression		0.64	Corner counts
Algebraic			1977 and 1978 on-board surveys
Linear	0.24	0.41	
Exponential	0.21	0.34	
Regression	0.51		1978 on-board survey
Logit	0.58		1977 telephone survey

The differences among the estimates from the four procedures are attributable to three factors: (a) use of different portions of the data for different estimates, (b) estimation of different types of elasticity, and (c) influences of the estimating techniques themselves. Although it is not possible to fully separate the influences of the three factors, several conclusions about the direction of their influence can be drawn.

The first comparison is between types of elasticity. Because shrinkage ratios include the influence of trips by people newly introduced to the system, they are of higher value than aggregate elasticities. The second set of estimates allows a comparison between shrinkage ratios and aggregate elasticities, which is unaffected by data source or differences in estimating technique. The shrinkage ratios are about 50 percent larger than the elasticities. While this should in no way be taken as a rule regarding the relative difference, it confirms the importance of distinguishing between the two concepts.

There is no similarly simple ranking between individual and market elasticities. However, in any market there are some individuals with elasticities larger than the aggregate market elasticity and others with values smaller than the market value. This must be true, since the market elasticity is a weighted average of the individual elasticities. An important point implicit in this is that much information on the diversity of individual responses is embodied in the individual elasticities. Estimation of only aggregate elasticities loses all this information.

CONCLUSIONS

Two conclusions arise from the empirical results. The first is that fare elimination provokes an inelastic ridership response. The second is that the differences in response among individuals cannot be explained by their socioeconomic characteristics. For policy purposes, the first conclusion implies that a fare reduction will lead to a revenue loss, which thus requires a subsidy increase. With zero fare, the revenue loss is obvious; however, the implication is that, even with a small fare reduction, Mercer Metro would have experienced a drop in revenue. The second result implies that general fare policy has very little leverage as a tool for reaching particular user groups. If, for instance, a policy goal is to provide mobility to the poor, free fare is only an indirect way of doing so, since large numbers of riders other than the poor will also participate. The spillover from target to non-target groups is great.

For research purposes there is a more-fundamental set of conclusions. The original research design for evaluation of the Trenton free-fare demonstration placed strong emphasis on recording what happened: There was little emphasis on learning why it happened. The data collection program reflected this bias. It should be noted that at a level of generalization that is not too broad the answers to the question "Why?" are self-evident: The changes occurred because the fare was reduced to zero. However, for several important purposes this explanation is inadequate. The fact of a diversity of responses among individuals suggests that the link between fare change and ridership response has complexities that are not easily identified. Without a more complete understanding of why individuals responded as they did, we can estimate neither how the Trenton population would respond to an alternative policy nor (except in general terms) how the population of another city would respond to an off-peak free fare.

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Abridgment

Factors That Influence Local Support for Public Transit Expenditures

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Survey data collected in Ann Arbor, Michigan, are used to assess the importance of various types of motivation to support a property-tax millage earmarked for public transit. A key finding is that user benefits are relatively less important than nonuser benefits in garnering local support. Concern over fuel depletion and overuse of automobiles, stimulation of business within the city, ability to use the service should one wish to, and a perception that the service offered is of high quality are major factors in transit support.

Faced with skyrocketing prices and uncertain supplies of fuel, urban travelers are increasingly turning to public transportation. Since transit users rarely pay their full costs, however, the operating deficits of many systems are increasing sharply with this added demand for service. Transit managers and local public officials are understandably hesitant to ask for higher taxes to finance transit during a period when real or spendable income is on the decline.

An incentive to generate local funds for transit service is provided by legislation passed at the federal level during the 1970s. Since 1974, each local dollar spent on operating a public transit system in larger cities is eligible to be matched by a federal dollar, up to the city's allocation limit (which is based on its population and density). In 1978, federal operating assistance was extended to small urban (population less than 50 000) and rural areas. Even with the substantial price reduction in transit brought about by the federal matching funds, many communities have garnered only a limited local share. As a consequence, they are receiving only a fraction of their full allocation of operating assistance funds.

The research reported here indicates that many public officials have been overly cautious in their hesitancy to place transit-financing referenda on the ballot. It may in fact be possible to obtain rather widespread support for a local tax if it is earmarked for provision of public transit. The results of the analysis to be summarized in this paper indicate that transit's constituency is potentially quite broad--supporters of transit are unusually diverse.

CASE-STUDY CITY

Ann Arbor, Michigan, has proved to be an excellent site to research the issue of local support for public transit expenditures. As is true of many states, Michigan law enables its cities to place referenda on the ballot that propose special property tax assessments to raise revenues for specific urban services. In 1973, a proposal was placed on the ballot in Ann Arbor to increase the property tax by $0.0025 which is equal to approximately $50 for the average-valued single-family house within the city. The assessment was to be used to provide a transit service of considerably higher quality than existed at the time. It is worth noting that, because the referendum was placed on the ballot in 1973, the prospect of federal matching funds did not yet exist.

The millage proposal passed by a margin of almost 2:1 (61 percent). Late in 1976, the new transit system was fully operational in all sectors of the city; implementation was carried out incrementally over a three-year period. A propitious opportunity to study local support for transit financing developed at this time. City residents could see what their tax dollars were buying; it was decided to study how many residents would favor continuation of the millage and why.

DATA USED IN THE ANALYSIS

The city of Ann Arbor obtained a technical assistance grant from the Urban Mass Transportation Administration to evaluate public response to the improved transit system. A telephone survey of 1175 randomly selected Ann Arbor residents was administered in March and April of 1977 by the University of Michigan's Survey Research Center. The questionnaire was quite detailed; numerous attitudinal, behavioral, and situational measures were included.

To measure willingness to pay the property tax for transit, the following question was asked:

> In April 1973, Ann Arbor voters approved a proposal to finance the public transportation system. This costs about $25 per year for a family living in a house worth $20 000, or about $50 per year for a family living in a house worth $40 000. Suppose the question of continuing this tax were on the ballot again; would you vote to continue the tax or would you vote against it?

It is noteworthy that respondents were informed how much the transit system costs them. (In the case of renters, a cost estimate was furnished based on an assumed monthly rental rate of 1 percent of the assessed value.)

In the analysis of responses to the support question, a number of measures were used as predictor variables. The objective was to determine which personal attitudes, behavioral patterns, and situations in life make a person more willing to pay a local tax earmarked for public transit. A brief description of the measures used in the analysis follows.

Transit Use

The following measures of transit use were obtained:

1. Trips taken: The number of trips the respondent took by transit in the previous 30 days,
2. Transit to work: Whether or not transit is the mode usually taken in the journey to work (coded 1 if yes, 0 if no), and
3. Transit to shop: Whether or not transit is the mode most often used on shopping trips (also coded 1 if yes, 0 if no).

Benefits from Use by Others

Measures of benefits to others were as follows:

1. Service for the poor: The extent to which the individual feels that transit should be a service mainly for the poor (responses were scaled on a five-point Likert scale that indicated the level of agreement with a statement that said that transit should be a service mainly for the poor),
2. Business stimulation: The degree to which the respondent feels that transit stimulates local business (responses were similarly scaled in a five-point agree-disagree format),
3. Use by family: The extent to which the individual's support arises from use by his or her own family members (the same five-point scale was used), and
4. Low fares: The respondent's assessment of whether fares should be lowered, maintained at current levels (very low, $0.25, with no charge for transfers), or raised. Respondents were informed that fares defrayed 16 percent of the system's operating costs (a three-point scale was used to measure responses).

Need for Transit

Transit need was measured by these criteria:

1. Automobile shortage: Whether there are more licensed drivers in the respondent's household than available automobiles (coded 1 if yes and 0 if no),
2. Nondrivers: The number of nondrivers (among persons nine years of age or older) in the household,
3. Working parents: Whether or not both parents (or the only parent) work and at least one child aged 9 through 17 years lives at home (coded 1 if yes and 0 if no), and
4. No other options: The degree of difficulty the individual feels he or she would experience in getting around without transit (scaled on a four-point scale).

Socioeconomic Status

Measures that indicated socioeconomic status were as follows:

1. Low income: Whether the individual's income is low, that is, under $7500 (coded 1 if yes, 0 if no);
2. High income: Whether the individual's income is high, that is, $25 000 or more (coded 1 if yes and 0 if no)--these two income variables allow an implicit comparison with the omitted category, middle income;
3. Owner occupancy: Whether the respondent's home is owner occupied (coded 1 if yes and 0 if no); and
4. Educational level: Level of education of the respondent in years of school completed.

Environmental Concern

Aspects of environmental concern measured were as follows:

1. Fuel conservation: The extent to which the respondent feels that transit should be used more as a fuel-saving measure (scaled in a five-point agree-disagree format), and
2. Reduced automobile role: Whether the individual feels that automobile use within the city should be discouraged through such policies as restricted zones and parking limitations (scaled in the same five-point format).

Ability to Use Transit

Transit use ability was measured by three criteria:

1. Personal fear: The degree to which an individual fears being mugged or assaulted while waiting for or riding in transit vehicles (on a five-point scale);
2. Work constraints: The presence of constraints, both temporal (e.g., work hours) and spatial (e.g., location of workplace), that preclude use of transit on work trips (coded 1 if constraints exist and 0 if they do not); and
3. Shopping problems: The perceived level of difficulty experienced in using transit on shopping trips, particularly when packages are carried (coded on a five-point scale).

Satisfaction with the Service

A single measure of the individual's perceptions regarding the quality of transit service being provided was used.

FOUNDATIONS FOR TRANSIT SUPPORT

The survey of Ann Arbor residents indicated that support for the transit millage tax had increased since its passage four years earlier. Of the 1175 respondents, 82.3 percent favored continuing the tax. A series of regression analyses were performed to assess the roles played by the preceding attitudes, behavioral patterns, and life situations in bringing about support for the transit millage tax. The fraction of variance (R^2) explained in these analyses was quite low--under 0.20. The reasons for this include (a) limited variance in the dependent measure (support) due to the high fraction of supporters and (b) the random noise one typically finds in survey data (as opposed to aggregate data). After the stronger predictor variables had been combined into a single equation, the following coefficients emerged:

Variable	Coefficient	Significance Level
Owner occupancy	-0.069	0.01
Educational level	0.008	0.05
Fuel conservation	0.037	0.01
Reduced automobile role	0.045	0.01
Business stimulation	0.028	0.01
Low fares	0.131	0.01
Service for poor	-0.020	0.01
Personal fears	-0.022	0.01

Variable	Coefficient	Significance Level
Work constraints	-0.138	0.01
Overall system quality	0.027	0.01
Constant term	0.664	
R^2	0.14	

The two situational measures that best predict willingness to support local transit expenditures are owner occupancy and educational level. The negative relationship between home ownership and support for the transit tax clearly shows that renters are more likely to favor the millage. Since the property tax payments of homeowners are usually more visible than those of renters, this outcome is not surprising. Examining the data, we find that 14 percentage points separate renters from homeowners; approximately 87 percent of the renters in the sample (61.3 percent of all respondents) favored the transit tax. The strong positive relationship between education and support for the transit millage tax may be due in part to the presence of a major university in the case-study city of Ann Arbor. The data do indicate that (a) the highly educated overwhelmingly support transit and (b) they do so not so much out of personal use, but rather because they perceive other sorts of nonuser benefits.

One strong nonuser benefit that seems to motivate local taxpayers to support transit financing is fuel conservation. The highly significant relationship between the attitude that greater use of transit can reduce society's consumption of fossil fuel and the willingness to pay the transit tax indicates that concern over fuel supplies within this city may well be an important motivating factor in support of transit expenditures.

Similarly, those who favor a lesser role for automobiles as a means of personal transportation are strongly inclined to support local taxes dedicated for transit provision. Interestingly, many of those respondents who favor automobile disincentives were not frequently transit users at the time of the survey. Presumably this group feels willing to make greater personal use of transit if policies such as restricting automobile use downtown or reducing the availability of parking were implemented.

Lest one conclude that transit supporters in Ann Arbor are not sensitive to the economic well-being of the downtown area, it should be noted that business stimulation is a major factor in transit support. Belief that quality transit service can stimulate tax downtown business activity is a highly significant predictor of transit support. Many nonusers of transit apparently are willing to pay the transit millage tax because they feel that the gains to them of a healthier local economy are worth the cost of the tax. Examining the data closely, one finds that respondents who hold this view often are employed in downtown retail establishments.

Belief that fares should be kept low is another highly significant predictor of transit support. Users and nonusers alike are far more likely to support the millage tax if they feel that fares should not be raised to defray a larger portion of operating costs. Among other things, this finding indicates that policymakers may actually erode support for transit-financing measures by raising fares substantially. It should be noted, however, that relatively few respondents favor reducing fares further or eliminating them entirely.

The often-stated opinion that transit should be viewed as a service mainly for the poor does not emerge in Ann Arbor. To the contrary, there is actually a strong negative relationship between this view and support for the transit millage tax. Examination of several related measures reveals that rather than being insensitive to the needs of the poor, most respondents see transit as a service that should be available to and meet the needs of everyone, which includes the poor. The view that only the poor should ride transit does not prevail in this community.

Although many respondents support transit without using it themselves, those who feel that they could not use it if they wished are much less likely to be willing to help finance it. Fear for one's safety while waiting for or riding in a transit vehicle has a strong negative relationship with the support measure. Similarly, the presence of constraints that preclude use of transit on work trips is highly inimical to support. Option value is clearly a very important factor in willingness to pay a tax for transit.

The importance of a good public image of transit in garnering local support for a financing measure is clearly indicated in this analysis. Regardless of respondents' use patterns, those who are satisfied with the overall quality of the service offered are far more likely to support the millage tax. This finding reinforces the truism that taxpayers, like private-sector consumers, are increasingly demanding their money's worth.

After consideration of the factors important to predicting an individual's willingness to pay a tax earmarked for transit, it may be instructive to briefly examine factors that have a surprisingly weak association with support. Members of the three classes of income do not vary remarkably in their support for the millage tax. Those in the sample who have low incomes support the millage tax in 90 percent of all cases, 75 percent of those with high incomes do so, and the middle-income respondents are about halfway between those percentages. Thus, while income has a negative relationship to transit support, the relationship is not particularly striking.

Perhaps of greater policy significance, users (those who had ridden transit at least once during the previous 30 days) are not significantly more likely to support the millage tax than are nonusers. Whereas 30.1 percent of those sampled had ridden within the previous 30 days, 82.3 favored continuation of the millage tax. Therefore, slightly more than half of those interviewed support the sizable transit assessment without using it themselves. Even those who need transit for mobility are not significantly more supportive than nonusers who see transit as bringing about other socially desirable effects.

POLICY CONCLUSIONS

One could argue that Ann Arbor is not a typical U.S. city and therefore that the conclusions reached in this analysis must be viewed as representing an exceptional case. In counterpoint, excluding students from the sample during analysis did not produce a noteworthy change in the extent or nature of transit support. Nonetheless, the influence of a major university on community attitudes and behavior is often subtle. A cautious interpretation is that, although most or all the factors present in Ann Arbor exist in other communities, they may well be less pronounced than they are in this city.

To the extent that the results of this research are transferable, the constituency for transit in U.S. cities is very diverse. Besides those who themselves ride the system, supporters also include those who wish to see a healthier local economy, environmentalists, and even those who view transit as something of a back-up mode. With this broad spectrum of supporters, it is probable that city officials generally have been too cautious in proposing transit-financing plans. The results of this analysis indicate that a quality transit service, the benefits of which are effectively communicated to the public, can command a high degree of support at the local level.

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Abridgment

Organization Theory and the Structure and Performance of Transit Agencies

GORDON J. FIELDING, LYMAN W. PORTER, DAN R. DALTON, MICHAEL J. SPENDOLINI, AND WILLIAM D. TODOR

Relationships between structural and performance variables were studied in 16 public transit organizations in California. Data were collected from archives, personal interviews, management surveys, and on-site observations. Statistical analyses focus on associations between structural variables and organizational efficiency, effectiveness, and employee commitment. Organization size, span of control, centralization, and length of managerial tenure were all associated with higher levels of organizational performance. Specialization and formalization were found to be associated with lower levels of performance on certain efficiency and effectiveness indicators.

In order to obtain a fair share of the increasing quantity of financial support available from government agencies, the administrative intensity of transit organizations has been increased. This paper presents some of the results of research aimed at determining how these changes in organizational structure affect transit performance (1). Data for the study were collected from organizational archives, personal interviews, management surveys, and on-site observation of 16 fixed-route bus systems located throughout California. Statistical analyses focused on the relationships among structural variables (organizational size, span of control, number of specialities, administrative intensity, formalization, standardization, and centralization), attitudinal variables (job satisfaction and employee commitment), and organization performance (service efficiency and effectiveness and managerial tenure).

STRUCTURAL AND PERFORMANCE VARIABLES

Six characteristics of organizational structure were identified for analysis. Three measure the structural configuration of organizations: size, span of control, and length of managerial tenure. The remaining characteristics--centralization, formalization, and standardization--are measures of structuring behavior within the organization (2).

Formalization, standardization, and centralization allow organizations to carry on many activities efficiently. They knit together diverse activities of an organization through programs that link activities together. Structuring of activities gives a great deal of predictability and stability to whatever occurs in organizations. However, there are some costs in terms of inflexibility and red tape.

Standardized measures of performance in transit are a fairly recent phenomenon. Measures have been agreed on, but collection of the data and their reliability vary. This study uses the performance indicators developed by Fielding, Glauthier, and Lave (3), in which each ratio is constructed so that higher values indicate better performance on that indicator. Reliability was enhanced by comparing results for 1976-1977 with data gathered from the same agencies in previous years.

Distinction is made between measures of efficiency and of effectiveness, since these are different concepts and should be measured separately. Efficiency is a measure of resources used to create transit service, whereas effectiveness measures the use of services produced. Three ratios were used to assess the efficiency of producing service, and five ratios were used to assess the cost and level of consumption.

The measures of organizational performance include statistics on employee turnover and the three efficiency and five effectiveness measures. Analyses consisted of correlating various structural and demographic variables with the performance measures. In some cases, a clear pattern seems to emerge for a particular structural dimension and performance. In most cases, however, structural dimensions show only moderate relationships with a few performance indicators. It is worth noting that in these latter cases, the relationships that demonstrated significance did so in a consistent manner (e.g., several effectiveness measures indicated a positive relationship with a particular organizational variable) and in accordance with the direction of the relationships that was suggested in the literature.

Organizational Size

A good deal of research has focused on the issue of how the size of an organization may influence various aspects of organizational success. An examination of the literature indicated mixed findings. Five of six studies that were performed in the last decade reported no association between size and performance. However, based on the results of several other studies, size appears to be positively associated with increased organizational efficiency (4). An analysis of the relationship between size and performance for our sample of 16 transit organizations indicates that organization size is positively related (though insignificantly) to only one measure of efficiency--revenue vehicle hours per vehicle. This is perhaps due to the fact that larger bus systems that operate in metropolitan areas usually provide service on an 18- or 20-h basis, whereas a 12-h schedule is characteristic of transit systems in smaller cities. Thus larger transit agencies may be more efficient in vehicle use than are smaller organizations.

One measure of effectiveness, the percentage of population served, also correlated positively with size. Large transit organizations usually operate service that extends beyond the inner city. Their route coverage enables them to serve a higher percentage of the population. One measure with which size is negatively correlated is turnover of operating employees. Larger organizations in our sample had a lower turnover of coach operators than did smaller properties. One reason that might account for this finding is that operators in larger agencies receive higher pay than do operators in smaller organizations. Higher rates of pay may contribute to the employee's willingness to stay with the organization.

In general, there are few valid relationships between organization size and performance. Some performance variations are associated with total size, but available research suggests that total size may interact with other structural variables in determining such differences. Also, the effects of organization size may operate through intervening constructs at the individual and group levels. On the basis of the accumulated evidence, there is no clear trend with respect to the effects of size and performance in the transit industry.

Span of Control

Very few studies have examined the effects of span of control on performance (5). Only two studies actually posited the concept that long spans were superior. Both studies suggested that long spans provide the opportunity for better initiative and better communications as well as for availability of more human resources to the individual manager (6,7).

The analysis of the transit performance data indicates that vehicle-use and system-ridership measures were both positively correlated with span of control, whereas operating expense per passenger demonstrated a slightly negative relationship. Also, managerial turnover was negatively correlated with span of control. Thus, longer spans of control are associated with lower managerial turnover, lower overall operating expense per passenger, and better vehicle-use and ridership figures. Although some of the correlation figures are low, the trend in the relationships supports the idea that perhaps managers who are responsible for more employees are able to perform their duties more effectively than are managers in organizations in which there is close supervision. Certain organizational efficiencies are also realized when longer spans of control are used, especially at the lower managerial and supervisory levels. Longer spans mean fewer managers at the lower levels, which translates into fewer managers in the organization as a whole. This has a direct impact on administrative costs. Thus, within an acceptable range, the span of control of individual managers, particularly at lower levels of management, may be increased beyond an organization or industry average without detriment to the organization's effectiveness and quite possibly with an increase in its efficiency.

Specialization

Specialization, indicated by the number of occupational titles in an organization, has some interesting implications for organizational performance. Previous research has suggested that increased specialization is associated with increased innovation and creativity, which are both inputs into organizational effectiveness (4). Although it appears that increased specialization may be positively associated with individual performance, the relationship with total organizational performance may be negative. Results from the sample of transit organizations illustrate this point. The number of specialists in an organization was negatively correlated with revenue vehicle hours per employee. Since most specialists are employed in the mid-level managerial ranks, they generally do not affect the total revenue vehicle hours that an organization is able to provide. Increased numbers of specialists increase the size of the organization's administrative staff, which produces a lower figure of revenue vehicle hours per employee. On a per-employee basis, then, organizations that employ many specialists and support personnel do not realize proportionately more revenue vehicle hours and are not as efficient. Likewise, the existence of more specialized employees is most likely to be associated with increased administrative costs that significantly affect the overall organization budget.

Centralization

Much of the early research in this area examined the effects of decentralization on employee attitudes and organizational performance. The results of these studies indicated that decentralized organizations more efficiently used human resources, which resulted in increased job involvement and increased performance (8,9).

More-recent research has pointed out that a relationship between decentralization and both efficiency and effectiveness is not always found. In fact, in our sample of transit organizations, centralized structures were associated with more revenue vehicle hours per employee and revenue passengers per revenue vehicle hour, as well as with lower operating expense per revenue vehicle hour, per total passengers, and per revenue passenger. Centralized structures were also associated with lower turnover for both managers and operating employees. No single structural variable was characterized by as many significant and consistent relationships with performance measures as was degree of centralization.

These results are not altogether surprising when analyzed in the context of the particular organizational environment that characterizes most transit organizations. The term "environment" here refers to several factors that may mediate the relationship between centralized or decentralized structures and performance. For example, Perrow has espoused a form of contingency theory in which an organization's technology was viewed as the most important source of interorganizational variations in patterns of influence; that is, the appropriate degree of centralization was contingent on how routine the technology was. He suggested that organizations characterized by more-routine technologies (such as transit organizations) are best suited to a more-centralized structure (10). Other researchers have suggested similar mechanisms that might account for the appropriateness of a more-centralized structure, which include concepts of mechanistic (as opposed to organic) environments and varying degrees of integrating and differentiating task situations (11,12). For example, managers would have less inducement to decentralize in a stable environment than in an environment characterized by rapid change and instability that necessitated rapid feedback of accurate information and a timely response in order to maintain the equilibrium of the organization.

With respect to the tasks of transportation organizations, the type of technology and environment that characterizes their operations would seem to require a more-centralized structure. The associations obtained between the measures of centralization and the performance indicators seem to support this view.

Formalization and Standardization

Formalization and standardization represent what an organization's procedure is and how it functions. The literature suggests that extremely low or high amounts of formalization, standardization, or both may hinder the organization's function (13). That is, extremely low levels of both may lead to uncertain standards, and extremely high levels may induce rigidity. Neither situation would result in improved attitudes or performance.

Experience with the transit organizations in the sample indicated that the amount of standardization and formalization ranges from almost total lack of (written) rules, standards, and procedures to extreme conformity to such regulations. One major determinant of standard procedures and written rules and regulations seemed to be the inclination of the general manager of the organization rather than an industrywide point of view that rules, regulations, and procedures are essential management tools. In some cases, general managers were quite vocal about their ideas of standard operating procedures, whereas others felt that each manager had an understanding about his or her particular job and responsibility and that this knowledge was acquired through experience.

Most of the literature in this area has examined the effects of formalization on organizational performance. Classically, formalization has been examined with respect to the existence of rules, regulations, and codified job duties that govern employee behavior. It has been argued that increased formalization represents a hindrance to effectiveness because managers under highly formalized structures tend to do everything by the book. Thus, creative, innovative, or adaptive behavior is severely constrained (14).

The analysis of the relationship between formalization and performance supports the basic findings in the literature. There was no relationship between formalization and the three efficiency measures. However, formalization did correlate negatively with two effectiveness measures associated with capacity use. Formalization also correlated positively with both managerial and operator turnover. Thus, higher degrees of formalization are associated with lower levels of effectiveness and higher levels of turnover. Although this finding in no way constitutes an indictment of high levels of formalization, it does lend support to the notion that transit managers would do well to avoid excessive degrees of formalization in their organizations.

Manager's Length of Employment

Although job tenure is not a structural variable, it is an important employee characteristic that has an impact on both attitudes and performance. In the sample, a series of questions was asked about the length of time an employee has worked with the particular transit organization--both as a manager and as nonmanagerial employee. A job-tenure measure computed from these data was then correlated with the performance indicators associated with each individual's organization. The results were interesting in that management experience was significantly correlated with two measures of efficiency and five measures of effectiveness. Length of employment was related to better ridership statistics, improved vehicle use, and lower operating expense per vehicle hour and per passenger.

Several employee characteristics are worth considering with regard to their possible effects on organizational performance. Organizations whose management force has had more experience in the organization seem to show better performance on the whole. The amount of management experience that managers have had in other types of organizations (which includes transit organizations) does not appear to have as great an impact on overall performance as does the total amount of time that each manager has spent in the particular organization, either in a nonmanagerial or in a managerial role. The reason for this finding lies in the particular quality of information that an individual accrues as a function of his or her membership in an organization. It has often been suggested that a person who has more organizational seniority is also more organizationally intelligent, which means that the person knows how to adapt to the demands of co-workers, subordinates, and the organizational situation.

There has been little empirical research on the relationship between organizational tenure or seniority and performance. What little has been done has focused on individual attributes and individual performance, but no systematic research efforts have examined organizational performance.

One interesting relationship that should be mentioned is that seniority correlates rather highly with the size of the organization; larger organizations are characterized, to some degree, by a more-experienced workforce. Large organizations may provide more opportunity for advancement; this creates an incentive for longer job tenure. The important point is that perhaps gains in performance by large transit organizations are due to characteristics of the workforce in conjunction with structural characteristics affected by size.

CONCLUSION

Several aspects of organizational structure are related to and can possibly affect certain facets of transit organization performance. In terms of efficiency, effectiveness, and turnover rates, it was found that organizational size, span of control, centralization, and managerial tenure were all associated with higher levels of organizational performance. Specialization and formalization are associated with lower levels of performance on certain efficiency and effectiveness indicators.

The results confirm relationships that have been proposed about certain associations between structure and performance. The implications for transit managers, especially those involved in organizational planning, are significant and should be used to estimate the probable outcome of altering the structure of an existing organization. One important concept that is partly rejected by the results is that there is one best way to organize transit organizations: There are instead several, depending on the organizational context.

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Stratification Approach to Evaluation of Urban Transit Performance

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In a period of growing transit operating deficits, increasing attention and concern is being directed at both the decreasing levels of productivity of transit systems in general and the broad differences in measured service performance compiled for various transit systems. In making these performance assessments, analyses have commonly relied on highly aggregated industrywide data and have not given adequate consideration to the changing and unique operational context within which individual transit systems must function. This paper presents a stratification approach to the evaluation of urban bus transit system performance. The stratification scheme was used on the premise that there exist many environmental and policy factors outside the control of the transit operator that constrain the performance of the transit system. Factors such as area population, population density, union work rules, system configuration, fleet age, and operational forms have strong influences on the productivity and efficiency levels of an individual transit service. By implementing the stratification procedure and compiling temporal data pertaining to both environmental and policy influences and system performance, the possible bias in making assessments and comparisons of existing transit systems can be controlled, and changes in performance levels of a system in response to both external changes and operational improvements can be predicted.

Performance measures based on available operating, financial, and ridership statistics have recently been considered as criteria for the evaluation of public transit systems. Such measures can provide much insight into the operation of a particular system. In addition, these measures can be used to examine the differences among various transit systems and the changes that may occur from year to year. However, the injudicious application of generic performance indicators in the direct comparison of systems can provide misleading information about the relative effectiveness of the systems' operation and service. To compare systems adequately, it is necessary to adopt an approach that can allow for the unique local environments over which the operator has limited influence.

Implicit in past research activities on transit performance has been the necessity of addressing the issue of comparability of productivity elements and procedures by which comparable elements can be defined and generated (1-3). Yet little research has been done on the examination of performance measures on a stratified basis. In general, the existing research focuses on the performance evaluation in terms of such broad categories as the type of operation (e.g., fixed route versus demand responsive) and organization (municipal service versus transit district) in order to facilitate the comparability of system performance for use in managerial analyses (1). The purpose of this paper is to extend the issue of comparative evaluation of the systems and to examine the external factors that cause the variations in performance from one system to another.

Table 1. Stratification factors, variables, and data sources.

Stratification Factor	Variable	Data Source
Congestion	Average vehicle operating speed	Systemwide measure derived from 1975 American Public Transit Association (APTA) operating report; will also be available from Financial and Reporting Elements (FARE) system; calculated by dividing bus miles by bus hours
Wage rate	Average wage per driver	Systemwide measure; derived from APTA data and calculated by dividing compensation to operators by operator person hours; wage will be available from FARE
Population	Number of people in urban area in which system operates	Obtained from 1975 APTA data; in FARE system this is reported by metropolitan planning organization (MPO)
Population density	Population per square mile of land area in urbanized area, central city, and service area	MPO will provide these data to satisfy FARE requirements and will obtain necessary data from system route maps and available census population data
Organization type	Qualitative distinction (e.g., municipal transit authority, contract management)	Obtained directly from transit management; not provided by FARE; highly susceptible to error due to varying definitions of management types
Network configuration	Qualitative distinction (e.g., radial, grid, circumferential)	Determination made from route maps of transit systems; also susceptible to error due to definitional inconsistencies
Local transit policy	Percentage of trips by elderly, percentage of work trips, percentage of elderly population	Elderly population available from census reports; distribution of trips by rider characteristics (age, sex, income, handicap) and by trip purpose (work, shop) will be provided by MPOs from transit-user surveys; available from FARE
	System age	Years transit system publicly operated; information available from transit systems

STRATIFICATION FOR EVALUATION OF PERFORMANCE

If all bus systems operated in identical environments and under similar policy constraints, their performance in different locations could then be explained only in terms of variations in level of service. Presumably, under such conditions, performance differences would then be a function of operator-controlled variables; thus the operator would have the potential to improve the system's performance by increasing the level of service provided.

However, environmental and policy factors external to the local transit operating decisions are not all alike, and it is the major thesis of this research that some of the ways in which they differ affect the inherent productivity of the bus systems. Population density, congestion, and network configuration are most often cited as intruding environmental and policy effects (1,3). These and other elements outside the transit operator's control can have a significant effect on certain performance indicators that are used to describe system productivity. Their impact becomes apparent when vehicle mileage, for example, is used in a productivity measure. Since vehicle mileage is affected by each of the above factors, there is little doubt that a vehicle mile traveled in Milwaukee is not the same as a vehicle mile traveled in New York City. The absence of congestion, for instance, may raise the vehicle's average speed; the result is that more vehicle miles are driven by a particular driver. The failure to consider such an effect will result in misleading productivity measures. Consequently, several environmental and policy factors that appear to constrain performance of transit systems are given below and discussed in the following sections.

Factors	Type of Influence
Population	Environmental
Population density	Environmental
Congestion	Environmental
Wage rate	Policy
Local transit policy	Environmental and policy
Organization type	Policy
Network configuration	Environmental and policy
System age	Policy

STRATIFICATION FACTORS

The following discussion presents several factors that affect bus transit performance either directly or indirectly. As such, these factors are potentially useful in establishing a stratification scheme that can be used to explain the variation in the productivity observed among bus operations. In the discussion of each factor, a basis for its use and possible variables used to quantify each factor are presented. Table 1 gives a list of stratification factors and the variables by which the factors are measured. Also included are their respective data sources. For the purpose of this discussion of an application of the stratification approach, only three factors were chosen, those for which data are now available on a consistent basis so that the factors can be measured.

Congestion

Transit productivity is closely related to travel speed. As speed increases, a given driver can operate over more route miles in a given period. To a certain extent, vehicle operating speed can be controlled by the operator. For example, by increasing or decreasing the number of stops along a route, operating speeds will decrease and increase, respectively. However, vehicle operating speeds are mainly determined by street-system characteristics and local traffic policies and perhaps affected only marginally by transit operating policy. In general, a bus transit management operates its vehicles as fast as traffic conditions permit in order to maximize vehicle use. Thus it is felt that the average vehicle operating speed actually achieved by an urban transit system reflects to a large extent the degree of congestion present in the urban area.

Since operating statistics are reported only on a systemwide basis, the measure of speed is necessarily rough. Nevertheless, incorporation of systemwide average vehicle speed as a stratification variable is defensible on the ground that if some of the detail is obscured, this is so for all systems in the sample.

Wage Rate

A major component of the operating cost is wages paid to drivers and support staff. In general, labor costs are responsible for 50-60 percent of the total operating expenditure. However, since labor costs differ by geographical area, this factor is important for system stratification. The variable used in this analysis is the average wage per vehicle operator of a transit system.

Population

If an indicator of productivity such as passengers per revenue vehicle mile, for example, is used as a measure of transit performance, consideration must then be given to the population characteristics of the community the system serves. If levels of service are equal, passenger use has been found to vary directly with population. Accordingly, total population of the urban area is the variable used in the system stratification scheme.

Other Factors

As shown in the list above, there are several other factors that can be considered in the stratification procedure. Such factors include population density, organization type, and network configuration. Local transit policy is also a critical factor. Although these factors could not be included in the present analysis because of the absence of relevant data on a consistent basis, a brief discussion of their general significance and possible effects is presented in the following paragraphs.

Population Density

There is little disagreement that the population as well as the area of a city play some role in both the provision and the consumption of transit service. Although size of the population alone can give some indication of ridership levels, additional insight into transit performance can be gained if land area is integrated into the analysis. In general, transit service is more efficiently and effectively provided in high-density areas (1). Furthermore, transit operational and financial performance is affected not only by density of residential population, but also by the density and size of nonresidential (i.e., industrial and commercial) clusters in an urban area (4). The significance of such a relationship permits estimation of the effect of different land-use policies on transit performance.

Organization Type

Identification of organizational structure and management can also contribute to the differences in transit performance, since they vary with type of service, the area served, and the preferences of local government. In a study by Bakr and others (5), the ability of various types of organizations to undertake tasks commonly associated with the management of a transit system was examined. It was observed that government-managed transit systems appeared to perform less effectively due to the lack of necessary support personnel needed for operation and management responsibilities. On the other hand, transit authorities, by their nature, were found much more efficient and effective in providing service, since they are much more flexible and innovative in implementation of management and operational policy. The researchers also concluded that contract management performs a justifiable role in the current state of development in the public transportation sector. It can help improve overall performance, since contract management can provide standardized procedures, planning, and scheduling techniques. Managerial performance can be improved, since expertise is accumulated from years of experience, which includes extensive experience in labor negotiations.

Network Configuration

A bus system's performance can be affected by the way in which certain geographical, topographical, and governmental policy constraints force it to develop its network. Network configuration reflects the nature of a city's land-use and street-network patterns. Thus the consideration of bus system network layout can offer insight into aspects of quality and accessibility of transit performance. For example, rectangular networks generally do not follow desire lines as closely as do radial networks, and consequently more transfers may be required, which affects the quality of the system.

Local Transit Policy

In addition to the factors described above, local transit policy is a critical determinant of the performance of transit systems. Since public transportation may exist for different reasons in different cities, it is only reasonable to consider various policy issues to see what goals and objectives the system is expected to achieve. For example, it seems that most performance measures do not reflect the extent to which systems serve special groups such as the elderly and the handicapped. Failure to recognize urban areas that have large concentrations of such special population groups may result in inaccurate assessments of transit performance. In general, it would seem reasonable to assume that those transit systems that provide a high level of service to the elderly and the handicapped would incur higher unit operating costs than do those systems in cities with a small elderly and handicapped population.

Similar distinctions can be made by disaggregating transit operations with respect to peak-period and base-period service. In general, a system largely oriented toward commuters would appear to be much more efficient and effective during peak hours than during the off-peak period. This situation is common for systems that provide late-night (owl) service.

The number of years the system has been publicly owned can also reflect differences in operating and financial performance. It might be reasonable to suggest that those systems that have recently made the change from private to public ownership reflect poor service and passenger use together with low quality of service, which might be indicated by limited accessibility to the service. Initially, such systems are likely to be characterized by absence of the strong public and political support needed for successful development of good management and high ridership.

Although lack of reliable and uniform data does not allow stratification of systems on such bases as organizational type and network configuration, information on rider characteristics provided by user surveys required by the Financial and Reporting Elements (FARE) system of the Urban Mass Transportation Administration can make possible examination of performance on the basis of certain policy varibles such as the percentage of the elderly and the handicapped served.

STRATIFICATION APPROACH

Stratification can be accomplished in many ways. Techniques range from those schemes that stratify by one criterion--for example, whether a system is large or small--to a level of disaggregation that generates a unique description for each transit system. The method developed in the current study

Figure 1. Schematic representation of stratification scheme.

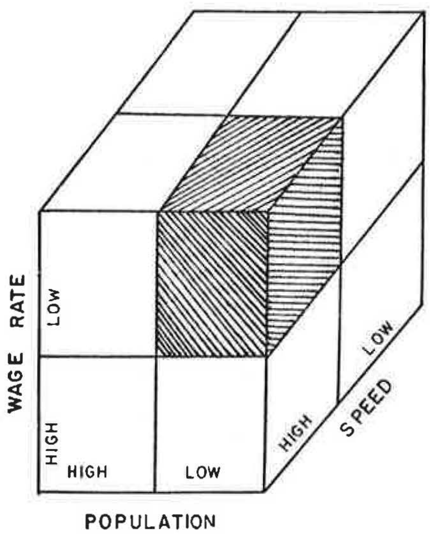

Table 2. Initial stratification of wage, speed, and population variables.

Level	Average Wage ($/h)	Average Speed (mph)	Population (000 000s)
Low	<4.75	<12.5	<250
Medium	4.75-6.00		250-750
High	>6.00	≥12.5	>750

seeks to achieve a level of stratification that lies between these two extremes.

The approach taken is basically a classical taxonomic procedure. To begin, all systems are included in one class. Based on the stratification factors selected, for which data are available, systems are stratified to form cells, or groups of stratification-factor levels. The performance of transit systems within each cell can then be explained by the stratification factors and factor levels.

The primary variables for the stratification approach presented here include average driver wage, average vehicle operating speed, and total urban population of the area in which the system operates. These are variables that not only are reflective of the operating environment under which the systems provide service, but also are essentially independent of the systems operator's influence on transit operations. In addition, measures that reflect system performance are needed, since it is the purpose of stratification to explain variation of performance from system to system. In the present analysis, resource use indicators were considered, such as vehicle miles per vehicle, vehicle miles per driver, and revenue passengers per driver. These measures reflect vehicle use, labor productivity, and labor use, respectively.

In general, each variable can be considered separately, in relation to another, or both to determine appropriate stratification groups. For instance, in considering total population, the stratification can be initiated by disaggregating the corresponding variable into two or three intervals. This stratification then results in a small number of cells; each cell contains many systems. Alternatively, it is possible to stratify in such a manner that each system defines its own unique cell. The objective in determining which stratification scheme is most appropriate involves a trade-off between maximizing the extent to which the variability in system performance can be explained through stratification and maintaining a manageable and practical stratification scheme.

Figure 1 illustrates a simplified schematic stratification scheme. For example, the shaded portion of Figure 1 indicates those bus systems that can be characterized as having an operational service environment with low population, high speed (low congestion), and low wage rate. Development of a final stratification scheme involves the incremental modification of the initial stratification shown in Figure 1. For example, the scheme may involve changing both the number of factors used and the factor levels (or one of these) until an adequate stratification is achieved.

In order to assess the adequacy of a proposed scheme, one must examine the stratification scheme with respect to the performance measures; i.e., does the particular stratification scheme adequately explain the variability in the performance measures? In other words, once cells have been obtained, a check is made to see whether the measures (computed as the mean of each cell) vary with each cell. To make this determination, univariate analysis is used to study the behavior of the mean values for the performance measures within each cell of the stratification scheme. This particular statistical procedure is effective in establishing whether (a) performance variation can be explained by environmental and policy factors or (b) performance variation cannot be explained by using such factors.

STATISTICAL METHOD

The analysis of variance (ANOVA) was applied in this study for development of the stratification scheme for evaluation of transit system performance. ANOVA is merely a procedure by which the total variation in the dependent variable is subdivided into meaningful components. For this application, the dependent variables are the performance measures. The meaningful components are the stratification (independent) variables that are hypothesized as adequate explanations of the variation in performance for the transit systems sampled.

The statistical criterion that is used to examine the adequacy of the scheme is the R^2-value (coefficient of determination). R^2 is simply interpreted as the proportionate reduction of total variation associated with the independent variables. As the R^2-value increases, it will be stated that the variation of the selected performance measure decreases. The change in the R^2-value then becomes the basis for the introduction, modification, or both of the stratification variables. The level of significance in explaining the total variation of a performance measure by a stratification scheme was set at 5 percent. Furthermore, the Burr-Foster Q-test (2) was used to establish the homogeneity of population variances, which is required by the ANOVA technique.

EXAMPLE OF STRATIFICATION APPROACH

The three stratification (independent) variables used here include average driver wage, average vehicle speed, and total urban area population. These variables were disaggregated into several intervals. For the initial iteration, strata were formed as shown in Table 2. The initial choice of variables and class intervals is a judgmental decision. However, the major requirement statistically for the formation of class intervals

Table 3. Results of stratification by wage, speed, and population variables.

Transit Operation	Stratification Variable: Wage ($/h)	Stratification Variable: Speed (mph)	Stratification Variable: Population	Performance Measure: Vehicle Miles per Vehicle	Performance Measure: Vehicle Miles per Driver	Performance Measure: Revenue Passengers per Driver
Cell 1: Low Wage, Low Speed, Low Population						
Central WV TA, Clarksburg, WV	3.65	11.11	28 864	25 218	23 642	47 743
Broome County Transit, Binghamton, NY	4.21	12.46	167 224	35 262	21 322	39 291
Duke Power Company, Anderson, SC	4.38	11.44	27 556	24 116	14 470	20 011
Duke Power Company, Greensboro, NC	3.23	11.77	73 638	29 257	21 672	36 632
Montgomery Area Transit, AL	3.99	11.24	138 983	27 724	21 887	38 850
Mean				25 489	20 599	36 506
Cell 2: Low Wage, Low Speed, Medium Population						
Metropolitan Transit Authority, Des Moines, IA	4.37	9.44	255 824	20 785	19 900	–
Cell 3: Low Wage, High Speed, Low Population						
Corpus Christi Transit System, TX	3.08	13.42	212 820	56 933	31 882	37 257
City Utilities, Springfield, MO	4.19	12.81	121 340	18 216	21 528	22 211
Greenfield and Montague Transportation Area, MA	3.38	12.69	18 116	18 722	18 722	27 149
Bay County Metro TA, Bay City, MI	4.53	13.52	78 097	41 160	14 316	9 564
Monterey Peninsula Transit, CA	4.06	12.96	93 284	38 071	22 208	16 819
Hudson Bus Lines, Lewiston, ME	3.05	16.40	65 212	11 187	12 065	9 170
Mean				29 953	20 120	20 362
Cell 4: Low Wage, High Speed, Medium Population						
Metropolitan Tulsa Transit Authority, OK	3.86	12.70	371 499	34 333	25 328	30 010
Metropolitan Transit Authority, Wichita, KS	3.53	12.99	302 334	37 687	27 961	32 064
Sun Tran-City, Tucson, AZ	4.50	13.01	297 451	40 953	25 173	33 671
Austin Transit Corporation, TX	4.57	13.61	264 499	46 607	21 909	30 425
Central Pinellas Transit Authority, St. Petersburg, FL	3.42	13.86	495 159	47 121	27 487	26 954
City Transit Division, Southeastern Pennsylvania TA	4.32	15.10	685 942	41 721	16 688	16 954
Mean				39 924	24 091	28 346
Cell 5: Low Wage, High Speed, High Population						
North Suburban Mass Transit District, Des Plaines, IL	4.69	14.59	6 714 578	14 409	14 409	17 187
Dallas Transit System, TX	4.68	13.62	1 338 684	31 584	24 076	44 625
Mean				22 997	19 242	30 906
Cell 6: Medium Wage, High Speed, Low Population						
Kanawha Valley Regional Transit Authority, Charleston, WV	6.00	13.62	157 662	34 709	28 635	47 983
Lane County Mass Transit, Eugene, OR	5.25	14.49	139 255	48 067	22 531	22 375
South Carolina Electric, Charleston, SC	4.96	12.53	228 399	41 684	24 222	60 514
South Carolina Electric, Columbia, SC	4.89	12.76	241 781	38 982	24 892	53 728
Ft. Wayne Public Transportation Corporation, IN	5.73	13.45	225 184	29 882	24 902	29 898
Madison Metro, WI	5.00	14.02	205 457	22 030	25 041	74 885
Mean				35 634	25 037	48 230
Cell 7: Medium Wage, Low Speed, Medium Population						
CNY Centro, Syracuse, NY	4.95	11.55	376 169	25 831	18 806	47 823
Calgary Transit, Alberta, Canada	5.58	11.90	403 319	29 518	–	–
Capital District TA, Albany, NY	4.80	11.78	486 525	26 975	20 036	43 203
Metro Regional Transit Authority, Akron, OH	4.77	11.96	542 775	29 890	14 945	24 221
Sandwich Windsor, Windsor, Ontario, Canada	5.12	10.17	258 643	28 507	20 332	57 935
Mean				27 113	18 530	43 295
Cell 8: Medium Wage, Low Speed, High Population						
New Orleans Public Service, Inc., LA	4.72	10.27	961 728	23 792	15 023	59 092
Metropolitan Dade County TA, FL	5.66	10.24	1 219 661	–	21 127	65 794
Rhode Island Public Transit Authority	4.95	10.72	795 311	35 392	20 444	53 005
Mean				29 592	18 864	59 297
Cell 9: Medium Wage, High Speed, Medium Population						
City and County of Honolulu DOT Services, HI	5.45	14.44	442 397	44 490	21 902	66 154
Cell 10: Medium Wage, High Speed, High Population						
City of Detroit DOT, MI	4.93	14.63	3 970 584	36 032	26 052	–
Metropolitan Atlanta Rapid Transit Authority, GA	5.71	13.91	1 172 778	37 742	25 315	54 255
Metropolitan Transit Commission, St. Paul, MN	5.82	12.91	1 704 423	25 846	21 899	44 089
Metropolitan Transit Authority, Houston, TX	5.61	13.43	1 677 863	40 132	23 304	40 024
Southwest Ohio Regional Transit Authority, Cincinnati, OH	5.87	12.68	1 110 514	28 008	22 353	52 912
Tri-County Metropolitan Transportation District, Portland, OR	5.84	14.57	824 926	39 335	23 953	31 616
Mean				33 040	23 812	44 579
Cell 11: High Wage, High Speed, Medium Population						
Tacoma Transit System, WA	7.54	12.60	332 521	27 473	21 105	43 229
Toledo Area Regional Transit Authority, OH	6.30	13.48	487 789	29 190	25 675	62 186
Mean				28 331	23 390	52 707

Table 3. Continued.

Transit Operation	Stratification Variable: Wage ($/h)	Speed (mph)	Population	Performance Measure: Vehicle Miles per Vehicle	Vehicle Miles per Driver	Revenue Passengers per Driver
Cell 12: High Wage, Low Speed, High Population						
Bi-State Development Agency, Alton, IL	7.10	12.50	2 987 850	26 081	19 971	35 032
City of Long Beach, NY	6.43	12.15	8 351 266	39 933	24 323	48 596
Milwaukee Transport Services, Inc., WI	7.28	11.76	1 252 457	34 608	19 748	50 412
Niagara Frontier TA, Albany, NY	6.23	10.79	1 086 594	–	17 158	51 600
Regional Transportation District, Denver, CO	6.41	11.80	1 047 311	29 000	16 162	25 252
Chicago Transit Authority, IL	7.70	8.84	6 714 578	36 204	16 383	–
Montreal Urban Community Transit Commission	7.27	9.87	2 743 208	24 232	15 888	63 900
Toronto Transit Commission	7.02	12.15	2 628 043	37 921	–	–
Mean				29 858	18 519	45 799
Cell 13: High Wage, Low Speed, Medium Population						
Ottawa-Carleton Regional Transit Commission, Ontario, Canada	6.66	11.88	602 510	34 070	21 030	57 055
Winnipeg Transit System, Manitoba, Canada	6.25	10.96	540 262	30 516	17 147	71 752
TA of River City, Louisville, KY	7.41	12.33	739 396	22 141	15 599	34 914
Mean				28 093	17 925	54 574
Cell 14: High Wage, High Speed, High Population						
Alameda-Contra Costa TD, Oakland, CA	8.56	14.42	2 987 850	30 003	18 527	33 960
Indianapolis Public Transportation Corporation, IN	6.43	12.86	820 259	22 809	18 200	34 378
San Diego Transit Corporation, CA	7.28	14.47	1 198 323	36 145	23 758	58 135
Southern California Rapid Transit District, Los Angeles, CA	6.28	13.22	8 351 266	30 775	18 576	45 354
Central Ohio Transit Authority, Columbus, OH	6.06	12.58	790 019	27 435	20 558	37 858
Southern Michigan TA, Detroit, MI	9.21	16.60	3 970 584	27 614	26 009	27 660
Transport of New Jersey, Trenton, NJ	7.11	14.24	7 168 164	37 451	26 423	41 812
Mean				30 289	21 722	38 980
Cell 15: Medium Wage, Low Speed, Low Population						
Cumberland-Dauphin-Harrisburg TA, PA	5.22	11.41	240 751	17 315	20 595	33 561
Savannah Transit Authority, GA	5.73	11.88	163 753	33 922	22 869	44 974
Tri-State Transit Authority, Huntington, WV	4.96	12.06	167 583	24 491	25 190	36 463
Berks Area Reading TA, PA	5.49	10.00	167 932	27 397	20 091	37 882
Luzerne County TA, Kingston, PA	5.95	12.13	222 830	–	22 045	43 056
Mean				25 781	22 158	39 187

Note: TA = Transportation Authority; DOT = Department of Transportation; TD = Transportation District.

Table 4. R^2 and significance values for stratification evaluation.

Stratification Variable	Performance Measure	R^2	Significance
Average driver wage	Vehicle miles per vehicle	0.489	0.013[a]
Average vehicle speed	Vehicle miles per driver	0.500	0.012[a]
Total urban area population	Revenue passengers per driver	0.570	0.001[a]

[a]Significant at the 0.05 level.

is that variances among cells formed must be homogeneous.

The stratification cells formed are shown in Table 3. By using the ANOVA technique, it was found that the variability in each of the performance measures can be adequately explained by the proposed stratification scheme. Table 4 gives the values for R^2, the criterion used to evaluate the scheme. It can be noted that this stratification scheme, which uses average driver wage, average vehicle speed, and total urban area population as independent variables, explains 49 percent of the variation in vehicle use, 50 percent in labor productivity, and 57 percent in labor use. On the basis of these results, it can be concluded that the stratification scheme appears to be statistically acceptable. The variation that remains unexplained can be due to a variety of factors, among which are differences in level of service and inaccuracies in data.

Implications of these results can now be examined in terms of the selected performance measures. For illustrative purposes, the issue of system comparability is discussed in the following paragraphs.

The types of results shown in Table 3 can be used to make a specific evaluation of the performance of a particular system. As an example, consider those systems that make up cell 14. Here the performance of an individual system (that of Indianapolis, for example) can be compared with the mean performance of all the systems in that cell. While this is being done, however, several questions may arise regarding the remaining variation in performance among systems in that cell. This can be the result of policy or operational conditions.

If we look first at the vehicle-use measure (vehicle miles per vehicle), Indianapolis has a value (22 809) that falls below the mean (30 289). Although the high average operating speed of the Indianapolis system suggests that the ratio should be higher (since more vehicle miles would be generated at higher speeds), this is not always the case. In fact, a lower-than-average value may indicate that the system is providing a higher level of service by using a large fleet for the number of vehicle miles operated. On the other hand, service may be characterized by low frequency; this results in fewer miles traveled by each vehicle. Consequently, for low values of this measure, both effective and ineffective use of vehicles can be the case, depending on the particular characteristics of the system.

Likewise, labor productivity, indicated by vehicle miles per driver, can also be interpreted in different ways. For instance, due to certain policy constraints, run cuts and schedule problems may not permit efficient allocation of operating personnel between peak and off-peak periods. A low value (18 200) for Indianapolis Public Transportation Corporation relative to the mean (21 722) may suggest such a problem. On the other hand, the high value for Transport of New Jersey (26 423) suggests that this type of policy constraint has less influence in this system. However, it also suggests that other policy constraints require a system that uses all drivers to service areas.

Finally, revenue passengers per driver, a labor-use indicator, shows a wide range--from 27 660 for Southern Michigan Transportation Authority to 51 835 for San Diego Transit Corporation. In this case, low patronage may be the result of improper or inadequate route coverage; this may indicate that the system covers a service area with low transit demand. Low patronage may also be the result of certain service-related policy constraints. For example, if a system is mandated to provide an extensive service for the transportation disadvantaged such as the elderly and the handicapped, it may not show a high value for revenue passengers per driver. Other local transit policies, particularly those associated with fare levels and fare structures, can also affect the patronage significantly.

EFFECT OF STRATIFICATION BY WAGE, SPEED, AND POPULATION ON OTHER PERFORMANCE MEASURES

Since stratification helps to explain the variation in performance among urban transit systems, there may be certain performance measures that can be better explained by the stratification than those shown in the previous section. The statistical results are given in Table 5. It can been seen that, for stratification on the basis of wage, speed, and population, the variation in performance measures such as total operating cost per vehicle, driver cost per vehicle hour, and revenue passengers per vehicle hour (among others) is explained reasonably well by this scheme as indicated by R^2-values of 0.548, 0.807, and 0.673, respectively. There are also certain other performance measures (such as driver cost per total cost and operating ratio) that are not significantly explained by the variables used in this stratification scheme.

Although urban population, wage rate, and average vehicle speed have been identified as the basic set of stratification variables, there are other variables that are potentially useful in establishing a stratification scheme, as was indicated in Table 1. It is not possible at this time to consider all these variables, due to the lack of data. However, similar analyses to this one should be undertaken once the appropriate data become available on a consistent basis so that those factors that would facilitate the understanding of the variation in performance from one system to another can be determined. As a preliminary indication of the effect that one variable has on transit performance, the following section presents the stratification of 51 bus systems by the age of the systems since they have been publicly operated.

Table 5. Effect of stratification by wage, speed, and population on selected performance measures.

Performance Measure	R^2	Significance
Vehicle miles per employee	0.526	0.005[a]
Vehicle hours per bus	0.427	0.055
Percent peak vehicle use	0.516	0.012[b]
Total operating cost per vehicle mile	0.672	0.001[a]
Total operating cost per vehicle	0.548	0.004[a]
Driver cost per vehicle hour	0.807	0.001[a]
Driver cost per total cost	0.328	0.263
Total maintenance cost per passenger	0.469	0.032[b]
Total administrative cost per passenger	0.480	0.062
Total cost per passenger	0.534	0.003[a]
Percentage of population served	0.341	0.290
Percentage of transfers	0.366	0.248
Revenue passengers per vehicle mile	0.647	0.001[a]
Revenue passengers per vehicle hour	0.673	0.001[a]
Revenue passengers per population served	0.581	0.001[a]
Revenue per vehicle	0.483	0.038[b]
Revenue per revenue passenger	0.431	0.053
Operating ratio	0.277	0.502
Deficit per passenger	0.450	0.042[b]

[a]Significant at the 0.01 level. [b]Significant at the 0.05 level.

TRANSIT SYSTEMS STRATIFIED BY SYSTEM AGE

Inherent in this discussion is the fact that, depending on the adequacy of the data and the refinement desired, there are some stratification variables that may be better than others in explaining variation in transit performance. For example, knowledge of the age of a system since it became publicly operated can add insight into transit operational performance, as discussed in the section that describes stratification variables.

Table 6 gives the results of stratification by system age for the 51 bus systems for which data could be obtained. The analysis covered the years up to 1975. It should be noted here that the analysis includes only those systems that operate in the United States. Canadian systems were not considered, since Canada's governmental transit programs differ greatly from those under which U.S. systems operate. The results reported are significant at the 95 percent confidence level. The results show that systems that have become publicly owned after 1969 show significantly lower vehicle use (2085 vehicle-h/vehicle) than do systems that were publicly owned in 1969 or earlier (2462 vehicle-h/vehicle). Similarly, passenger use appears lower for younger systems, as indicated by the low value of 17.2 for revenue passengers per

Table 6. Results of stratification by system age.

	Mean Performance				
Performance Measure	Public After 1969	Public Since 1969 or Earlier	All Systems	R^2	Significance
Number of observations	26	25	51	-	-
Vehicle hours per vehicle	2085	2462	2262	0.107	0.024[a]
Operating expense per vehicle ($)	33 512	42 231	37 508	0.129	0.012[a]
Revenue per passenger ($)	0.38	0.30	0.34	0.104	0.028[a]
Deficit per capita ($)	4.38	9.54	6.68	0.118	0.018[a]
Revenue passengers per capita	17.2	36.2	26.1	0.157	0.025[a]

[a]Significant at the 0.05 level.

capita as compared to 36.2 revenue passengers per capita for older systems.

Consequently, systems that have been publicly owned since 1969 or earlier (six years or longer) appear to be more efficient in terms of vehicle and passenger use. Because of strong and continuing political and public support, such systems have been able both to make certain capital improvements and to implement policies that provide increasing service levels. Purchase of new buses, for example, has allowed transit systems to provide longer hours of service with fewer vehicles, whereas certain policy issues such as fare stabilization have helped to assure continued patronage.

If we consider only the financial efficiencies, however, those systems that have been public since 1969 (less than six years) appear to be more cost efficient. Table 6 shows that operating expense per vehicle, on the average, is lower ($33 512) than it is for older systems ($42 231). Not only can these systems operate at lower unit costs, but they also appear to be more revenue efficient; revenue per passenger is $0.08 more than it is for the older systems (Table 6). In general, the revenue efficiency of younger systems may be explained by a fare policy that reflects the momentum of the profit-making objective of privately operated transit systems.

It should be noted that, for each of the performance measures presented in Table 6, the R^2-values (which reflect the extent of explanation of variation in transit performance) range between 0.104 and 0.157. These values indicate, for example, that only 10.4 percent of the variation in vehicle use (as measured by vehicle hours per vehicle) can be explained by stratifying 51 transit systems according to system age. These results are as expected, and they suggest that other environmental and policy variables might be more useful in explaining variation in urban transit performance when considered together with system age.

CONCLUSIONS

In this paper, a method has been developed by which certain environmental and policy variables have been found useful in explaining the biases inherent in transit performance measurement. Through the example presented, the extent of influence on transit resource use of the elements of wage rate, average operating speed, and population has been identified.

Since such a procedure appears to explain performance variation adequately, its usefulness in comparative evaluation is evident. Such evaluations lend themselves to direct comparison of systems within their respective cells. Bus system performance can be compared against the mean cell values of performance indicators of similar properties. These mean values constitute a par against which comparisons can be made, primarily by managers of a transit property.

Stratification is therefore useful in explaining the possible bias in making assessments and comparisons of bus transit systems. However, it is important to stress that the stratification scheme presented here is only a beginning. Subsequent analyses that use additional environmental and policy factors will undoubtedly improve the reliability and validity of the stratification scheme. The stratification approach to comparing the performance of alternative systems holds promise of being a powerful program-analysis and system-evaluation tool.

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Effects of Small-Scale Transit Improvements on Saving Energy

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The effects of small-scale transit improvements on saving energy in New York State's eight metropolitan planning organization (MPO) areas are examined. Actions included in the transportation system mangement (TSM) plans of the eight MPO areas are analyzed for their effects on ridership, mode shifts, and energy savings, as well as on the energy costs of development, implementation, and operation. Each of 11 transit-related TSM actions is analyzed separately. These transit improvements result in average annual energy savings of more than 25 million equivalent L of gasoline over the period 1978-1980. This is about 0.1 percent of the total annual gasoline consumption in New York State but is 2.6 percent of transit energy consumption in the eight MPO areas. When demand-responsive services, which have high energy costs, are excluded, the average annual saving increases to 3.1 percent of transit energy consump-

tion. Small-scale transit improvements can thus play a role in the energy conservation efforts in New York State but cannot be expected to have a major impact on the state's energy situation.

In recent years, the focus of attempts to improve public transportation systems has been on small-scale improvements designed to make transportation systems more efficient. Although energy has not usually been a stated criterion in evaluating such improvements, it has been generally assumed that public transit can play a major role in any conservation effort.

This paper is part of a broader study undertaken by the Planning Research Unit of the New York State Department of Transportation (NYSDOT) in conjunction with the New York State Energy Office to quantify expected energy savings for the years 1978-1980 for all elements of the state energy conservation plan. Specifically, this paper analyzes several categories of transportation systems management (TSM) actions related to mass transit to determine energy savings and costs.

METHOD

Determination of statewide energy savings by category and by area is the goal of the analysis; this requires an aggregate approach. Transit-related energy savings come primarily from a reduction in automobile vehicle kilometers due to mode shifts to mass transit. Energy costs are incurred by increased vehicle kilometers of travel (VKT), increased bus maintenance, and construction of transit equipment or system facilities. Savings and costs are expressed in equivalent liters of gasoline. The following formulas are used to calculate savings and costs:

Savings = (change in transit ridership x proportion of automobile drivers who divert to transit x average automobile trip length x factor for car left home)/automobile fuel efficiency.

Cost = (change in transit kilometers traveled/bus fuel efficiency) x 1.104 + construction costs + 0.105 (change in transit kilometers traveled).

In the cost formula, 1.104 is the factor that converts liters of diesel fuel to equivalent liters of gasoline and 0.105 is the factor that takes into account increased maintenance costs that arise from increased VKT (1). Average automobile trip lengths are 13.4 km upstate (2) and 15.9 km in the Tri-State area (3). Average automobile fuel efficiency in New York State was 5.06, 5.23, and 5.40 km/L in 1978, 1979, and 1980, respectively (4). Average fuel efficiency for buses has been studied by the U.S. Department of Transportation and the U.S. Environmental Protection Agency (5). Average figures are 1.70 km/L for local transit buses and 2.13 km/L for express buses. Finally, a study on the use of the car left at home has indicated that energy savings should be reduced by 40 percent to take into account such use. The factor for the use of the car left at home is therefore 0.6.

Since only 34.6 percent of workers in the New York City metropolitan area drive an automobile for the journey to work as compared with 65.7 percent in upstate metropolitan areas (6), the proportional diversion potential in the New York City metropolitan area is about half the diversion potential upstate. When diversion rates for small-scale transit TSM actions are estimated, the rate for the Tri-State area was one-half the diversion rate for upstate areas. Where appropriate, the outlying counties (Putnam, Orange, and Dutchess) of the 12-county Tri-State area are treated in the same manner as are upstate areas. For this study, diversion rates will express the proportion of new transit riders who formerly drove an automobile.

For most types of actions, case studies provide estimates for ridership increases. A review of the literature reveals appropriate percentage increases for systemwide actions such as passenger amenities, marketing, and passenger information. Finally, for routing and scheduling improvements, a typical ridership change is estimated from averages of documented ridership changes that result from such improvements.

RESULTS

Routing and Scheduling Improvements

Average ridership and VKT changes were obtained from actions in which such information was available or easily estimated, and these averages were applied to projects from which no data were available. The average ridership increase was 40 000, whereas the average bus VKT increase was 46 000. Two projects considered separately were a Tri-State action that involved a ridership increase of 5 million and a Rochester action that involved a VKT decrease of 390 000.

Other studies (7) have indicated that from 33 to 50 percent of new riders drawn to transit by improvements in frequency of service would otherwise have driven an automobile. The 33 percent figure is used except in cases in which new service is provided to areas not already served. In those cases, the 50 percent diversion rate is used. The diversion rate is halved for the nine inner counties in the Tri-State area.

Routing and scheduling improvements result in annual savings of between 1 325 000 and 1 500 000 L; over 80 percent of the savings occurred in the Tri-State area. Three upstate areas show negative figures; in these cases, the energy costs from increased bus operation and maintenance outweigh savings from new passengers diverted to transit.

Express-Bus Service

A study of express-bus service in New York City revealed that the rate of diversion from driving an automobile to riding an express bus was only 4.1 percent (8). This low diversion rate can be explained by the fact that in general the trip time to Manhattan was longer by express bus than by automobile. The fact that any diversion occurred in this situation indicates the important role that comfort can play as an inducement to using mass transit.

Figures from six express-bus studies across the country were used to determine a rate of diversion from driving an automobile to riding an express bus for upstate areas. These figures ranged from 16 percent in Seattle, Washington, to 55 percent in San Bernardino, California. Most rates fell in the 40-50 percent range. Because most of these studies considered additional service changes such as park-and-ride lots, exclusive bus lanes, and signal preemption, a 33 percent diversion rate is a reasonable estimate for express-bus service in upstate metropolitan areas and express-bus projects in the Tri-State region that operate outside New York City.

The effect of express-bus service on energy consumption is somewhat surprising. The energy costs from the increase in bus VKT are significantly greater than energy savings from increased ridership. Statewide, this results in an annual cost of 550 000 equivalent L of gasoline. It appears that the most energy-efficient change in service is the conversion of an existing bus line to express service, since this involves no change in bus VKT. This type of change, however, tends to attract a great proportion of riders of the local transit service. Provision of express-bus service may fare less well as an isolated project than do other transit-related TSM actions. This suggests that express-bus service should be packaged with other complementary actions.

Park-and-Ride Service and Transportation Corridor Parking

In considering transportation corridor parking, there are two basic types of park-and-ride lots: (a) remote park-and-ride service, which involves parking in outlying areas and using public transportation for the major portion of the journey to work, and (b) peripheral park-and-ride service, which involves (as the name suggests) parking on the outskirts of the central business district (CBD) and using public transportation for final trips within the CBD. In general, lots more than 4.8 km from medium-sized downtown areas are classified as remote, and lots within 2.4 km are classified as peripheral (9). This analysis uses a distance of 4.8 km as the dividing line between the two types.

Four areas in the state are using or constructing park-and-ride lots--the Tri-State region, the Capital District, Syracuse, and Rochester. All these areas could provide data on either the number of new spaces or the change in bus ridership associated with the park-and-ride lots. To complete the data necessary for the energy calculations, average figures for annual number of cars and passengers per space in a park-and-ride lot and the average occupancy of a car that used the lot were needed. These averages were obtained from park-and-ride studies in six cities across the country (10,11) and from recent surveys in Albany. The annual number of cars per space is 200, or 80 percent of full capacity (250 cars/space is the equivalent of full capacity, since there are 250 workdays in a year). Average automobile occupancy differs for remote and peripheral lots. It is 1.15 for the former and 1.33 for the latter. The difference can be readily explained by the assumption that more carpooling takes place for the long automobile trip to a peripheral lot than for the essentially local trip to a remote lot. From these two averages, we can compute the annual number of passengers per space, which is 230 for remote lots and 266 for peripheral lots.

Since park-and-ride lots capture automobiles on their way to work and save the energy formerly expended on that portion of the trip between the lot and the CBD, the distance between the lot and the CBD is used as the average automobile trip length in the energy calculations for this section. This average distance is estimated at 19.3 km for the Tri-State region.

To determine diversion rates, averages from a five-city park-and-ride study were used (10). For remote lots, the rate of diversion from automobile driver to transit user averaged 45 percent, whereas for peripheral lots the figure was 70 percent. In the Tri-State region, the diversion rate is halved. Some areas used existing lots for park-and-ride service. In these areas, there were obviously no energy costs for construction.

The results of the energy calculations show that park-and-ride service can have a positive effect on energy consumption in the state. On the average, park-and-ride service saved 6 400 000 equivalent L of gasoline annually during 1978-1980. Although the diversion rate is higher for peripheral lots, use of remote lots has a more-pronounced effect on energy savings because of a greater reduction in automobile VKT.

Shuttle-Transit Service

Shuttle-transit service can link two activity centers or can operate as a circulator within the CBD. Shuttle-transit service is being provided or planned in Westchester County, the Capital District, Syracuse, and Rochester. Free downtown bus service in Albany and Syracuse has resulted in an increase of 1000 riders/day (2.0 percent). This number can serve as an estimate for Westchester County's program. For future projects in Westchester and Albany, a conservative estimate of an additional 500 passengers/day is used.

The assumption is made that such service does not divert automobile trips made into the CBD to other modes but that it does divert some automobile trips within the CBD. The automobile trip length used in the energy calculations must be adjusted accordingly. An average trip length of 1.6 km for trips within the CBD is appropriate. For shuttle service between two activity centers, the distance between centers can serve as a measure of trip length.

Based on figures from two studies on free-fare CBD transit service (12,13), a 25 percent rate of diversion from driving an automobile to using shuttle-transit service is used for all projects in the state. Shuttle-transit service can result in modest energy savings of 150 000 equivalent L of gasoline annually in New York State. The most energy-efficient programs in the category are those that do not require an increase in bus VKT. When new service has been provided, the energy costs of increased bus operation and maintenance outweigh the energy savings. Free-fare programs within the CBD that use existing transit lines are the most promising type of shuttle-transit service in terms of saving energy.

Passenger Amenities

Passenger amenities can be described as those characteristics that contribute to the comfort, convenience, or attractiveness of the transit user's environment (other than the commonly measured attributes of travel time, fare, frequency, and schedule).

All areas in the state include actions for such amenities as bus shelters, new buses, modification of existing transit vehicles, rehabilitation of transit stations, and bus or transfer terminals. In general, many studies (7,14-19) indicate that provision of passenger amenities has a small but positive effect on transit ridership. A federal study indicates that an optimistic estimate of the change in ridership that results from a major program of providing bus shelters, transfer stations, and other amenities is an increase of 5 percent (20). None of the state's metropolitan areas can be said to be undertaking a major program of providing passenger amenities, which suggests the figure of 2 percent as an estimate of the increase in ridership.

This figure of 2 percent applies to the entire state program of amenities and is not an annual figure. For computing annual changes, this figure of 2 percent will be adjusted according to the proportion of actions for amenities being taken in the specific year involved. In all cases, the base for computing ridership changes is the 1977-1978 fiscal-year ridership data.

Fare-Collection Improvements

A review of the literature about fare-collection improvements indicates that many such actions either have no effect on ridership (21-24) or do not induce mode shifts from automobile to transit (13). Consequently, only actions within New York State that produce documented ridership increases or could reasonably be expected to produce such increases were included in the analysis of energy savings.

For purposes of analysis, these actions can be divided into three types--the Uniticket program, transfer actions, and fare-structure modifications. The Westchester County Department of Transportation has published a detailed report on the Uniticket program (25), which shows that the rate of diversion from driving an automobile as a result of the Uniticket program is 13.5 percent. Because of a limited marketing budget, the program has thus far attracted primarily commuter rail users to the suburban bus; automobile commuters to Manhattan have not been induced by the Uniticket program to use commuter rail. The average length of the diverted trip must therefore be adjusted. The Westchester report indicates that 3.2 km is a good estimate of average automobile trip length from home to the commuter rail station.

Among transfer programs, Syracuse reports a 0.5 percent ridership increase. This figure of 0.5 percent can be used to calculate bus-ridership increases in New York City and Rockland County as a result of transfer programs. A 50 percent rate of diversion from automobile driver to transit user is assumed in Syracuse and Rockland and a 25 percent diversion is assumed in New York City.

Binghamton's metropolitan planning organization (MPO) staff estimates an 8 percent ridership increase due to the modified fare structure. This 8 percent increase can be applied to Elmira. A 50 percent rate of diversion from automobile driving is assumed.

Energy costs for improved fare collection come from new fare boxes. Net annual energy savings from improved fare collection average slightly less than 1 500 000 equivalent L of gasoline statewide. Approximately 85 percent of the savings are realized in the Tri-State area.

Passenger-Information Improvements

Passenger-information improvements can be defined as those actions that increase understanding of how to use a transit system. Passenger-information improvements usually do not provide the initial impetus for using public transit. However, once a potential new rider has decided to use public transit, passenger information becomes an important aspect in translating the decision into behavior and in retaining a first-time rider as a transit user. All areas in the state are undertaking programs to improve passenger information. The most common involve signs and map revisions. There is conflicting evidence on the effect of improved passenger information on ridership. One study suggests that there has been no effect (26). There is evidence that information programs are affected by the law of diminishing returns within a fairly short period of time (7). One study suggests that the maximum increase in ridership that would result from a major marketing effort of informational and promotional programs would be from 2 to 4 percent (20).

No area in New York State is undertaking a major program to improve passenger information that leads to an assumption of a 0.5 percent increase in ridership. This figure of 0.5 percent applies to the entire program of improved information and is not an annual figure. To determine annual changes, this figure must be adjusted according to the proportion of information improvements taken in a specific year. This analysis is similar to that performed for passenger amenities.

Energy savings that resulted from improved passenger information averaged slightly less than 3.5 million equivalent L of gasoline annually. Once again, energy savings in the Tri-State region account for most of the savings in the state.

Demand-Responsive Service

In New York State, demand-responsive service includes dial-a-bus operations and services for the elderly, the handicapped, or both provided by vehicles under the Urban Mass Transportation Administration's Section 16(b)(2) program. Little research has been done into the mode of travel previously used by riders of demand-responsive service. Two studies report a rate of diversion from automobile (driver and passenger) of 50 percent (27,28), whereas two other studies indicate an 11 percent rate of diversion from driving an automobile (29,30). It is reasonable, given this variation in diversion rates, to assume that 20 percent of the users of demand-responsive service in New York State formerly drove an automobile. Since most of the demand-responsive service provided in the Tri-State region is in suburban areas in which conventional transit service is not extensive, the 20 percent diversion rate is used for the entire state.

Energy costs come from the operating and maintenance costs involved in provision of service and to a lesser extent from the manufacture of the necessary minibuses. These costs outweigh the energy savings. On the average, the annual energy cost of demand-responsive service is more than 3.8 million equivalent L of gasoline. A relatively large number of vehicle kilometers is required by the nature of demand-responsive service. Demand-responsive service is meant to improve the mobility of groups unable to get around by automobile or conventional transit and so result in more induced trips than do most other programs.

Maintenance Improvements

All areas in the state report programs to improve maintenance. There are three basic ways in which improved maintenance can lead to energy savings. If buses are given regular maintenance, they will run more efficiently, which increases average mileage. According to transportation officials working with the Metropolitan Transit Authority for New York City, an increase of 0.042 km/L can be expected from improved maintenance. This mileage improvement will not occur instantly but can be expected to increase more quickly with time. An increase over the base-year figure of 0.021 km/L for the first year of the maintenance program, 0.032 km/L for the second year, and 0.037 km/L for the third year is assumed. Transit bus kilometers per liter for each MPO area can be used to calculate energy savings:

$$\text{Energy savings} = (\text{bus VKT}/\text{bus kilometers per liter}) - [\text{bus VKT}/(\text{bus kilometers per liter} + \Delta\ \text{bus kilometers per liter})] \times 1.104,$$

where 1.104 is the factor that converts liters of diesel fuel to equivalent liters of gasoline.

Improved maintenance extends the life span of buses. If improved maintenance programs statewide can extend transit bus life spans from 12 to 13 years, only one-thirteenth of an area's bus fleet will be replaced per year as opposed to one-twelfth. Savings will come from the energy required for bus construction:

Energy savings = (number of buses in fleet/12) - (number of buses in fleet/13) x 1.08 x (10^{12}J/bus) x (2.87 x 10^{-8}),

where 1.08 x 10^{12} J/bus is the energy needed to manufacture a bus (1) and 2.87 x 10^{-8} is the factor that converts joules to equivalent liters of gasoline.

Energy costs will increase as a result of an increased amount of maintenance. A figure is available for the energy needed per dollar spent on maintaining equipment (31); this figure has been adjusted for the Tri-State area to reflect different operating conditions. An increase in the amount allocated to maintenance in an authority's operating budget can indicate the existence of a program to improve maintenance. In the Tri-State region, it is assumed that the amount of money allocated for maintenance will increase by 0.25 percent annually. Two formulas for energy costs can be constructed. For the Tri-State region:

Energy costs = proportion of operating budget assumed to go to improved maintenance x 1977 operating expenditures x 0.333,

where 0.333 is the energy in equivalent liters of gasoline per dollar spent for maintaining equipment in the Tri-State region. For upstate areas:

Energy costs = (maintenance $\text{forecast}_{\text{year } i}$ - maintenance $\text{forecast}_{\text{year } i-1}$) x ($\text{CPI}_{\text{year } i}/\text{CPI}_{\text{year } i-1}$) x 0.443,

where CPI is the consumer price index and 0.443 is the energy in equivalent liters of gasoline per dollar spent for maintaining equipment in upstate areas.

Calculations show that savings of more than 1 800 000 equivalent L of gasoline can be gained annually from improved maintenance. This assumes that bus mileage improves more quickly with time and that the life span of the bus is extended immediately.

Monitoring Transit Operations

The types of transit actions being taken in New York State include real-time monitoring (by two-way radio and other communications systems) of specific situations and broader systemwide monitoring to increase and standardize data collection on transit operations and to improve the internal efficiency of the transit system.

The effects of monitoring actions are indirect in terms of impact on ridership. However, improvements in the efficiency of the transit system can lead directly to energy savings by reducing overall bus VKT. Field tests of the RUCUS package (a set of computer programs designed to expedite and improve the efficiency of scheduling for mass transit) in four cities nationwide showed a decrease in vehicle hours on the order of 1.3-4.8 percent (32). If it is assumed that average speed is approximately the same on all transit systems and that average speed is not changed by RUCUS, these figures can serve as the percentage decrease in vehicle kilometers that results from increased scheduling efficiency. It is assumed that reduction in vehicle kilometers realized from use of RUCUS comes from elimination of duplicate service and therefore does not affect ridership levels.

The formula for calculating savings from monitoring actions is

Energy savings = (decrease in bus VKT/average bus mileage) x 1.104,

where average bus mileage can be obtained for each system and 1.104 is the conversion factor for diesel fuel to equivalent liters of gasoline.

Installation or improvement of communications systems and implementation of computer-based programs such as RUCUS involve energy costs. A study has provided a figure for energy costs per dollar spent on electrical equipment (31). The formula for calculating energy costs for monitoring actions is

Energy costs = cost in dollars of communications system or computer-based program x 0.112 equivalent L of gasoline per dollar.

Energy costs outweigh energy savings in two of the three years covered in this study, with an average annual net cost of 110 000 equivalent L of gasoline. Monitoring actions may have a more-positive effect on energy in the long run as the increased internal efficiency of the transit system gradually increases the operating efficiency of the system.

Marketing

Marketing actions are defined as efforts to publicize the existence of the transit system itself or of various special programs. All areas in New York State are taking marketing actions, which include promotional advertising campaigns, tie-ins with local merchants, and barter arrangements. The evidence regarding to what extent ridership actually increases is conflicting. Some studies report no lasting gains (7,33), whereas others suggest that there is a definite positive effect (13,23,34,35). The general consensus is that marketing actions result in a slight increase in ridership but that it has been a short-term effect, which suggests the need for ongoing marketing programs.

A federal study cites an upper limit of 2-4 percent for ridership increases that result from a major marketing campaign. Since no metropolitan area in the state is undertaking a major marketing campaign, a 1 percent increase in ridership can be expected from the existing and proposed marketing programs. In comparison to ridership assumptions made for other TSM actions, marketing has twice the impact of passenger information on ridership and half the impact of passenger amenities.

This 1 percent ridership increase is not an annual figure but rather applies to the entire marketing program over the three years with which this study is concerned. To compute annual changes, this figure of 1 percent must be adjusted according to the proportion of the marketing budget spent in a specific year.

A 50 percent diversion rate from driving an automobile to using transit is estimated for marketing actions (25 percent for the Tri-State area).

Marketing actions can save a sizeable amount of energy: By 1980, more than 8.3 million equivalent L of gasoline will be saved annually through marketing actions. Approximately 95 percent of these savings are realized in the Tri-State area. It should be emphasized that, for maximum effectiveness,

Table 1. Energy effects of small-scale transit improvements in New York State by category.

Category	Net Energy Savings (L 000 000s gasoline) 1978	1979	1980
Routing and scheduling improvements	1.55	1.49	1.35
Express-bus service	−0.56	−0.56	−0.57
Park-and-ride service	5.41	6.57	7.26
Shuttle-transit service	0.16	0.15	0.13
Passenger amenities	10.68	10.42	14.14
Fare-collection improvements	1.64	1.42	1.37
Passenger-information improvements	2.75	2.94	4.11
Demand-responsive service	−4.45	−4.86	−6.98
Maintenance improvements	1.17	2.40	2.87
Monitoring	0.29	−0.09	−0.53
Marketing	2.41	5.30	8.60
Total	21.05	25.18	31.75

marketing actions should be taken as part of a continuous and ongoing marketing program.

DISCUSSION AND CONCLUSION

Table 1 summarizes the energy effects of 11 transit-related categories of TSM actions in New York State. Total energy savings from transit-related actions amount to 21.0, 25.2, and 31.7 million equivalent L of gasoline in 1978, 1979, and 1980, respectively. According to Federal Highway Administration monthly state gasoline reports, in 1977, gasoline consumption in New York State was 23.5 billion L. In the overall state energy situation, transit-related TSM actions result in annual savings of only 0.1 percent of total gasoline consumption.

There are several reasons for considering the energy savings reported here as conservative projections. First, factors such as energy costs due to construction and maintenance of transit equipment and facilities are included in the calculations; also included are second-order effects such as use of the car left at home. However, potential second-order savings like decreased maintenance requirements for automobiles due to decreased use and the elimination in some cases of the need for a second car in the household are not addressed. In other words, although second-order energy costs are considered fairly thoroughly, second-order savings are not, because the complexities of such calculations are beyond the scope of this paper. In addition, energy savings have been claimed only for new transit riders diverted from driving an automobile, and no credit has been given for current riders who might otherwise divert to the automobile.

A final reason for considering these energy savings as conservative projections is the synergistic effect that can be obtained by packaging actions together. Express-bus service and park-and-ride lots, marketing and passenger information, and passenger amenities and maintenance are examples of complementary pairs of actions. In these and other cases, the effect of the package of actions is greater than the sum of the effects of the individual actions.

In conclusion, minor transit improvements in the eight MPO areas of New York State result in average energy savings of more than 25 million equivalent L of gasoline over the three years 1978-1980. This represents 2.6 percent of total energy consumed by transit in these eight areas. If demand-responsive service is excluded, savings rise to 3.1 percent of total energy consumed by transit. These energy savings are conservative projections. Although minor transit improvements cannot be expected to make a major impact on New York State's energy situation, such improvements can contribute positively to the state's conservation efforts.

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Integrated Transit-Network Model (INET): A New Urban Transportation Planning System Program

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The Integrated Transit-Network Model (INET) is a new Urban Transportation Planning System (UTPS) computer program for analysis of transit systems. Its objectives are to account for the interaction of highway and transit networks, exploit existing highway network data, provide for accurate but simple and inexpensive transit-network coding, provide input for other UTPS programs, furnish useful evaluative reports, and help bridge the gap between systems and operations planning. A small transit network is hypothesized to demonstrate INET's features and explain its assumptions, mechanics, and operation. Special subjects are route layout, cruise and stop delay time, exclusive and mixed rights-of-way, scheduling, and cost and impact estimates. There is a brief discussion of INET's use with real transit and highway data; the results testify to INET's exceptional simplicity and accuracy.

The Urban Transportation Planning System (UTPS) is a set of computerized and manual tools that aid analysis of urban transportation problems; the system was developed and distributed jointly by the Urban Mass Transportation Administration (UMTA) and the Federal Highway Administration (FHWA).

The Integrated Transit-Network Model (INET) is a new UTPS program by means of which planners can study the interaction of transit (bus) service and automobile service on shared rights-of-way. By using available highway network information, INET greatly simplifies coding. It cuts data collection costs and allows the study of more alternatives with no increase in cost.

INET needs only the simplest and most-straightforward network description but produces detailed estimates of service, resources, and impacts. INET writes a file of the transit network for analysis by other UTPS programs that analyze the shortest path, impedance, cost, passenger loading, and other factors.

GOALS AND CAPACITIES

INET's goals are to reveal the interaction of highway and transit systems, exploit existing highway network data, facilitate accurate but inexpensive coding, provide input to UTPS, give planners useful reports, and help bridge the gap between systems and operations planning.

INET unites descriptions of highway and transit systems. Since the transit-system coding references the already-coded highway network, separate maps and data bases are not needed: The transit system simply overlies the highway system.

Therefore, INET coding of existing and planned systems is much faster than the old UTPS separate-network process (1); its simplicity will become apparent in the examples below. The clarity of the new process means that planners can learn it quickly and become versatile with it.

INET's great conceptual benefit is consistency in the highway-transit network, since most public transit consists of buses on street systems in mixed automobile traffic. In such traffic, bus speed is a function of (among other things) automobile speed. Since automobile speed is part of the highway-system description, INET represents both modes and both systems. Since INET's automated treatment of highway-transit interaction supports models of multimodal supply-and-demand equilibrium (2), INET can automatically investigate the impact on transit of changes in the highway system and demand.

INET allows indirect study of those few links on which bus traffic slows automobile traffic. (Now a printed report, this function will soon be automated.)

Since all transit service cannot be represented on the highway network, INET will code exclusive rights-of-way (such as those for rapid rail) separately.

INET brings together traditional systems planning and short-range operations planning. For long-range use, INET analyzes alternatives quickly by using appropriate macroscopic coding. For short-range use, especially promising alternatives (or portions of them) can be studied and more detail can be added. INET computes the time of day or night that a trip on a line will arrive at a particular point, so planners can study multitudes of options and still produce a rough service schedule.

INET accepts existing or proposed schedules, so current service can serve as an analytical baseline. INET can use an existing system description (which includes schedules) to evaluate short-range service modifications.

UTOWN: INET CODING SCHEME

In the hypothetical Utown, the central business district (CBD) abuts on a lake and is separated from the rest of the region by a river. The arterial street system is simple, and a north-south freeway runs west of the CBD.

Coding Utown's Highway Network

A UTPS highway network is coded for Utown (Figure 1). The five transportation-analysis zones are numbered 1 through 5. The network is highly aggregated, so only arterials and the freeway are coded explicitly. Each coded link stored in the network file contains information such as the A node and the B node, the distance, the number of directional lanes, the automobile travel time, and the type of link facility and link area. Automobile speeds are estimated on each link by equilibrated (capacity-restrained) traffic assignment of peak automobile trips to the Utown highway network. These speeds can be directly estimated by the planner and input on highway-link data cards.

Example 1: Preliminary Route Layout

Utown citizens want a new bus route, the Green Hornet, between the western suburbs and the CBD (Figure 2). Note in Figure 2 that the inbound route starts at highway node 127, mixes with automobile traffic through nodes 108, 126, and so on, and terminates at node 102. The outbound route is the reverse. Also, note that there are bus stops at nodes 127, 124, 103, and 102 to serve zones 4, 2, and 1. The proposed headway is 20 min.

The preceding information (the minimum data needed to describe a line) is input to INET with appropriate key words on an &ROUTE card; at least one &ROUTE card is used for each line. (The use of more than one &ROUTE card is introduced in the section entitled "Further Examples.")

The coded &ROUTE card for the proposed bus line would be set up as follows:

```
&ROUTE M = 4, L = 10, H = 20, N = -127, 108, 126,
   -124, 123, -103, 122, 119, -102, &END.
```

There may be as many as 1200 &ROUTE cards to describe the lines in a network. A card may be more than one card image in length, like all UTPS control cards. &ROUTE cards follow the general UTPS coding conventions (3).

A line is identified on the &ROUTE card by a mode number (M) and a line number (L). M ranges from 4 to 8, and L can range from 1 to 255. In the example above, the mode is specified as 4 (M = 4), the line number as 10 (L = 10), and the headway as 20 min (H = 20).

The line's route appears as a sequence of node numbers (N) present in the highway network. Adjacent nodes imply a link. From the sample &ROUTE card shown above, . . ., 126, 124, 123,. . . implies two links: 126 to 124 and 124 to 123. Those nodes where passenger activity occurs (e.g., bus stops and stations) carry a minus sign. In this line description, a bus stops only at nodes 127, 124, 103, and 102. The other nodes only specify the route.

If the running-time calculation (described later) is adequate for planning, only four key words (M,L,H,N) need be coded to describe a line. Other key words and data could complement these four key words (as described elsewhere).

INET OUTPUTS, CALCULATIONS, AND CODING DETAILS

With only the information from an &ROUTE card such as that just described, INET produces a detailed route description (Figure 3). A look at this description reveals several of INET's functions.

The "Headway" section has the values Nominal, Maximum, Factor, and Actual. If an Actual headway (H) is not coded, INET calculates the best headway between a given nominal headway (NH) and a maximum headway (MH). The headway value Factor (FH) is optional. H is the actual fixed time in minutes between servicings by vehicle crews. If H is coded, the other three parameters are not, and INET cannot adjust the headway. Not coding H and coding NH and MH instead lets INET adjust the headway for more-efficient or more-productive service.

NH is a rough estimate of the minutes between servicings by vehicle crews and lets INET calculate a revised headway.

MH is the upper bound to which INET can adjust NH to conserve a vehicle crew. The UTPS transit-assignment program ULOAD uses MH to revise a headway for ridership at a peak load point. ULOAD never calculates a headway greater than the specified maximum. Hence MH can be called a policy or courtesy headway.

FH is a time specified to ensure headways that correspond to clock times or to synchronize line schedules with a common transfer point. When FH is present, NH and MH must be multiples of it; headways revised by INET will be multiples of FH. For example, if FH = 10, the calculated headway is constrained to multiples of 10 min.

The value listed after "Vehicle-Crews" is the number of crew units needed, computed from headway, layover time, and running time. The heading "Capacity" for the line (in passengers per hour) is the actual headway divided into a user-specified vehicle capacity ("Pass/Veh," see Figure 3).

Under the heading "Company," there is a user-specified integer between 1 and 99 used by INET in summary reports. It lets the user group lines

Figure 1. Utown highway network.

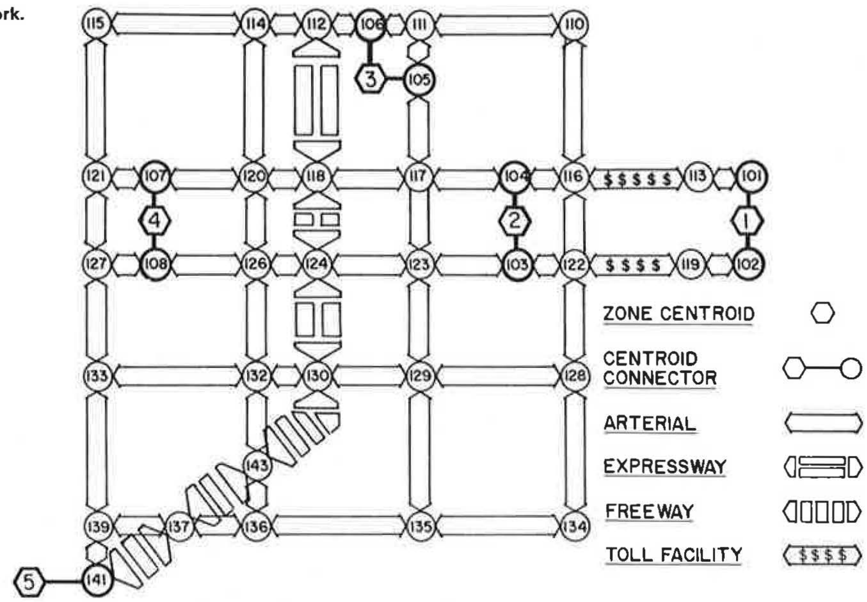


Figure 2. Green Hornet transit line.

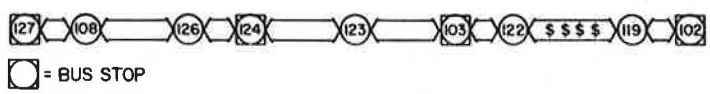


Figure 3. INET Report 8: detailed route description.

```
M O D E   4    L I N E   10

----------HEADWAY---------- VEHICLE-CREWS:      8            COMPANY:  1
NOMINAL:  0.0  FACTOR:  1.0 CAPACITY (PPH):   150          TECHNOLOGY:  1
MAXIMUM: 60.0  ACTUAL: 20.0 PASS/VEH:  50,  MIN LAYOVER:  3.0 MINS,   0%

---------READ DOWN (TRIP  1)---------  --------READ UP (TRIP  1)-------
------ROUTE------- -------LINK-------  ----ROUTE---- -------LINK-------
NODE TIME  DIST SP TIME  DIST SP DS W  TIME  DIST SP TIME  DIST SP DS W
---- ----  ---- -- ----  ---- -- -- -  ----  ---- -- ----  ---- -- -- -
 127 0800                              0853 10.60 12  4.9  1.40 17  0 0
 108        1.40 17  4.9  1.40 17  0 0        9.20 11  4.6  1.60 21  0 0
 126        3.00 18  5.2  1.60 18  0 0        7.60 10  6.5  1.00  9  0 0
 124 0817   4.00 14  6.6  1.00  9  0 0  0837  6.60 11  9.0  2.00 13  0 0
 123        6.00  9 22.5  2.00  5  0 0        4.60 10  8.7  1.20  8  0 0
 103 0850   7.20  9 11.0  1.20  7  0 0  0820  3.40 10 10.4  1.80 10  0 0
 122        9.00  8 13.6  1.80  8  0 0        1.60 10  1.0  0.0   0  0 0
 119        9.00  8  1.0  0.0   0  0 0        1.60 12  8.2  1.60 12  0 0
 102 0926  10.60  7 21.2  1.60  5  0 0  0800

FIRST TRIP:                     0800.0                            0800.0
LAST TRIP:                      0900.0                            0900.0
TRIPS:                               4                                 4
ROUTE MILES:                      10.6                              10.6
RUN TIME (MINS):                  86.0                              53.1
LAYOVER (MINS):                   14.0                               6.9
TRIP TIME (MINS):                100.0                              60.0
% LAYOVER:                          13                                11
'COST' INDEX:                     3143                              1891

AREA TYPE        1    2    3    4    5         1    2    3    4    5
CODED ST/MI    0.6  0.3  0.3  0.0  0.7       0.6  0.3  0.3  0.0  0.7
SDT FACTOR     8.0 12.0 12.0  1.0  4.2       8.0 12.0 12.0  1.0  4.2
```

with site-specific, administrative, or other significance (e.g., garage, service corridors, and traditional transit lines).

Under "Technology," there is an integer between 1 and 8 that allows the user to associate a set of impact rates (energy or fuel consumption and pollutant emission) with each mode. These rates are applied for the appropriate mode to vehicle-crew miles to estimate aggregate system values for energy consumption and pollutant emission. (These values operate in another INET report that is discussed under the heading "Further Examples.")

The minimum layover ("Min Layover") is the greater of two user-specified parameters: a number of minutes or a percentage of running time. Values may be specified by line on an &ROUTE card or defaulted on an &PARAM card that provides mode-specific default values.

The line is reported for both directions. In Figure 3, "Read Down" displays the links from left to right on the &ROUTE card. "Read Up" displays them from right to left. Under these headings, there are two subheadings, "Link" and "Route."

Transit-Link Speed

The most-important link information in Figure 3 is probably the transit-link speed (SP), a value calculated from highway speeds, transit-vehicle performance, and delay from passenger service stops. In determining a line's speed, INET uses various parameters; these include the type of right-of-way, known as the way type (W). W is coded on the &ROUTE card as one of four values:

1. W = 0, transit in mixed automobile traffic (default);
2. W = 1, transit on reserved lane or lanes;
3. W = 2, transit on contraflow lane or lanes; or
4. W = 3, transit on exclusive guideway.

Since INET's default value is W = 0, there is rarely need to code W. INET infers the cruising speed of a transit vehicle from the average automobile speed on the shared link. INET's simple transit-speed model assumes that a link time is the sum of the vehicle's cruising time along the link plus a stop delay time. Cruising time is the time the vehicle takes to traverse the link with no stop at either node. Stop delay time accounts for slowing down, stopping, and starting up at the A node or the B node.

Cruising Time

The calculation of transit cruising time is automatic and straightforward; it varies with W and with area type. For transit in mixed traffic (W = 0), the cruising-speed calculation uses a highway-transit speed conversion function and the highway speed on the network description (HR). HR derives from a UROAD (equilibrium) traffic assignment or is manually specified for the highway link as an estimated speed. The calculation uses a simple piecewise linear relationship to translate highway-link speed to transit-link speed. INET has one such function for each mode (M = 1-8) and highway-link area type (1-5). INET's user may change any of the 40 functions (eight modes multiplied by five area types) to reflect site-specific performance by using speed-function update cards.

To calculate a link's transit cruising time, INET first enters the highway-transit speed function with the link's highway speed (from the network file) to obtain the transit cruising speed. For mixed traffic (W = 0), INET uses the congested or estimated highway speed. For transit running on a reserved (W = 1) or contraflow (W = 2) lane, the speed is that of free-flowing automobiles. Given the cruising speed, INET obtains the cruising time by dividing the speed into the link distance from the network file ("Dist" column in Figure 3).

For transit running on an exclusive guideway (W = 3), INET calculates cruising speeds in the same way as for a reserved or a contraflow lane. However, if the link is not in the highway network, INET calculates the distance for an exclusive guideway link from the XY-coordinates of the nodes present in the network data base. If the link is in the network, INET uses coded highway distance. Since an exclusive guideway is rare, it is normal to specify line speed on the &ROUTE card, as described in Example 3 in the section "Further Examples." INET can also input special transit links with speed or distance information, as described in Example 4 in the same section.

Stop Delay Time

Stop delay time (SDT) is added to a link whenever the link has a stop at the A node or the B node. SDT is the sum of dwell time and acceleration and deceleration time. INET finds the dwell time (in minutes) in a table it has indexed by the line's mode (M) and the link's area type. The acceleration (deceleration) time is calculated from the vehicle acceleration rate (in miles per hour per second) from the same table and the cruising-speed profile. The dwell time and acceleration table provide default values, which may be overridden.

It is important that SDT calculations reflect aggregation in network coding. If one coded stop in the network represents five actual bus stops, the computed SDT must be five times the average per-stop delay. SDT can be modified by a stop density factor, also tabulated by mode and area type. Supplied by the INET user, the stop density, in actual stops per mile, is used to represent the true number of stops automatically.

If INET's method of link-time calculation is inappropriate, overriding values can be used in line descriptions. The two key words are speed (S) and SDT. Any &ROUTE card's S or SDT may be values the user wishes INET to associate with all line (or line-segment) links. (See Example 4 in "Further Examples.")

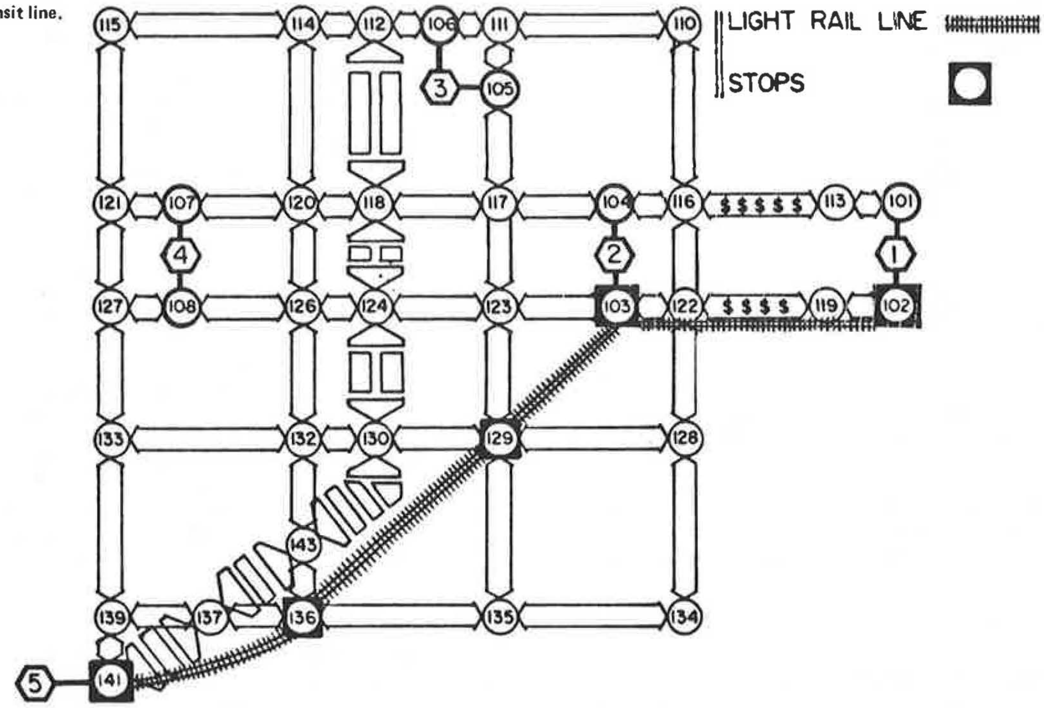
Under the heading "Route" in Figure 3 there are four columns: "Node," "Time", "Dist," and "SP." "Node" describes the line's route through the highway network as given with the node-sequence key word (N) on the &ROUTE card. "Time" shows the estimated clock times at which one trip will reach each stop (discussed below). "Dist" is the cumulative distance in miles. SP values are the cumulative average speed of the vehicle on the line along the route, which is based on bus running speed and SDT.

Nontransit Links

The final element needed to describe the line is supporting nontransit links (e.g., walk links or automobile connector links) that connect transit service with zone centroids (1). For the line in Figure 2, there are walk connector links from 4 to 108, from 2 to 103, and from 1 to 102 (where 4, 2, and 1 are the zone centroids shown in Figure 1). INET specifies nontransit links in the same way that it does transit lines: The &ROUTE card references the highway network, and links are described in the node sequence (N).

For Example 1, the nontransit links would be

Figure 4. Light Flash transit line.



described as follows [the key words for nontransit links are mode (M), link group (LG), node (N), and way type (W)]:

&ROUTE M = 1, LG = 1, N = 2, 103, -1, 102 &END.
&ROUTE M = 1, LG = 2, N = 4, 127, W = 3 &END.

N gives a node sequence in which adjacent numbers mark links, but links with a negative B node are not included. In the example above, node 127 is not connected to node 2, and 103 is not connected to 1. Thus, three separate mode-1 links are described: 4 to 127, 2 to 103, and 1 to 102.

INET calculates non-transit-link times in the same way that it does transit-link times. Cruising time is a function of a speed dependent on mode and area type. (There is, of course, no SDT.)

FURTHER EXAMPLES

Example 2: Expanded Line Information

Suppose that the proposed line in Example 1 is analyzed further by means of UTPS software and that demand estimates show it to be feasible. A more-detailed service study is now required: time of operation, vehicle crews, and a first attempt at scheduling.

The line (Figure 2) will run from 8:00 a.m. to 9:00 a.m. daily. The scheduling department reports that the minimum layover time at the end of a run is 10 min or 10 percent of trip time, whichever is longer. With only these data, INET can estimate additional vehicle crews needed and make a first attempt at scheduling.

This information adds three key words to the &ROUTE cards for the line--"Period," "Lay," and "LPC" (explained below):

&ROUTE M = 4, L = 10, H = 20.0; Period = (0800, 0900);
LAY = 10.0; LPC = 10; N = -127, 108, 126, -124, 123, -103, 122, 119, -102 &END.

"Period" specifies a service period with two numbers--the time that the first run begins (8:00 a.m.) and the time that the last run begins (9:00 a.m.). This period is used (with trip calculations) to print out the first run's arrivals at each stop (i.e., a partial line schedule or headway sheet).

Minimum layover (Lay) is used to calculate the vehicle crews needed to serve the line at a given headway. Here, Lay = 10.0. The percentage of running time (LPC) sets the minimum layover at 10 min or 10 percent of the running time, whichever is greater.

INET Report 8 (Figure 3) displays the detailed description of the line M = 4, L = 10. Note that the clock time of the first run's arrival at each stop appears in the "Route-Time" column. The time at node 127 is 8:00 a.m., the time at node 124 (the next stop) is 8:17 a.m., and so on. These times are computed from bus running time and SDT, as described earlier.

Computation of a total, rough operating cost index for the time period is based on up to three factors: vehicle-crew miles, hours, and units.

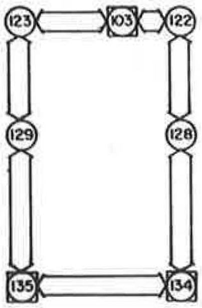
The report shows that eight vehicle crews are needed at a headway of 20 min, calculated from headway, line running time, and minimum layover time.

INET defines two-way bus lines as (a) moving symmetrically in both directions in the node sequence N shown on the &ROUTE card, (b) having the same headway in both directions, and (c) being served by the same vehicles in both directions. INET synchronizes outbound departure times and the inbound linking trip. The result will be less than or equal to the number obtained by treating each direction separately, estimating vehicles for each, and adding the two.

Example 3: Varying Way

More than one &ROUTE card is used to describe a transit line with varying way type (W). As in Figure 2, the line will use normal streets and a contraflow lane, and a high-occupancy-vehicle (HOV) lane is proposed for the Utown freeway. The HOV

Figure 5. Blue Loop transit line.



lane would serve only buses and carpools at peak periods with limited stops. The line can be coded as follows:

```
&ROUTE M  = 4, L = 40, H = 30; Period = (0700, 1000);
  N = -106, 112 &END.
&ROUTE M = 4, L = 40, N = 112, 118, -124, W = 2
  &END.
&ROUTE M = 4, L = 40, N = -124, 123, -103, 122, 119,
  -102, W = 3 &END.
```

Note that three &ROUTE cards are needed due to the change of way type from local streets (W = 0, default), to contraflow (W = 2), and to HOV lane (W = 3). Nominal line characteristics (such as headway, layover time, and time period) need be specified only on the first &ROUTE card for that line.

Example 4: Exclusive Guideway

As shown in Figure 4, a light rail transit (LRT) line is proposed from the southwestern suburbs along an abandoned rail right-of-way to the CBD. Some of the rail right-of-way follows highway links, but some of the proposed LRT guideway follows no existing street segment. INET readily accommodates the latter condition, either with link data cards or directly with &ROUTE cards. The &ROUTE cards are by far the simplest way to code exclusive guideways due to availability of highway nodes.

Link Specification by Using &ROUTE Card

Transit links not in the highway network may also be input on &ROUTE cards, given three constraints: The nodes must be in the highway network if XY-coordinates are needed to calculate distance, the way type of the &ROUTE card segment on which the link appears must be exclusive guideway (W = 3), and the transit speed must be coded either on the &ROUTE card or on the &PARAM card.

Grade-separate fixed-guideway transit is rare (and special coding can usually be input with &ROUTE cards), so these coding conventions are not restrictive. In fact, coding routes on a fixed guideway is usually simpler than it is for transit on the normal highway network. Fixed guideways generally run parallel to street segments.

Figure 4 shows that, in coding the line, only &ROUTE card coding is used, because LRT vehicle speed can be directly estimated and coded and highway-network coordinates are accurate enough for distance estimates. If we assume that the guideway is straight between nodes, the LRT line is easily coded:

```
&ROUTE M = 6, L = 1, H = 5.0, W = 3, S = 40; SDT
  = 1.0; N = -141, -136, -129 &END.
&ROUTE M = 6, L = 1, W = 3, S = 30; SDT = 1.5;
  N = -129, -103, 122, 119, -102 &END.
```

Separate &ROUTE cards are used even though the way type does not change, due to changes in running speed (40-30 mph) and SDT (1.0-1.5 min) from the suburban to the urban part of the line. Each &ROUTE card implies a consistent level of service, whether it is the same way type, the same speed or SDT, or both for all links on the card.

Optional Transit-Link Data Cards

INET users will rarely need link data cards, but they may override or augment data in the highway network according to mode.

These cards can also describe fare structure. A fare code is used as an index to a fare table (in UPTS program UPATH) of modal link-specific fares, such as fare zone charges. These codes correspond to the modes coded on the card. A direction code indicates a two-way link whose impedance and fare code in the A-B direction are identical to those in the B-A direction.

Impact Estimates

INET generates energy and pollution indexes based on technology-specific impact rates. These technology codes are mode-specific indexes keyed to INET's table to energy and pollution impact rates for eight modes. The user may modify any or all of INET's rates with update cards. These rates (based on vehicle-crew miles) describe energy consumption and pollutant emission by mode and way type in INET Report 13. This simple flat-rate model ignores the effects of speed variation and deadheading.

In Figure 4, note that links 141 to 136, 136 to 129, and 129 to 103 show on the LRT route, even though they are not coded in the highway network. This is because they were coded as W = 3 on an &ROUTE card: Their distances will be computed from XY-coordinates.

INET writes a transit-network file for input to UPATH and ULOAD. Planners may perform the entire demand estimation and system evaluation of a system coded for INET by interfacing with the rest of UTPS. The network file for the LRT line, feeder lines, and supporting nontransit links could be produced for path finding and transit-impedance estimation with UPATH and UPSUM. These impedances could be used in a demand estimation that projects LRT patronage. Patronage estimates could then be assigned to the LRT binary network description with ULOAD and planning evaluations made with the outputs. Therefore, INET supports long-range system planning by using a coding scheme that makes it easy to represent both fixed-guideway alternatives and bus transit.

Example 5: Operations Planning

This example shows INET investigation of a new loop bus route to Utown. Figure 5 shows the route (M = 4, L = 30)--the Blue Loop--that provides coordinated transfers at node 103.

Arrival times are specified with the stop-time (ST) key word. ST overrides stop arrival times calculated by INET and displayed in INET Report 8 (Figure 3). The ST key word is a series of three numbers--a stop-node number followed by two 24-h clock times. The first clock time is that at which the left-to-right (reading the node sequence N) direction of the line passes that stop node, and second is that time at which the right-to-left direction of the line passes the same node. For

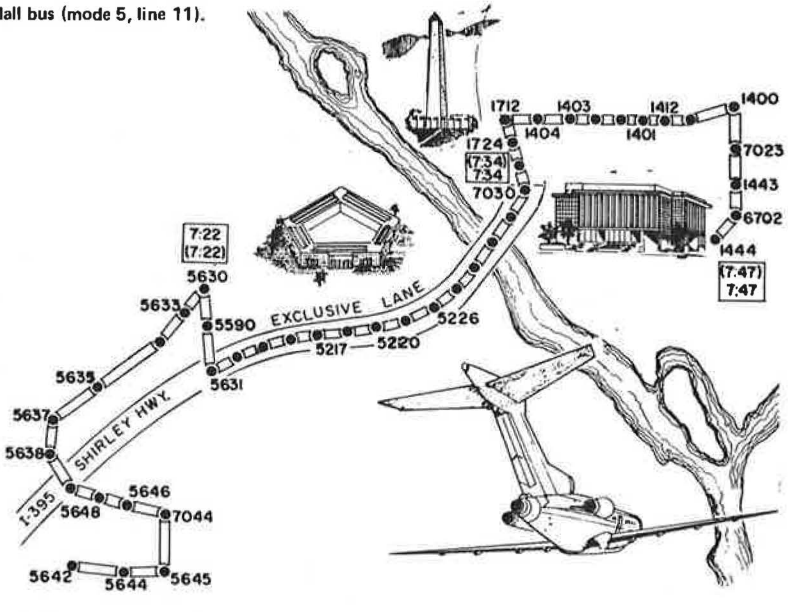


Figure 6. Route map for S.W. Mall bus (mode 5, line 11).

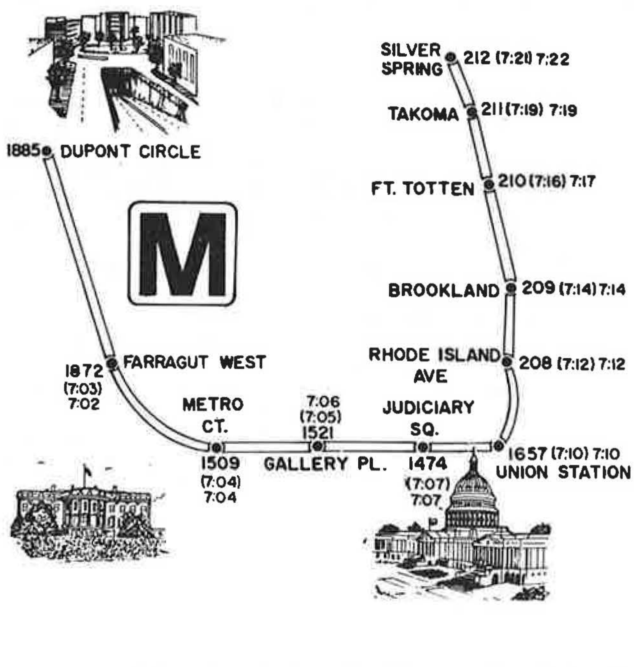


Figure 7. Route map for Metro Red-Line subway.

example, if for M = 4, L = 30 (Figure 5), stop node 103 had an outbound arrival at 8:00 a.m. and an inbound arrival at 8:30 a.m., the coding would be as follows:

```
&ROUTE M = 4, L = 30, H = 10; Period = (0700,
  0930);
N = 123, -103, 122, 128, -134, -135, 129, 123;
  ST = 103, 0800, 0830 &END.
```

PLANNING APPLICATIONS

Transit-System Planning

System planning usually looks toward a horizon 5-15 years away and reviews many alternatives. Since highway networks are usually coded for future years, many alternatives can be coded quickly and easily by INET with the network data base.

Another INET advantage for long-range planning is the use of highway automobile speed to determine transit speed. For all non-grade-separated transit, vehicle speed is a direct function of the speed of the surrounding automobile traffic. INET's computation of transit running speed has improved patronage estimates because service variables are more accurately assessed and reflect changes in the highway system. The more-refined calculations of running speed bring more-accurate resource estimates of vehicle crews, hours, and miles.

INET assists long-range planning with reports that distinguish and differentiate the characteristics of alternatives. In addition to the detailed line report (INET Report 8) used in the examples, other evaluative reports offer planners important guidance and insights before they begin expensive patronage forecasting.

The link report of number of transit vehicles per hour summarizes the volume on highway links by mode and way type. When modes share a line with the same way type, a summary line is produced that gives the number of vehicles per hour. This is useful in gauging the impact of transit vehicles on highway-system performance and might be important in a congested CBD.

The service summary report summarizes line miles, average miles per hour, and vehicle miles of travel (VMT) by way type and mode. It describes systemwide service for estimation of impact and cost and for documentation of differences among service alternatives.

The line summary report gives line information by mode from INET Report 8, as well as mode totals of various line statistics.

The resource-requirements report summarizes need for vehicle-crew units, hours, miles, and cost by company code and mode.

Finally, the impact summary report summarizes energy and pollution impacts by mode and way type.

Transit-Operations Planning

Transit-operations planning is short-range analysis (up to five years) of system modifications and improvements. Typically, alternatives are not capital intensive but involve route modifications, additions, or deletions.

Again, INET's simple coding scheme and use of the highway network let planners test a variety of proposed service changes. Since changes are usually perturbations of existing service, INET's acceptance of known service schedules is an important feature.

After an alternative is selected, INET will make a first attempt at scheduling and estimate the resources required.

INET is merely a first link to operations planning. A major effort is underway to provide the special software needed for scheduling and operations analysis. Already INET allows the transit system to be further analyzed in UTPS according to system accessibility (UMATRIX, UMODEL) and station requirements (USTOS) (4).

EXPERIENCE WITH INET

Is INET as quick and easy as is claimed? Can these simple default models produce accurate transit-link times? The answer is an unequivocal and heartening "yes." The reassurance comes from research and development at UMTA, where INET is used with real-world data from the Washington, D.C., Metropolitan Council of Governments.

The most-complicated case has been the development of a network data base for existing transit service in the Shirley Highway Corridor. Of modest size, it includes 167 zones, 2700 links, 50 transit routes, and 2 subway lines. The time spent in coding the Shirley Corridor network is divided as follows:

1. Add data to highway-network file where necessary and check out and debug to obtain complete highway-system description to satisfy INET's requirements. Time: 24 person hours.
2. Code and debug route cards. Time: 45 person hours.
3. Run INET, analyze transit speeds, and update cruising-speed and dwell-time tables where necessary. Time: 20 person hours.

Thus, coding takes less than 90 person hours by a young, inexperienced engineer; the second time, he or she should take about half that length of time. Coding a new alternative by adding to or deleting from existing service would require less than one day.

As for INET's accuracy, the results were amazing. Because an existing service was coded, INET's estimates of transit travel times could be compared with printed schedules. Every estimated run time was within 5 percent of the schedule, many were precisely on the mark, and most were within 1 min.

Figure 6 is a route map that shows a bus route through 44 nodes, the middle 14 of which are on the exclusive HOV lane on Shirley Highway (Interstate 395). The remaining 30 nodes are roughly split between the Virginia suburbs and downtown Washington. When time checks were made on entering and exiting the exclusive lane and at the downtown end of the line, at all three points INET times coincided exactly with the scheduled times.

Figure 7 depicts a Washington, D.C., Metro subway line. Comparing Metro schedules with INET output shows that no INET time is more than 1 min different from Metro's. These concurrences are the rule rather than the exception and reinforce the satisfaction with INET's performance.

Those who wish more information on the INET program may obtain a book on the subject from UMTA (5).

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Value of Urban Transit Operating-Cost Models as Forecasting Tools

JAMES D. ORTNER

Eight urban transit operating-cost models were reviewed to determine their value as forecasting tools. The models were found to have structural problems. In the average-daily-cost model and annual-cost model, the association of inputs with outputs was assumed to have a strong positive correlation. Case-study transit system data were used to test these relationships. The findings indicate that these two models were not reliable because strong positive

correlations existed in too few of the expected relationships. The eight models were not designed to include variables that measure the influence of institutional factors on operating costs. The necessity to subsidize transit operations has led to increasing involvement of the public sector in transit operating decisions. Planners are advised to refrain from relying totally on any of the eight models for estimation of operating costs. Such additional techniques should be considered as developing probabilities of changes in cost categories and generating alternate scenarios of operating conditions.

Traditionally, urban transit operating-cost models have been used in three ways--to explain and predict variation in expenditures among different public transit systems that operate similar services, to explain and estimate trends in expenditures of individual transit systems, and to compare costs of different modes (such as buses on freeways versus rail transit). This paper will examine only the first two uses of cost models. Examples of the third type can be found in studies by Boyd and others (1); Meyer, Kain, and Wohl (2); Vuchic and Stanger (3); and Lee (4), who refers to 23 articles on this particular subject.

Eight operating-cost models are presented in the following discussion: average-daily-cost model, annual-cost model, slowness model, urban-environment-cost model, Holthoff model, Merewitz model, cost-per-vehicle-hour model, and total-operating-cost model. These represent the recent thinking on the subject of measuring operating costs. This paper focuses on the value of these eight models as forecasting tools, which is an issue of current concern among transportation planners who are responsible for informing public officials of the future operating costs of proposed or on-going programs.

A review of the eight models finds structural deficiencies that diminish their value as forecasting tools. The average-daily-cost and annual-cost models associate specific inputs with specific outputs. The rationale for this association is that correlations indicate strong positive relationships. However, an examination of correlations of data from several case-study transit systems indicates that these models are not reliable. Strong positive correlations existed in only a few of the relationships.

A major weakness of the other models reviewed in this paper is their failure to recognize the influence of institutional factors on operating costs. The changeover from private to public ownership of public transportation has brought local, regional, state, and federal officials into the process of determining the type and level of transit service. Quantifying the past actions of public officials is at best a difficult task. Forecasting their future behavior toward transit seems clearly impractical.

This paper concludes by suggesting that two other techniques for estimating future operating costs be researched further--development of probabilities of changes in cost categories and generation of scenarios of future operating conditions.

MODELS OF INDIVIDUAL TRANSIT SYSTEM OPERATING COST

Two models are reviewed under this category--average daily cost and annual cost.

Average-Daily-Cost Model

This model was developed by Ferreri (5). Unit operating costs for an entire system or route are illustrated as follows:

$$C = x_1 VM + x_2 VH + x_3 PR + x_4 PV \quad (1)$$

where

- C = average daily operating cost of route or system (dollars);
- x_1 = expenses associated with the number of miles over which revenue vehicles operate, maintenance, and garaging;
- x_2 = expenses associated with the number of hours during which revenue vehicles operate, operator wages, and fringe benefits;
- x_3 = expenses associated with the amount of passenger revenue collected, accidents, and liability;
- x_4 = expenses associated with the size of the peak-period fleet, administration, and storage areas;
- VM = average daily vehicle miles of service of the specific route or system being analyzed;
- VH = average daily vehicle hours of service of the specific route or system being analyzed;
- PR = average daily revenue of specific route or system being analyzed (dollars); and
- PV = peak vehicle needs on specific route or system being analyzed.

Ferreri used Equation 1 to estimate the operating cost of each route as well as that of the overall Miami, Florida, transit system. He concluded from his research that (5)

> For long-range planning projections a simplified operating cost formula using only vehicle miles and vehicle hours is more than adequate and probably desirable because of the need to estimate only for miles and hours of service on each route. On the other hand, for short-range service improvements and fiscal planning, a more-accurate allocation formula such as the four-variable method is appropriate.

Contrary to Ferreri's conclusions, his model and the annual-cost model reviewed in the next section are not reliable forecasting tools.

Annual-Cost Model

The format used in the annual-cost model was developed by W.C. Gilman and Company, Inc., and Alan M. Voorhees Associates (6) to project operating costs of the bus-system element of an integrated Washington, D.C., rail-bus system. Roess and others (7,8) extended this analysis to rail-transit systems.

As in the average-daily-cost model, inputs are associated with one of four outputs. Levine (9) notes that the annual-cost model has many similarities to the average-daily-cost model. Both models assume a linear equation and apply similar methodologies to the issues. One major difference is the use of annual revenue passengers rather than average daily passenger revenue.

Total operating cost is shown as follows:

$$C = x_1 VM + x_2 VH + x_3 PV + x_4 RP \quad (2)$$

where

- C = annual operating expense,
- x_1 = unit cost of vehicle-mile-associated expenses,
- x_2 = unit cost of vehicle-hour-associated expenses;
- x_3 = unit cost of peak-period fleet-associated expenses,
- x_4 = unit cost of revenue-passenger-associated expenses,
- VM = annual system vehicle miles,

VH = annual system vehicle hours,
PV = size of peak-period fleet, and
RP = annual revenue passengers.

Both the average-daily-cost and the annual-cost models are based on the assumption that the specific inputs and outputs shown below have strong positive correlations (R = rail; B = bus):

Input	Output and Mode
VM	Maintenance of way and structure (R)
	Maintenance of equipment (R)
	Maintenance (B)
	Power (R)
	Fuel (B)
VH	Direct operations (B,R, or both)
	Fringe benefits (B,R, or both)
	Social Security (B,R, or both)
PV	General and administrative costs (B,R, or both)
	Advertising (B,R, or both)
	Station (B,R, or both)
RP	Liability insurance (B,R, or both)

Data from four case studies were analyzed to determine whether the relationships listed above could be verified empirically. The four transit districts used as case studies were Southern California Rapid Transit District (SCRTD); Alameda-Contra Costa Transit District (AC Transit); San Francisco Municipal Railway (Muni); and Chicago Transit Authority (CTA). The Statistical Package for the Social Sciences was used to calculate the correlations between input and output variables. Input data for the four case studies were correlated by using deflated 1967 dollars.

Findings illustrated in Tables 1-4 reveal that the strong positive correlations assumed in the average-daily-cost and annual-cost models existed in only a few of the relationships. For example, for SCRTD over an 11-year period, vehicle hours had strong positive correlations with every input variable.

A major weakness of the models is their failure to consider systems such as Muni and CTA whose costs during the analysis period escalated while output declined. For Muni, the strongest positive relationship was between the input for power and fuel and revenue patronage (0.7083). For CTA, the strongest positive correlation was between injury-and-damage expenses and revenue patronage (0.3674). These findings suggest that the models are not reliable for forecasting expenditure trends.

An interesting finding from the correlation analyses is that direct operations correlates more strongly with vehicle mileage than with vehicle hours. Since most transit workers are paid hourly and work in direct operations, it would seem likely that changes in the value of direct operations would correlate more strongly with changes in vehicle hours than with changes in vehicle mileage.

MODELS OF COST PER VEHICLE MILE

Four models of operating cost per vehicle mile are reviewed: the slowness, urban-environment-cost, Holthoff, and Merewitz models. All inputs are expressed in terms of cost per vehicle mile rather than in four categories as was the done with the two models just discussed, because (10)

> It is generally good practice to model costs or resources on a per-vehicle-mile or per-vehicle-hour basis in order to reduce the problem of unequal variation (heteroscedasticity) from one observation to the next. For example, the difference in dollar expenditures on vehicle maintenance between two large firms may be great in absolute terms but rather modest when expressed in cost per mile.

Slowness Model

The slowness model was developed by Miller and Holden (11). It is based on the premise that vehicle miles operated and vehicle hours operated are the two most important determinants of operating costs. These two variables are combined by dividing vehicle hours by vehicle miles to form a ratio called slowness (vehicle hours/vehicle miles). Levine (9) comments that the slowness model is derived down from Ferreri's (5) average-daily-cost model. The variables in the Ferreri model that relate to peak vehicle needs and passenger revenue are dropped in the formulation of the slowness model because they are a function of the slowness variable. The final form of the slowness model becomes

$$C = a + bS \quad (3)$$

where

C = cost per vehicle mile,
a = those operating inputs associated with vehicle miles divided by total vehicle miles for the time period analyzed, and
S = total vehicle hours x 60 for the time period analyzed divided by total vehicle miles for the time period analyzed to yield minutes per vehicle mile--the slowness variable.

Can the slowness model be used to estimate future operating costs? It was noted earlier that two variables found in the average-daily-cost model--size of peak-period fleet and passenger revenue--are a function of the slowness variable. However, vehicle miles and vehicle hours remain in the function. Correlation analyses of output variables from the four case-study transit systems are illustrated in Tables 5-7. The findings highlight a strong positive correlation between vehicle miles and vehicle hours. The results could be severely distorted by forming a function of two variables that have a correlation greater than 0.95. This outcome casts doubt on the practice of calculating the slowness variable rather than expressing all costs as a function of either vehicle miles or vehicle hours. The slowness model is therefore not recommended for forecasting future operating costs.

Urban-Environment-Cost Model

Miller (12,13) developed the urban-environment-cost model. It was later expanded by Foster (14) and Veatch (15).

Miller (13) hypothesized that managerial efficiency (controlling factor prices and output) alone does not account for the wide range in operating costs among different transit systems and that bus operating costs are a function of a city's setting (schedule speed, intensity, and city age) as shown in the following equation:

$$C = a + b_1 VM + (b_2 1/VM) + b_3 A + b_4 W + b_5 SS + b_6 I + b_7 CA + u \quad (4)$$

where

C = operating cost per vehicle mile,

VM = million vehicle miles per year,
1/VM = 1/million vehicle miles per year,
A = average age of bus fleet,
W = maximum wage rate,
SS = schedule speed (total annual vehicle miles/total vehicle hours),
I = intensity (total annual vehicle miles/number of route miles served), and
CA = city age (0 = old city, i.e., a city that did not meet conditions listed below, and 1 = new city, i.e., a city that had grown at least 200 percent in population from 1920 to 1960 and at least 68 percent from 1940 to 1960).

Table 1. SCRTD correlation matrix for 1966-1976.

	VM		VH		PV		RP	
Input	Coefficient	Significance Level	Coefficient	Significance Level	Coefficient	Significance Level	Coefficient	Significance Level
Maintenance	0.9919	0.001	0.9899	0.001	0.9081	0.001	0.8946	0.001
Fuel and oil	0.9328	0.001	0.9366	0.001	0.6855	0.014	0.9786	0.001
Direct operations	0.9856	0.001	0.9745	0.001	0.9339	0.001	0.8438	0.001
Pension and medical	0.8723	0.001	0.8672	0.001	0.9744	0.001	0.6261	0.026
Social Security	0.9508	0.001	0.9288	0.001	0.9577	0.001	0.7758	0.004
General and administrative costs	0.9536	0.001	0.9531	0.001	0.9642	0.001	0.7908	0.003
Advertising	0.9157	0.001	0.8772	0.001	0.8781	0.001	0.7914	0.003
Station	0.9660	0.001	0.9456	0.001	0.9265	0.001	0.8081	0.002
Insurance	0.9456	0.001	0.9298	0.001	0.8946	0.001	0.8439	0.001

Note: VM, VH, PV, and RP are as defined in Equation 2; N = 10.

Table 2. AC Transit correlation matrix for 1961-1977.

	VM		VH		PV		RP	
Input	Coefficient	Significance Level	Coefficient	Significance Level	Coefficient	Significance Level	Coefficient	Significance Level
Maintenance	0.9819	0.001	0.9203	0.001	0.8958	0.001	0.6955	0.001
Fuel and oil	0.8308	0.001	0.7908	0.001	0.7399	0.001	0.6169	0.004
Direct operations	0.9653	0.001	0.8733	0.001	0.9421	0.001	0.6091	0.001
Welfare and pensions	0.9315	0.001	0.8719	0.001	0.8759	0.001	0.6276	0.003
Social Security	0.7455	0.001	0.7211	0.001	0.6940	0.001	0.6173	0.004
General and administrative costs	0.8695	0.001	0.7495	0.001	0.8775	0.001	0.4576	0.032
Station	0.7170	0.001	0.5656	0.009	0.8615	0.001	0.2701	0.147
Advertising	0.7319	0.001	0.6516	0.002	0.8236	0.001	0.3986	0.056
Insurance	0.5492	0.011	0.5313	0.014	0.5634	0.009	0.2752	0.142

Note: N = 17.

Table 3. Muni correlation matrix for 1960-1976.

	VM		VH		RP	
Input	Coefficient	Significance Level	Coefficient	Significance Level	Coefficient	Significance Level
Way and structure	0.5516	0.011	0.4292	0.043	0.6987	0.001
Maintenance	−0.3280	0.099	−0.2526	0.164	−0.1680	0.260
Power and fuel	0.5104	0.018	0.2919	0.128	0.7083	0.001
Direct operations	−0.6748	0.001	−0.4702	0.028	−0.7648	0.001
Fringe benefits	−0.7185	0.001	−0.5254	0.015	−0.8494	0.001
Social Security	−0.5804	0.007	−0.3531	0.082	−0.7213	0.001
General and administrative costs	0.1539	0.278	0.3413	0.090	0.1009	0.350
Accident claims	−0.3201	0.105	−0.2759	0.142	−0.3500	0.084

Note: N = 17.

Table 4. CTA correlation matrix for 1960-1976.

	VM		PV		RP	
Input	Coefficient	Significance Level	Coefficient	Significance Level	Coefficient	Significance Level
Materials and supplies	−0.3040	0.135	−0.1348	0.316	−0.4412	0.050
Power and fuel	−0.5098	0.018	−0.1720	0.255	−0.2947	0.125
Labor	−0.8185	0.001	−0.0636	0.404	−0.9470	0.001
Pension	−0.8713	0.001	−0.0178	0.473	−0.9408	0.001
Social Security	−0.8707	0.001	−0.0909	0.364	−0.8966	0.001
Health	−0.8796	0.001	−0.0217	0.467	−0.9416	0.001
Injuries and damages	0.1789	0.246	0.3132	0.110	0.3674	0.073

Note: Data were available only for the total CTA system; N = 17.

Table 5. VM correlated with VH, PV, and RP.

Transit Property	N	VM Correlated with VH Coefficient	VH Significance Level	PV Coefficient	PV Significance Level	RP Coefficient	RP Significance Level
SCRTD	10	0.9929	0.001	0.8940	0.001	0.9056	0.001
AC Transit	17	0.9544	0.001	0.8618	0.001	0.7553	0.001
Muni	17	0.9591	0.001	NA	NA	0.8666	0.001
CTA bus		NA	NA	0.9749[a]	0.001	0.9315[b]	0.001
CTA rail				-0.6165[a]	0.005	-0.7176[b]	0.001

[a]N = 16. [b]N = 17.

Table 6. VH correlated with PV and RP.

Transit Property	N	VH Correlated with PV Coefficient	PV Significance Level	RP Coefficient	RP Significance Level
SCRTD	10	0.8825	0.001	0.9102	0.001
AC Transit	17	0.7088	0.001	0.8806	0.001
Muni	17	NA	NA	0.7194	0.001

To test his hypothesis, Miller (13) examined 1963 transit data for 33 cities, 8 of which were new and 25 of which were old. Five of the variables were found to be statistically significant--annual vehicle mileage, wage rate, schedule speed, intensity, and city age. He concluded that city environment should be considered when operating costs of transit systems in different cities were explained (13):

> The importance of these results for resource allocation in urban transportation is two-fold. First, predictions obtained by using the method described should yield significantly better results for use in alternative modes of transport in an urban setting. Second, drawing attention to those "city descriptor" variables which are outside the control of the transit firm should help cities evaluate the costs and benefits that may result from, for example, a modification of traffic flow patterns to enable buses to achieve a higher schedule speed.

Foster (14) notes that the variables used by Miller (13) account for 80 percent of the variation in the dependent variable of cost per vehicle mile. In the Nelson (16) model discussed later in this paper, the variables account for virtually all the variance in the dependent variable of total cost, although the environmental variables used by Miller were ignored by Nelson. To determine which model was correct, Foster analyzed operating-cost data of case studies over an 11-year period and concluded (14):

> In the early years of the (1960-1970) period, city variables exerted a significant effect upon the costs of bus operations. In more recent years, however, costs are more a function of firm considerations (wage rate, operating speed, and frequency of service).

An important contribution of the Miller model is the recognition that many factors affect urban transit operating costs. Miller conducted his research on firms whose data represent a time period when transit operations were privately owned or received minimal, if any, subsidies. Recent trends examined by Ortner and Wachs (17) illustrate that factors such as political influence on operating decisions from officials who allocate subsidies are affecting operating costs. Miller (13) did not consider this factor as a variable in his model. The rapid change in the structure of the transit industry during the past 15 years would make comparisons by means of Miller's model difficult. This point was recognized by Miller (18).

Holthoff Model

A third method that uses cost per vehicle mile was analyzed in a New York State Department of Transportation study (19). Inputs of rail and bus transit systems in New York State were expressed in terms of their unit cost per vehicle mile. Six input categories were used: wages and salaries, pensions, other employee-related benefits, fuel and power, materials and supplies, and miscellaneous.

The study revealed that employee-related inputs have been almost entirely responsible for past increases in operating costs. Increases in fuel, power, and other non-employee-related inputs were found to have little or no effect on operating-cost increases. Holthoff (19), like Miller (13), found differences in magnitude of operating cost per vehicle mile between transit systems to be attributable to differences in average vehicle speed, average employee earnings, and, in some cases, employee productivity.

Holthoff forecast operating costs through 1980 for New York State transit systems. His forecasting index was based on 1973 operating costs per vehicle mile of each system. In areas in which the operating environment remained unchanged, the model estimated operating costs within ±10 percent of the actual figure. However, when the operating environment changed, the total operating cost was estimated with a much larger error. For example, bus operations in Nassau County, New York, in 1974 changed from private to public ownership. The error in the estimate of total operating cost for 1974 was -35.8 percent and for 1975 it was -20.9 percent.

Holthoff's work has contributed significantly to operating-cost research. His format can structure simply but meaningfully whatever data are available on operating costs in terms of unit cost per vehicle mile or per revenue passenger. Forecasting of short-range operating-cost increases was shown to be possible, but the error of the estimate was still ±10 percent in what Holthoff considered to be a stable environment. Forecasting was shown to be highly inaccurate when major changes in the operating environment occurred, which suggests that another technique should be developed for planning purposes.

Merewitz Model

Merewitz (20) used a regression format (y = a + bx)

Table 7. PV correlated with RP.

Transit Property	N	PV Correlated with RP: Coefficient	Significance Level	Transit Property	N	PV Correlated with RP: Coefficient	Significance Level
SCRTD	10	0.6827	0.015	CTA bus	16	0.9609	0.001
AC Transit	17	0.3597	0.078	CTA rail	16	0.7574	0.001

to model Bay Area Rapid Transit (BART) operating costs. The dependent variables were conduct of transportation, rolling-stock maintenance, support-facility maintenance, maintenance of way and structures, and power. The independent variable was vehicle miles traveled. One variable--station and construction costs--was dependent on the number of stations opened rather than on vehicle miles traveled. Administrative costs were assumed to be independent of vehicle miles traveled.

After calculating a regression formula for each operating-cost account, Merewitz estimated the annual operating cost of BART to be $60.1 million (1973 dollars), based on 25 million vehicle miles and 34 stations. [In fiscal year 1977, the total operating cost of BART was $45.7 million (1973 dollars) and total vehicle mileage was 22.9 million.]

The concern in this paper is whether Merewitz's methodology can be used to forecast future operating costs. He has used trend extrapolation to develop linear relationships. The principal criticism of this method is that during periods of rapid change in basic parameters, estimates often have large errors. Data highlighted by Ortner and Wachs (17) illustrate that constant-dollar factor prices have been changing rapidly during the past few years. Accurate trends have been difficult to develop. Therefore, an alternative to the Merewitz model would be preferable for forecasting future operating costs.

MODEL OF COSTS PER VEHICLE HOUR

Lee (4,21) constructed a model of operating costs per vehicle hour. This model was developed in conjunction with a comparison of alternative transportation modes that could be operated in the I-66 Metro corridor west of Washington, D.C., in suburban Virginia.

The first calculation in the Lee model is to determine labor cost per vehicle hour by multiplying the following three operating inputs: the base wage, a ratio of total labor hours to vehicle hours (called the personnel factor), and a fringe-benefit factor. The personnel factor used by Lee was 2.0. This figure indicates that there are twice as many employee hours worked by transit personnel as there are vehicle hours of transit operation. This ratio allows for layovers, overtime, supervisors and inspectors, and maintenance and administrative personnel. To the labor cost per vehicle hour is added cost per vehicle hour of materials, fuel, and accidents to yield total operating cost per vehicle hour. For the I-66 Metro corridor, Lee (4) calculated bus operating costs as follows:

Base wage ($6.85/h) x personnel factor (2.00) x fringe-benefit factor (1.24) = total labor cost ($16.99/vehicle-h) + materials ($1.82) + fuel ($0.96) + accidents ($0.60) = total operating cost ($20.37/vehicle-h).

Although Lee (4,21) used his model in conjunction with a comparison of alternative modes, it has been described here because costs are expressed in terms of vehicle hours rather than vehicle miles. The use of the model as a forecasting tool is not recommended because the model suffers from the same basic problem as do the other models discussed earlier: It requires a stable operating environment for estimates to closely approximate actual figures. The model could serve a useful purpose if probabilities of changes in costs were used rather than forecasts of specific costs. With this technique it might be possible to develop different scenarios of transit finance.

MODEL OF TOTAL OPERATING COST

Nelson (16) developed the total-operating-cost model to determine whether economies of scale exist for large bus firms, what the impacts of wage rates are on the cost of bus transit, and how fleet characteristics affect cost. Nelson illustrated the model as follows:

$$\ln C = a_0 + (a_1 \ln VM) + (a_2 \ln W) + (a_3 \ln VEL) + (a_4 A) + (a_5 S) + (a_6 PUB) + (a_7 G) \quad (5)$$

where

- C = total operating costs (for the period specified),
- VM = bus miles (for the period specified),
- W = hourly wage rate for operating personnel,
- VEL = bus miles per bus hour,
- A = average age of bus fleet,
- S = average seats per bus,
- PUB = form of ownership (dummy variable: 1 = publicly owned, 2 = otherwise), and
- G = proportion of fleet purchased with a capital grant.

Miller and Rea (22) comment that, unlike other operating-cost models, the Nelson model is a gross operating-cost model because it includes factors that reflect depreciation and debt service shown in the Nelson equation as variable A (which reflects fleet age) and variable G (which reflects the proportion of the fleet purchased with a capital grant). They also note that variable VEL (bus miles per bus hour) is the inverse of the Miller and Holden (11) slowness variable.

Merewitz (23,24) applied Nelson's cost function to the operations of three bus systems in the San Francisco Bay Area: Muni, AC Transit, and Golden Gate Transit. He found that only Muni's operations were more costly in its bus operations than would be expected. The significance of the Merewitz research is that it showed Nelson's cost function to be applicable as a descriptive model for comparing variations between systems and for noting system inefficiencies in system operations. However, a problem with the Nelson model is that it requires extensive data for determining depreciation and debt-service factors. Its use for estimating future operating costs would be a time-consuming endeavor.

CONCLUSIONS

Eight operating-cost models have been reviewed. Structural problems limit their value for forecasting future operating costs. Case-study data illustrate that, since vehicle miles and vehicle hours are highly correlated, it does not make sense to use both variables in the same equation as was done in the models of average daily cost, annual cost, and slowness. In situations in which costs are rising and outputs are declining, the average-daily-cost and annual-cost models were shown to be unreliable.

The urban transit industry has been changing rapidly during the last 15 years. The ratio of expenditures to output is no longer predictable. One important reason is that political criteria, such as servicing all areas of a region with subsidized transit, have replaced efficiency criteria. This situation, which arose because of the need to subsidize operating deficits, allowed new actors (regional, state, and federal officials) to enter the urban transit policy-making environment.

The availability of data from reporting requirements of Section 15 of the Urban Mass Transportation Act of 1964, as amended, will present some interesting opportunities for cross-sectional analysis. Several of the operating-cost models, such as the urban-environment-cost and the cost-per-vehicle-hour models, could be applied to individual transit networks. For example, they could indicate which portions of a transit system could be altered or replaced by forms of privately owned and/or operated shared-ride systems. The California legislature has required that urban transit systems finance at least 20 percent of operating costs from fares. This requirement combined with the models discussed above could encourage better estimates of future operations and costs.

The need to forecast operating costs remains an important part of planning. Research in this area should now be directed toward developing techniques that can build on the experiences gained from using the models reviewed in this paper. Two techniques are recommended for further research--developing probabilities of changes in cost categories and generating a set of alternate scenarios that focus on different operating environments and their impacts on operating costs. These techniques do not focus on a fixed future. Instead, as Vanston and others (25) note, they minimize the risk inherent in planning against a single, unforeseeable future.

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Allocation of Bus Transit Service

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To achieve an equitable distribution of its transit service, the Southern California Rapid Transit District intends to allocate service by formula to the communities it serves. The formula would have measures of ridership and population. Before a decision maker can set the relative weights of these two variables, the effect on service levels in the various constituencies must be determined. This paper describes a study that determined the formula that came closest to prescribing the existing levels of service. Data on population, service levels, and ridership were obtained from a system of area accounts, in which data are maintained at the census-tract level and then aggregated into larger areas as required. Regression was used to determine that the formula that best fit existing service levels would have weights of 48 percent on ridership and 52 percent on population. It was found that a better fit was obtained when service was measured in dollars expended rather than in bus kilometers.

In any public enterprise, efficient operation is no more important than is the fair distribution of services. The inherent conflict between these two objectives can be dealt with in a transit service policy in which productivity is maximized within the constraints specified by a distribution policy. Total amounts of service for each subregion of a service area can be set and, given these amounts, the service within the subregions can be adjusted to be as productive as possible.

The question of distribution has previously been cast by Levine (1,2) as a problem in the allocation of transit operating deficits. Such an approach stems from the need to apportion deficits among tax-contributing political jurisdictions served by a single operator. In the case of Los Angeles, in which deficits are covered by tax funds collected on a geographic base broader than the area served (i.e., state and federal taxes), it is more appropriate to allocate the entire cost of service. Within that allocation, both deficits and user charges can be considered.

The Southern California Rapid Transit District (SCRTD) has been exploring the approach of formula allocation of service, which would function much like the formula used to distribute federal transit operating funds to urbanized areas. As with the federal formula, residential population would be one variable. The other variable, rather than population density, would be a measure of ridership.

A requisite for such an allocation formula is having a suitable data base. A system of area accounts was developed at SCRTD for this purpose. Maintained at the census-tract level, these accounts include transit service and use data in addition to the demographic data normally available by census tract. All transit data are attributed to bus stops and from there to the census tract in which the stop is located.

SCRTD obtains ridership data by bus stop for a number of purposes--scheduling, route planning, reporting as required by Section 15 of the Urban Mass Transportation Act of 1964, and area accounts. The cost of obtaining and processing the data is less than 1 percent of the operating budget, and the increment attributed to maintenance of the area accounts is a small fraction of that.

The question of distribution is inherently a political one and must be decided in a suitable manner. Before decision makers can or will make a decision on a formula, they must know how their constituencies will be affected. The subject of this paper is a study undertaken to determine the existing distribution of service in relation to a potential formula. By using multiple linear regression of the data provided by the area accounts, the level of service is estimated from explanatory variables such as ridership and population.

The SCRTD distributes its services over a broad and diverse geographic area. Although there has been no formal policy on allocation, the distribution is not random. The analysis reported here was undertaken in order to test an underlying (if unconscious) rationale. Questions of primary interest are

1. How closely is service level correlated with the combined factors of population and ridership within the local areas?
2. If we assume such a relationship, what is the relative emphasis on each of the two factors in the current distribution of service?
3. If a formula were adopted and adhered to, what would the effect be on service levels in the various geographic areas?

Some secondary questions were also addressed:

1. What happens if service level is defined by bus kilometers instead of by expenditure level?
2. Once variations in service level due to population and ridership are accounted for, what is the effect of a third variable that indicates transit dependency?

ALLOCATION FORMULAS

Allocation is the splitting of a resource among the members of a group. Any allocation formula can be reduced to the form

$$y_i = \sum_j a_j x_{ij} \qquad (1)$$

where

$$\sum_i y_i = \sum_j a_j = \sum_i x_{ij} = 1$$

where

y_i = fractional share of the resource that will go to the ith recipient,
x_{ij} = fractional share of the jth variable associated with the ith recipient, and
a_j = proportion of the total resource to be divided up according to the shares of the jth variable.

In the allocation of transit service, the resource is the total amount of transit service as measured by vehicle kilometers or cost. The recipients are the local service areas, which are the subdivisions of the total service area.

CHOICE OF VARIABLES

There has been no attempt to carry out a broad search for the best (in the statistical sense) explanatory variables for existing service allocation. Rather, it was deemed more germane to explore the effects of the few politically reasonable variables. Of major interest were ridership and population. Ridership is taken to mean boardings per day, although other definitions could have been used. Allocating service according to the amount of riding that actually occurs seems to be a way of paying attention to the efficiency of the service. On the other hand, the fairness of distribution of service to the community is served by allocation according to the population of each area. This recognizes the public's contribution through taxes.

A suggestion has been made that contributed tax monies could be used directly as a variable rather than population. When the areas used for units of distribution are not actually tax-collecting units, the tax contribution of each area must somehow be estimated. When broad sources of revenue are considered, a question is raised about the attempt to return service to residents in direct proportion to actual tax monies contributed. That would be in direct conflict with the view that transit is in part a welfare institution intended especially to bolster the mobility of the poor in compensation for their disproportionate lack of access to the automobile-dominated transportation system. A simple population count would treat people as equals without regard to wealth.

Although service level could be reckoned in several ways, the two measures explored were bus kilometers per day and dollars of operating cost per day. The latter might not seem to be a good measure of what the consumer receives or is offered, yet it can still be valid as an indicator of the resource expended on his or her behalf. There is no reason to think that resources are arbitrarily or uncontrollably wasted in some areas; hence the measure could be viewed as a reasonable indicator for comparisons among areas. In the congested areas in which costs are higher due to slow movement of the buses, it can be argued that the congestion causes the value of a kilometer of travel to be higher.

Cost is computed as a linear combination of kilometers and hours of bus travel while the bus is actually in service:

Cost = bus hours x \$30 + bus kilometers x \$0.31.

It might be better if other variables were included that would better allocate the higher costs of service during peak periods, but it is more difficult to aggregate such data on an area basis. To the extent that the degree of peaking is similar from one area to another, this shortcoming should have little effect on the resulting allocation.

CHOICE OF UNIT AREA FOR DATA AGGREGATION

There are several objectives in choosing the basic unit of area for the analysis. There should be

1. A large-enough number of areas for statistical reliability,
2. Areas large enough to smooth out local land-use variations (e.g., local parks, industrial areas, and arterial street locations), and
3. Areas that are internally homogeneous yet externally heterogeneous with respect to the variables of interest.

Although the data are compiled by census tract, these are not suitable for direct use and must be aggregated into larger areas. Besides being so small that random irregularities unduly influence the data, census tracts are purposely delineated to encompass populations of similar size. Being externally homogeneous with respect to population, they are inherently poor as units for regressions in which population itself is a variable that is being considered.

In a typical regression, one obtains as many data points or cases as practical to increase the statistical reliability of the relationship that is being determined. In analyzing a distribution within an area, the number of data points can be increased simply by dividing the total area into smaller parts. In this analysis, a division into 13 areas was of direct interest, since those areas (the SCRTD planning sectors) were naturally favored as the basic units for adjustment of service level. As a test of the effect of subarea size, a second set of 86 county zones was used. These areas had previously been defined by the county road department for the analysis of transit services and were aggregations of census tracts.

REGRESSION TRIALS

Even though the scope of the search for a good formula was narrowed considerably by the initial choice of variables that were politically viable, several problems in the data had to be explored, such as the inclusion or exclusion of service data from municipal operations, use of area totals or densities, and alternative indicators of service level.

The data used were from the 1970 census and from line checks taken during 1977 and 1978. Although these may not be true cross-sectional data (as they should be), the service levels were relatively stable during that two-year period, as was patronage. The population of the county was stable between 1970 and 1978. Data from park-and-ride services were not included, but one would not expect this omission to cause much error, since such service is less than 2 percent of the district's total and it is not concentrated in any one area.

The regressions were carried out by Anne Huck by using the Statistical Package for the Social Sciences. Table 1 gives the conditions of the 12 regression trials that were run. Table 2 gives the numerical results, the formula coefficients, and the coefficient of multiple correlation.

Missing Data for Municipal Operators

Within the service area of the SCRTD, there are several territories served primarily by municipal operators. Although they are mostly quite small (they provide less than 15 percent of the total service among them), they are major providers in a few relatively small areas. To the extent that municipal operations share in the use of public funds, the service they offer and the ridership they carry should be considered in analyzing the distribution of transit service. Since actual data on those operations do not exist in a suitable form for area accounts, some rough estimates were made.

The estimates were practical only in the cases with a few large zones. In the small-zone cases, in which municipal service could not be readily esti-

Table 1. Parameters of regression trials.

Parameter	Trial Number 1	2	3	4	5	6	7	8	9	10	11	12
Number of data points	78	86	86	77	77	12	12	12	12	14	12	13
Express service included			X	X	X	X	X	X	X	X	X	X
Variables expressed as												
Totals									X	X	X	X
Densities	X	X	X	X	X	X	X	X				
Service expressed as												
Cost (dollars)	X	X	X	X				X	X	X	X	X
Kilometers					X	X	X					
Municipal areas												
Included		X	X			X	X	X	X	X	X	X
Omitted	X			X	X							
Municipal service												
Estimated						X	X	X	X	X	X	X
Omitted	X	X	X	X	X							
No-car variable included							X					
Central business district included										X		X

Table 2. Computed coefficients.

Trial Number	Coefficient a_0	a_1	a_2	a_3	R
1	0.13	0.24	0.62	-	0.9920
2	0.14	0.25	0.61	-	0.9910
3	0.16	0.23	0.61	-	0.9834
4	0.17	0.22	0.62	-	0.9841
5	0.22	0.28	0.50	-	0.9565
6	-0.02	0.47	0.54	-	0.9620
7	-0.13	0.80	0.84	-0.51	0.9678
8	0.15	0.21	0.64	-	0.9800
9	0.05	0.50	0.45	-	0.9927
10	0.02	0.51	0.47	-	0.9911
11	0	0.54	0.46	-	0.9971
12	0	0.52	0.48	-	0.9967

Note: a_0 = constant; a_1 = coefficient of population; a_2 = coefficient of ridership (boardings); a_3 = coefficient of no-automobile households; and R = coefficient of multiple correlation.

mated, the regressions were run with and without the data points that represent the zones in question. Using these zones without accounting for municipal service has the same effect as if some areas were to have especially low SCRTD service and ridership relative to the population size of the zone. Omission of these zones from the analysis involves the assumption that service levels in areas dominated by municipal operations are consistent with levels in the SCRTD service areas. The effect of leaving out those zones was slight. Only one percentage point was transferred from the population coefficient to the ridership coefficient in the two-factor apportionment formula.

Variables Expressed as Densities or Totals

Although the formula variables for which the coefficients are to be determined are expressed in terms of totals for any specified area, the coefficient of multiple correlation (R) will be artificially high. Use of totals is associated with a scale effect in which a comparison of a larger area with a smaller one will tend to show a larger amount of service, ridership, population, etc. This induces a falsely high correlation of the variables. By using densities (riders per square kilometer, population per square kilometer, etc.), the effect can be neutralized.

Nevertheless, since we are looking for the best fit in terms of totals, that is the way that the final result should be presented.

Effect of Zone Size

The effect of the zone size can be inferred from a comparison of trials 4 and 8. The weighting of the ridership coefficient differs by only two percentage points; hence it might be concluded that the size of zone has no great effect on the determination of coefficients.

Express-Service Considerations

Express service is characterized by long distances between stops and long passenger trips. Therefore, the unit area size most suitable for allocation purposes will be larger than that for local service. Bus kilometers in express service are attributed to stops that precede express-operation segments of lines and may generally be considered to be balanced between directions. Boardings in express services are attributed to stops at which they actually occur, which are usually on a local segment of the line.

The consequence of this data arrangement is that a few census tracts will seem to be receiving an excess of service simply because they contain a stop that defines one end of an express segment of a line. The best way to deal with the situation would be to segregate express services and deal with them separately in a manner that recognizes the greater travel distances and dispersed benefits. However, since there really is not a great amount of express service, and since the end points are reasonably evenly distributed throughout the area, there is little effect on the regression coefficients by inclusion or omission of express kilometers. This can be seen by comparing the coefficients in trials 2 and 3; express kilometers of service were omitted in trial 2 and included in trial 3.

Choice of Variable to Describe Service Level

If regression trials 4 and 5 are compared, the choice of the variable to describe service level can be seen to have a marked effect. When service was measured in dollars (trial 4), the service level appears to be heavily weighted toward ridership (ridership coefficient, 0.62). When measured in bus kilometers (trial 5), the ridership coefficient is only 0.50.

The result can be explained as follows. Although ridership density is highly correlated with population density, it tends to fall off rapidly as population density declines, so that ridership is usually low in areas of moderate population density. Thus in areas of moderate density, in which population is the governing factor in determining service level, higher operating speeds are also prevalent. Higher speeds mean more kilometers per dollar of service cost. Thus, service measured in kilometers tends to correlate better with population, whereas service to be equivalent to one that specifies service in dollars tends to correlate relatively better with ridership. This means that for a formula that specifies kilometers of service to be equivalent to one that specifies service in dollars, it will have to have a relatively lower coefficient for ridership.

The correlation coefficient (R) is significantly better for dollars than it is for kilometers. In other words, not only is the relationship different, but it is more consistent in one case than it is in the other.

Constant Term

The normal result of a linear regression is a coefficient for each variable plus a constant term. Although a nonzero constant is to be expected from an investigation of a de facto allocation policy, it is not something to be included in an intentional formula. If that were done, the formula would allocate service to any defined area even if it had no riders or population.

To force a zero constant (trials 11 and 12), each data point was simply matched with another data point in the negative quadrant. However, this gives a false enhancement of the correlation coefficient.

Addition of a Transit-Dependency Variable

It is often said that transit service is allocated mostly on the basis of need and that need is expressed through demonstrated ridership. There is some circularity in this argument, in that ridership is to an extent a response to service offered. What if two areas are compared that have the same population and ridership yet differ in some other innate indicator of need?

It is not easy to say what single variable best represents transit dependency, but being without access to an automobile in the household seems to be a reasonable definition for an initial analysis. For data, a count of no-automobile households in each area was used, which was obtained from the 1970 census. This variable was appended to the other two for a three-variable regression.

The result was a negative coefficient for the transit-dependency variable. This means that, if two areas are equal in population and ridership, we could expect to find less service in the one with the highest transit dependency. Although this is in keeping with the normal market strategy in private business (i.e., to be the most competitive in areas in which people are most likely to have a ready substitute), it might not be what we think of as appropriate strategy for a public enterprise.

Best-Fit Formula

The coefficients for the formula that best fits the existing allocation of service are taken from trial 12:

$$S_i = 0.48R_i + 0.52P_i \qquad (2)$$

where

S_i = share of service dollars expended in the ith area,
R_i = share of boardings, and
P_i = share of residential population of that area.

The service levels prescribed by this formula differ from the actual levels by less than 20 percent in all 13 of the service sectors; the average deviation is 11 percent.

CONCLUSIONS AND IMPLICATIONS

Although service levels vary over a wide range throughout the service area studied, they follow a rather consistent pattern, which can be described by two variables--ridership and population. The existing patterns were not consciously laid down in those terms, but the politically and operationally determined need for service seems to imply at least a subconscious connection with these or similar factors.

Even though service levels seem reasonably consistent in following an apparent rationale, there was no easy way for decision makers to explain how service resources were allocated. The formula approach offers a way to explain the variation in service levels to the public. Those levels now in existence can be adjusted over time for greater consistency by means of a formula.

Intentional changes in the formula coefficients can be used as a policy tool to shift the relative emphasis of service between the provision of standby service for the population at large and more capacity in areas in which ridership actually exists.

The analysis addressed the issue of how services are currently distributed and the consequences of a range of trade-offs between the two formula variables chosen. Is there any basis for deciding what the relative weights should be?

More-productive service, in terms of the least cost per rider, will be the result of a formula heavily weighted toward ridership. Obviously, moving too far in that direction would be politically impossible because of the tax-support issue. But the actual amount of tax funds should allow a lower bound to be placed on the ridership coefficient in the formula. Through the fare box, the riders pay for 46 percent of SCRTD service, so it seems reasonable that at least 46 percent of the service should be apportioned according to ridership. To the extent that some of the tax support is used directly to subsidize certain fare payers (the elderly, the handicapped, and students), the minimum-ridership factor should be adjusted upward to about 51 percent. Thus the range for political decision seems to be a population coefficient between zero and 49 percent. Even at the higher end of this range, this would entail a slight reduction from the present split of 48:52 (ridership:population).

Until experience with a two-variable formula has been acquired, the complexity of additional variables may not be appropriate. The result of adding a variable that represents transit dependency seemed interesting enough to include in this discussion, however. Further research in this area might be worthwhile.

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Abridgment

Automation in Public Transit Operation and Management: Trends and Prospects

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Managers in the public transit industry are exploiting automated data processing (ADP) techniques in their efforts to measure and improve operating performance. Important ADP innovations are highlighted in this discussion; they are followed by a sketch of prospects for the future. The desirable integrating nature of ADP processes is suggested as an important means for structuring the flow of management information. Service planning and its complexities receive some comments. The Urban Mass Transportation Administration's support and research areas are summarized.

Faced with increasingly high operating costs and greater accountability as well as demands for more and better service, the highly visible public transit industry needs responsive, cost-effective tools to aid in systems management. In response, transit agencies have turned increasingly to automated data processing (ADP) methods for assistance in collecting, organizing, and analyzing transit system information.

A major factor that supports this trend has been the increased reporting requirements (and therefore data collection and processing requirements) mandated by Section 15 of the Urban Mass Transportation Act of 1964. No small incentive is provided by the Section 3 assistance for developing automated reporting systems. In addition, generally increased awareness by transit industry personnel of ADP methods has helped. The evolution of low-cost minicomputer and microcomputer technology has further encouraged operators to obtain or update data processing systems.

CURRENT APPLICATIONS

Uses of ADP methods have varied greatly; they depend primarily on the size and presence (or lack) of staff that accepts ADP processes. However, with many of the cost barriers now removed, there is an increasing commitment to automated systems by transit agencies of all sizes. To provide some perspective, several particularly innovative systems are noted here.

At the Chicago Transit Authority, a sophisticated on-line maintenance management system has been in use for several years. Its functions include reporting road calls and defects, scheduling preventive maintenance, monitoring vehicle availability, analyzing repair history, and evaluating maintenance-employee performance. This system has been used as a model for other agencies that have developed maintenance management information systems (MIS). Seattle's Metro is developing an on-line MIS that uses a powerful data-base management system to support a variety of functions that include route planning, scheduling and costing, payroll and personnel accounting, inventory controlling, and vehicle operations monitoring. Portland Tri-Met's comprehensive on-line maintenance management system is implemented on a minicomputer. For small transit agencies, perhaps the most-significant development is a first-generation general-purpose MIS, marketed as TRANS-PAC by MTD Project Services of Seminole, Florida. Implemented on a desk-size minicomputer, this system provides payroll support and operations and maintenance management data and outputs statistics required by Section 15. It can be easily installed at any small agency that has from 20 to 250 vehicles and is currently in operation at several agencies in Florida and at least one in California.

Automated data entry methods are becoming increasingly popular. Applications include on-line fuel meters (Dallas), passenger counters (Seattle), and fare boxes (Ft. Wayne) that have computer interfaces, employee data from identification cards (Chicago, Portland, Flint, and Nashville), and monitors of vehicle position and status (Cincinnati).

Long-range transit systems planners have used computerized techniques such as those of the Urban Transportation Planning System (UTPS) for years (1). For planning short-range service improvements, an efficient network-modeling capability has recently been added to UTPS. For making schedules, the RUCUS program has provided some capability, and other scheduling aids are developing. The Mini-Scheduler of the Sage Corporation of San Francisco is an example.

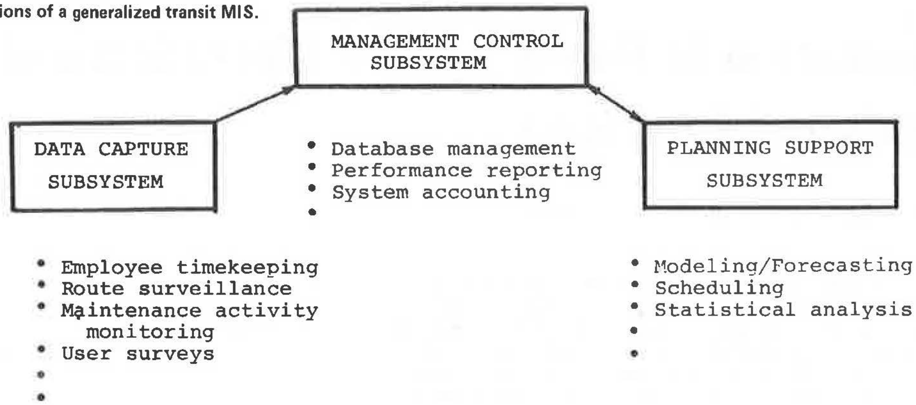
These recent accomplishments provide only a slight indication of the potential that remains for ADP methods in the following areas of transit operation and management: automated vehicle diagnostics, which includes equipment history analysis; parts inventory management for a wide variety of vehicles; computer-aided learning techniques for drivers, schedulers, and other staff; comprehensive service planning, which includes ridership estimation and cost analysis; manpower labor policy planning; financial and cash-flow management; and generally improved data collection, formatting, and reporting capabilities. All are complex and often interrelated management concerns that require integrated approaches to performance measurement and assessment.

SYSTEMS APPROACH TO OBTAINING AND MANAGING INFORMATION

After consideration of the current applications discussed above, there is obvious benefit to exploiting the significant data base that evolves naturally from use of ADP methods. If an overall systems view of agency functions and operations is taken, particularly useful flows of information can be established by design and as by-products of ADP subsystems within the agency.

Assume for the moment that a transit agency chooses to operate all feasible (cost-effective) activities by using ADP methods to improve efficiency and effectiveness. Assume as well that information for all activities could be automatically integrated and accessible to each management level that has a decision-making interest in the data. This integrated system could provide performance measurement and estimation for each responsibility center and could permit summarization of systemwide indicators. (Responsibility centers are definable activity centers that work with prescribed resources and output specific products or services. There is a manager responsible for the day-to-day operation of the center. Examples are the vehicle maintenance facility and the planning and scheduling depart-

Figure 1. Primary subsystems and functions of a generalized transit MIS.



ment.) Managers could tie goal-oriented measures of service delivery to those indicators of efficient operations. The traditional concepts of ratio analysis and the economic concepts of marginal and incremental analysis could be natural extensions of the data.

For assessing projects, the time value of money could be considered even for short-range operational commitments, especially those that may have long-range cost impacts. Thus, life-cycle cost analysis takes on meaning even for projects to be implemented in the near future. All influential aspects of agency operation could be scrutinized. Risk management methods that include the uncertain external contributions of inflation to costs and of recession on ridership could be forecast. Where appropriate, measured and forecast information could be produced as performance indicators and formatted in a way consistent with Section 15 requirements. As functionally envisioned, this overall MIS approach could provide performance evaluation capability as a management tool at the level of each individual responsibility center.

To move from a somewhat abstract discussion, an integrated MIS might appear functionally as in Figure 1. Here basic MIS functions are grouped into three fundamental subsystems: data capture, management control, and planning support. Within each of these subsystems are a number of well-defined modules, each of which takes on a specific function. For example, in the data-capture subsystem there may be individual ADP modules that feed information on ridership and revenue, vehicle maintenance, and parts availability. In the management-control subsystem there may be a module for property accounting and a module for route performance reporting. In the planning-support subsystem, modules may exist for forecasting ridership, costs, and resultant system performance. Specific indicators could be forecast for comparison with those most recently measured.

Obviously, the modules suggested by Figure 1 are only representative and could be arranged in a variety of ways depending on a specific transit agency's organizational structure and its management policies. These organizational vagaries are typical throughout the industry and further support the arguments for functional modularity. Thus a systematic framework into which various computerized modules could easily be inserted or modified provides the transit operator with maximum flexibility to change or expand the computerized management support process according to agency needs. Moreover, total process development costs over their life cycle are reduced by assuring consistency where data interfaces are required.

If we accept the systems view and the use of functions performed as modules of an overall process, we might ask pragmatically, How does one really implement a systems approach?

Though typically imagined as such, no single, large computer system need be implied. Computerized procedures that could contribute to some common denominator of essential, timely data are all that is required for overall management decision making. Visualized as a system of computerized processes, MIS modules could be developed incrementally and incorporated into the overall process according to some specified schedule. In reality, the computerized approach could be distributed to various responsibility centers with their own reporting capabilities and management tools. This approach allows for the fact that the software structure and computerized hardware essential for one module may be quite different from those for another. By being modularized, summary data for overall agency assessments may be systematically (and automatically) obtained through interfaces with the distributed data processing locations at individual responsibility centers. A computerized data-base manager is needed in cases in which many interfaces are required and much user control of the data is desired.

Further opportunities are possible when the variety of available computer and support technologies is considered. Because these numerous options exist, many decisions must be made as overall conceptualization progresses with the systems view in mind. In particular, the following types of fundamental questions must be addressed:

1. At what level of user sophistication should the processes be designed to support an overall MIS? At what level for each responsibility center?
2. What kind of ADP hardware configuration is desired or required?
3. How should staging of automated process development (integration) be accomplished?

In terms of system sophistication, transit agencies that have more-complex operating environments and greater financial and technical resources may be amenable to use of a highly flexible MIS. For many other transit agencies, a simpler turnkey type of system (i.e., one that only needs to be plugged in to be ready to work) may be preferred. However, a turnkey system does not have to be totally inflexible. Such approaches can include considerable user-oriented program organization and report-generation capability.

Depending on the desired level of automated capabilities, several hardware arrangements may apply. At some larger agencies, high-capacity multiuser computers and sophisticated support software may be desirable and cost effective for processing great quantities of data. At most other agencies, less-expensive microcomputer hardware may be suitable. In all cases, automated data entry methods will permit the movement toward more-efficient, paperless information systems. Used in conjunction with distributed processing technology, these systems offer endless possibilities for contributing to overall transit productivity.

Finally, the appropriate phasing of system implementation will vary among agencies depending on management objectives and resource availability. Usually, development of a transit MIS begins with the financial and accounting modules, since these interface with nearly all other system modules. In addition, these modules provide the means for meeting Section 15 reporting requirements. As modules are added to the MIS and experience grows, information flow becomes more comprehensive, which encourages the expansion of or interfacing with other analytical capabilities. The planning and scheduling support system is an example.

SPECIFIC RESEARCH IN SERVICE PLANNING METHODS

Because of their complex nature and high development costs, service planning methods are receiving particular attention in the Urban Mass Transportation Administration's Office of Planning Methods and Support. Projects are under way to develop what would in effect be modules of the previously proposed planning and scheduling subsystem. Many are ad hoc projects; they test the feasibility of certain analytical approaches and simplifying assumptions. Others emphasize data-collection technology.

For instance, pilot development of a stand-alone microcomputer system is being sponsored in cooperation with a particular transit agency that will provide a vehicle and driver schedule data base that will accept data typically collected from on-board surveys and counts. It will provide route-point analysis, ride checks, and on-time reliability statistics and will produce headway sheets, paddles (trip schedules), and timetables--all of which are essential to any transit operation.

Complementary to this effort, research in the near future will permit interfacing of this microcomputer system with a simply modified transit network planning capability that has comprehensive costing techniques. Vehicle and crew scheduling may be accomplished with a variety of operating objectives such as minimizing the extraboard (operator with no assigned run) or the overall vehicle-crew operating cost. With such a planning capability, another objective may be to minimize vehicle use, perhaps at the expense of driver hours. With simple analytical tools, many alternatives can be explored.

Design efforts will emphasize the concerns of the user and require minimal need for specialized ADP or computer systems knowledge. Modular considerations will permit packaging according to local requirements and allow computerized system growth as needs change and local experience and confidence evolve.

In summary, transit operating agencies must respond to local concerns and priorities and, to qualify for federal funding, must relate them to national goals as well. This implies flexibility in measuring, forecasting, directing, and reporting transit performance and productivity. Information management through automated data processing appears to offer this opportunity.

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Abridgment

Evaluation of Alternative Transit Routing Configurations in a Hypothetical Low-Density Area

KEITH M. THELEN, ARUN CHATTERJEE, AND FREDERICK J. WEGMANN

The provision of fixed-route transit services in low-density suburban areas poses significant problems for urban communities. Traditionally, fixed-route bus service has been provided to these areas as an extension of the radial system in the core city. However, little information exists that would guide the selection of a certain pattern under a given set of conditions. As energy continues to be in short supply, the question of extensions of fixed-route service to low-density areas may become more pressing. This paper discusses the intrinsic service characteristics of six alternative routing patterns in a hypothetical low-density area. Costs (determined from vehicle miles traveled), coverage area, passenger travel time, and competitiveness with the walk mode are the performance measures used to evaluate each routing pattern. The results indicate that different types of routing configurations do have different implications with respect to these performance measures. No single pattern was found to satisfy all service objectives equally well. Therefore, it is necessary for decision makers to assign priorities to different service characteristics and then to make the necessary trade-offs between those characteristics to arrive at a decision that meets community objectives.

Documentation is lacking of evaluations of different transit routing configurations in low-density areas. Lundberg and Brown (1), Vuchic (2), Sullivan (3), Sharma (4), and Ross and Wilson (5) discuss issues related to different routing configurations, but none examines the specific service characteristics of alternative routing configurations. This paper discusses such specific service characteristics and the trade-offs that must be made in the route-selection process.

STRATEGY FOR ANALYSIS

Network Characteristics and Routing Patterns

Six routing patterns were simulated in a 16-mile^2 hypothetical area. The area was assumed to have uniform densities and trip-generation rates so that the routing patterns did not have to accommodate locations that had a concentrated demand. It was also assumed to lie at the outer (suburban) end of a core-city route, and travel times are measured from each of 116 zones to the transfer point with the core route. No travel-demand pattern was superimposed on the transit routes. Components of the network on which the routing patterns were simulated are listed below:

Component	Description
Link length	0.2 mile
Zone size	0.4 $mile^2$
Vehicle speed	12 mph
Vehicle travel time per link	1 min
Walk speed	3 mph
Walk time per link	4 min
Wait time at transit stop	0 min
Service frequency	20 min
Total number of zones	116

Six different routing patterns were simulated in the study--one circular loop, two circular loops, four lines, two narrow loops, three narrow loops, and a meandering loop. Figure 1 (two circular loops) and Figure 2 (three narrow loops) illustrate two of the routing patterns and also the general characteristics of the hypothetical area.

Evaluation Tools and Measures

The package of computer programs known as the Urban Transportation Planning System (UTPS) was used as an analysis tool in this study. Three network-analysis programs--UNET, UPATH, and UPSUM--were used to generate performance measures.

Four types of service parameters were used for the analysis--costs (determined by vehicle miles traveled), passenger travel time, coverage area (area within 0.2 mile of transit service), and competitiveness with the walk mode (whether it is faster to get to the transfer point with the line-haul route by transit or by walking).

A service frequency of 20 min was assumed for all routes. The routes were not designed to minimize driver and vehicle requirements, which is a function of systemwide routing and scheduling. Thus, driver layover times have not been minimized. In addition, wait time was assigned a value of zero to eliminate inappropriate wait-time distortions that were introduced on some routes with the use of the UTPS package.

PERFORMANCE OF ROUTING PATTERNS

Table 1 presents the results of simulating different service patterns in the hypothetical area. The single-circular-loop pattern has the fewest number of vehicle miles traveled per hour and is therefore the least expensive to operate. It also provides the worst coverage area, is the second worst in terms of total passenger travel time, and is also noncompetitive with the walk mode for a large number of zones. It is apparent that costs can be minimized with the single-circular-loop routing pattern but only at the expense of other service elements.

The best service configuration in terms of total passenger travel time is the one that uses the four-line route. However, this would be the most expensive to operate since it has the largest number of vehicle miles traveled.

The best service pattern in terms of coverage area is the three-narrow-loop route. However, it is expensive to provide this service. The best service pattern in terms of competitiveness with the walk mode (to the transfer point) is again the three-narrow-loop configuration.

USE OF PERFORMANCE RESULTS IN DECISION-MAKING SITUATIONS

The results presented in the previous section show that the different routing configurations have varying implications with regard to cost, level of service, and coverage. The following example shows how the choice of a routing configuration would involve trade-offs between two service parameters--cost and coverage area. Similar trade-off decisions would have to be made when passenger travel time is weighed against costs. If decision makers are presented with accurate data on the trade-offs among routing patterns, they can select the configuration that most nearly achieves their objectives for a particular area.

Incremental-Cost-Effectiveness Approach: Cost Versus Coverage Area

A situation may exist where decision makers wish to achieve the greatest coverage area for the least cost when a particular area is served. If we assume that this situation is being applied to the routes in the area previously discussed, the information in Table 2 would be used to arrive at a decision on the appropriate route. To bring the first 51 zones within 0.2 mile of a route costs about $224 000/year, or $4404/zone/year, to serve. Bringing the next 38 zones within 0.2 mile of a route would cost an additional $180 960/year, or $4702/zone/year. The third level of expenditure would bring an additional 13 zones within 0.2 mile of the service at an additional annual cost of $37 440, or $2880/zone/year. The burden on decision makers would be to determine (a) the expenditure limit for the service, (b) the number of zones of service, and (c) the amount to spend for each zone brought closer to the service. An explicit consideration of objectives and trade-offs should be brought into the decision-making process. For each alternative, the information in Table 2 indicates what is to be gained with increased expenditures. Decision makers must decide in terms of local priorities whether improvements in coverage area are worth the additional cost.

Implications

From the previous discussion, it is apparent that a point of diminishing returns can be reached with increased expenditures. Although a detailed examination of alternative routing patterns may not always be a part of the decision-making process, the previous discussion points out the need for such assessments before a new service is begun.

The discussion on incremental cost-effectiveness also points out the need to educate and assist policymakers in making trade-offs in the decision-making process. In a climate where objective decision making is desired, specific objectives could be achieved with the proper guidance from staff persons.

Refinements Needed

One factor that significantly influences cost is frequency of service. Subsequent analyses could vary this parameter, and the incremental cost-ef-

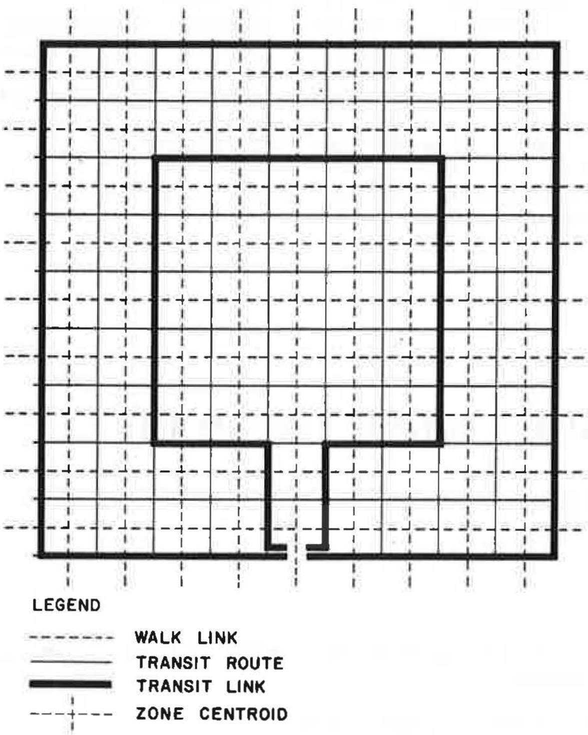

Figure 1. Two-circular-loop routing pattern.

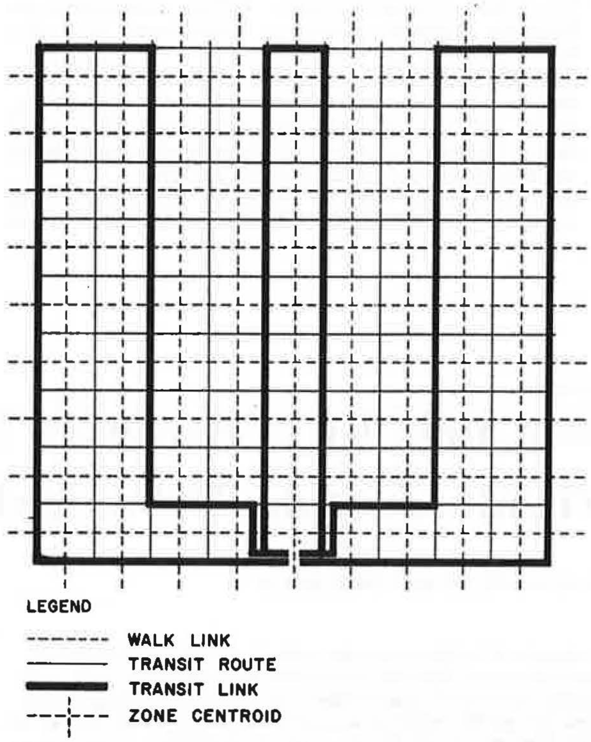

Figure 2. Three-narrow-loop routing pattern.

Table 1. Service attributes of alternative route configurations.

Service Pattern	Speed (vehicle miles/h)	Average Total Passenger Travel Time[a] (min)	Not Competitive with Walk Mode (no. of zones)	Coverage Area (no. of zones)
Two circular loops	71	29.379	10	102
One circular loop	36	33.328	25	51
Four lines	116	20.431	2	81
Two narrow loops	65	25.017	2	89
Three narrow loops	88	22.397	1	112
Meandering loop	71	37.638	5	86

[a]Consists of in-vehicle time plus walk time.

Table 2. Incremental cost-effectiveness: cost versus coverage area.

Routing Pattern	Annual Costs[a] ($)	Incremental Annual Costs[a] ($)	Incremental Coverage Area (no. of zones)
One circular loop	224 640	224 640	51
Two narrow loops	405 600	180 960	38
Two circular loops	443 040	37 440	13
Meandering loop	443 040	0	−16
Three narrow loops	549 120	106 080	26
Four lines	723 840	174 720	−31

[a]Cost figures assume $2.00/vehicle-mile operating costs 12 h/day, 5 days/week, 52 weeks/year of operation; and 20-min headways.

fectiveness approach could be expanded to include different service frequencies.

A precise cost-assessment analysis would have to be area specific if the suburban service were tied directly to the core route. Driver layover times could be minimized by specific adjustments to the routing patterns within the localities in which they are implemented.

Adjustments to the precise shape of the routing patterns would also be necessary in specific areas to accommodate nongrid or curvilinear street patterns. Adjustments to the precise shape of a route may also be necessary to accommodate specific activity centers.

SUMMARY

It is possible to reach general conclusions about the trade-offs between different routing patterns from the data presented in this study. Planners and operators can see the trade-offs among costs, coverage area, and passenger travel time among the various types of routing configurations presented in this paper and use the data to form general opinions on the advantages and disadvantages of each type. This work should be expanded and refined in real-life situations, however, if more definitive conclusions are desired.

The discussion of incremental cost-effectiveness illustrates two points. First, the discussion demonstrated how the data generated in the study can be structured and applied to decision-making situations. Second, it demonstrated the magnitude of trade-offs between routing patterns and that a point of diminishing returns could be reached with increased expenditures.

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Abridgment

Time Stability of Attitudes Toward Transit Use in the Orlando, Florida, Urbanized Area

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Early attempts at modeling transit use in the Orlando, Florida, Urban Area Transportation Study (OUATS) assumed that the rather low use of the area's inadequate transit system would continue into the future. Direct generation of modal split and the forecast of automobile person trips locked the area into forecasts of low transit use both in the original study in 1965 and in the first update of OUATS in 1970. In 1973, this shortcoming in the travel-forecasting procedures used in the area was corrected. A mode-share model was developed from expressions found in the Minneapolis area and calibrated to conditions in the Orlando area determined through a transit-attitude survey conducted in 1973. The questionnaire used in this survey was designed to provide input into a mode-share model so that future patronage of alternative transit systems could be determined. In 1978, another survey was accomplished as a part of an update to OUATS. This survey was designed to duplicate the earlier survey to the maximum extent possible. This duplication included attempting to question the exact respondent reached in 1973. The intent of the duplication was to allow for a validation of the modal-split relationships developed from the original survey. Although this validation is important, particularly to the Orlando area, there are other questions to which these results can be applied. A basic assumption of the urban transportation planning process is the stability of trip characteristics over time. Other studies have shown mixed results, and generally these studies are limited to trip-generation expressions. The results in the Orlando area indicate that those relationships that might be used in modeling mode use do remain stable over time, at least for the purposes of short-range planning (three to five years). This is particularly significant when the time frame of the two studies in Orlando is considered. The results of the two surveys also imply that there is stability over time in mode-choice attitudes, even over a period when significant changes occurred in socioeconomic factors generally related to mode choice. These results would therefore also tend to support similar stability in other areas over longer periods of time. This could be particularly important to other areas that might be considering updating existing mode-choice surveys.

Early attempts at modeling transit use in the Orlando, Florida, Urban Area Transportation Study (OUATS) assumed that the rather low use of the area's inadequate transit system would continue into the future. Direct generation of modal split and the forecast of automobile person trips locked the area into forecasts of low transit use both in the original study effort in 1965 and in the first update of OUATS in 1970.

In 1973, this shortcoming in the travel-forecasting procedures used in the area was corrected and a mode-share model was developed based on mode-share relationships found in the Minneapolis area. This model was calibrated to conditions in the Orlando area determined through a transit-attitude survey conducted in the area in 1973. The questionnaire used in this survey was designed to provide input into a mode-share model so that future patronage of alternative transit systems could be determined.

1978 TRANSIT-ATTITUDE SURVEY

In 1976, a major plan reevaluation was begun as part of OUATS (1). This major update of the transportation planning effort in the Orlando area necessitated validation of the model chain then in use. This validation effort was accomplished in the traditional manner by attempting to match existing highway ground counts with results from applications of the model chain based on existing conditions.

It was realized that the existing low use of the area's transit system would be extremely hard to duplicate through an application of the mode-share model developed in 1973 and therefore that the normal validation process could not be used. For this reason, it was decided that a second survey would be conducted in an attempt to determine whether transit-use attitudes had changed in the area. This survey would be used to validate the expressions developed from the 1973 attitude survey that were input to the mode-share model.

The purpose of the 1978 attitude survey was to determine whether opinions toward transit had changed since the original survey in 1973. An attempt was made to survey as many of the 1973 respondents or households as possible. In addition, the same questionnaire was used, with only minor revisions permitted.

The 1973 survey form was reviewed in an attempt to try to improve questions that might be misunderstood by those being interviewed. Additional questions were inserted to provide a check on the responses to certain questions. These revisions were minor in order to satisfy the Florida Department of Transportation's desire that the questionnaire not be changed from the basic format and terminology used in 1973.

COMPARISONS OF THE TWO SURVEYS

In 1973, a sampling procedure was developed to ensure that socioeconomic groups (determined by responses to the question regarding income) would be proportionately represented in the survey. The first step taken was to determine the proportion of households in each of the income groups from 1970 census results.

By using statistical error-limit analysis, it was calculated that the smallest income stratification group in the sample should be represented by 100 respondents (actually 97). Statistical error-limit analysis is based on the formula (2)

$$N = \pi(1 - \pi)(Z_\alpha/E_{max}) \quad (1)$$

where

N = sample size,
π = percentage of group that will respond in a certain way to a question,
Z_α = confidence point in the normal distribution, and
E_{max} = maximum acceptable error level.

If one assumes a maximum error of 10 percent and a confidence level of 95 percent, $E_{max} = 0.1$ and $Z_\alpha = \pm 1.96$.

The largest sample size for each income group would occur when the expression obtained its maximum value. This value would occur when $\pi = 0.5$ and $\pi(1 - \pi) = 0.25$, in other words, when the probability of a particular response is 0.5 and the probability of other than that response is also 0.5.

Therefore, the maximum sample size for each income stratification should be at least 97, as calculated by the following:

$$N = (0.5)(1 - 0.5)(1.96/0.1) = 96.04.$$

The other income stratifications were assigned sample sizes relative to the smallest group in the same ratio as that determined from the census, and the process of determining the original 1973 survey sample was accomplished. A total of 1588 interviews was conducted.

The 1978 telephone survey resulted in a total of 1337 telephone interviews. The sampling procedure used followed that established in 1973; however, many attempts were made to interview the same person interviewed in the earlier survey. If the attempts to talk to the same respondent were unsuccessful, attempts to interview another individual in the same household were made. If, after six attempts, a completed interview had not been made, another household in the immediate vicinity was selected by using a cross-referenced telephone directory.

The differences in responses to the income question in the two surveys appeared significant. To determine whether the differences in the income levels of the survey respondents were statistically significant, tests of the sample proportions were made. The procedure used tested whether two large samples represented the same universe or, in this case, whether the income grouping in the universe had changed. This test assumed that the proportions of one sample were equal to the proportions of the other sample. If this null hypothesis failed, it was assumed that the samples did not represent the same universe. The steps of this test are outlined below:

1. H_0: $\pi_1 - \pi_2 = 0$ (the null hypothesis, in which π_1 and π_2 are the assumed universe proportions of each sample);
2. $\alpha = 0.05$ [test with a level of confidence of 5 percent ($\alpha = 0.05$), which requires Z_α-values of ± 1.96]; and
3. Accept H_0 (if $-1.96 < Z < 1.96$).

The Z_α-value is obtained as follows:

$$\hat{\sigma}_{p_1 - p_2} = \sqrt{[\bar{\pi}(1 - \bar{\pi})/n_1] + [\bar{\pi}(1 - \bar{\pi})/n_2]} \quad (2)$$

where

$\bar{\pi} = (x_1 + x_2)/(n_1 + n_2)$,
$\hat{\sigma}_{p_1 - p_2}$ = standard error of difference between the sample proportions (estimated),
n = sample size, and
x = number of responses.

$$Z_\alpha = [(p_1 - p_2) - (\pi_1 - \pi_2)]/\hat{\sigma}_{p_1 - p_2} \quad (3)$$

where it is hypothesized that p is the sample percentage (x/n).

The results of this analysis are as follows:

Income Group ($)	Z_α	Comment
0-2999	1.64	$\pi_1 = \pi_2$
3000-5999	-0.71	$\pi_1 \neq \pi_2$
6000-8999	6.07	$\pi_1 \neq \pi_2$
9000-14 999	1.00	$\pi_1 = \pi_2$
15 000+	-6.44	$\pi_1 \neq \pi_2$

These figures show that changes in income stratification occurred in the Orlando area between 1973 and 1978. This result was expected because no attempt had been made to adjust income figures or to change stratification boundaries to account for inflation.

STATISTICAL COMPARISONS OF INDIVIDUAL RESPONSES

The comparison between the two surveys of responses to individual questions showed a remarkable amount of consistency. To determine whether the responses to individual questions from the two surveys were statistically the same, the process detailed above in Equations 2 and 3 was used. In this case, the test was conducted to determine whether the proportions represented in each response to the various questions indicated that the universe from which these proportions came had changed. If the null hypothesis failed, it indicated that the two survey proportions did not represent the same universe.

In general, the statistical evaluation of the responses to the two surveys indicated a high degree of stability in the population between 1973 and 1978. To further test the assumption that the two populations were the same, χ^2-tests were performed on those questions that provided direct input to the mode-share model. In this case, the χ^2-test was used to compare the matrix of responses to questions that concerned attitudes toward use of various system alternatives to the socioeconomic indicators that might cause those attitudes.

The results of the null-hypothesis χ^2-test indicate that there is a remarkable amount of stability of attitudes toward transit use in the Orlando area. Of the 32 cross-tabulations evaluated, only three indicated statistically significant differences in the survey populations. Two of the cross-tabulations that indicated significant differences dealt with trip purposes other than work or shopping compared with the need for a car at work during the day. A lack of clear trends in these cross-tabulations had been expected.

CONCLUSIONS

The close comparison of the results of the two surveys indicates that attitudes toward transit use in the Orlando area are not changing, at least not during this particular five-year period. These results were adequate to allow validation of the mode-share relationships established in 1973.

Although this validation is important, particularly to the Orlando area, there are other questions to which these results can be applied. A basic assumption of the urban transportation planning process is the stability of trip-making relationships over time. Other studies (3,4) have shown mixed results, and generally these studies were limited to trip-generation expressions.

The results in the Orlando area indicate that those relationships that might be used in modeling mode use do remain stable over time, at least for the purposes of short-range planning (three to five years). This is particularly significant when the time frame of the two studies in Orlando is considered.

The original survey was made in May and June 1973. This was before the Arab oil embargo. The resulting increased gasoline prices and general knowledge of an energy crisis apparently had little impact on the citizens of the Orlando area and their attitude toward mode choice. The significant changes in socioeconomic measures such as the price of gasoline and income were not reflected in significant changes in attitude toward mode choice.

The results of the two surveys also imply that there is stability over time in mode-choice attitudes, even over a period when significant changes occurred in socioeconomic factors, which are generally related to mode choice. These results would therefore also tend to support similar stability in other areas over longer periods of time. This could be particularly important to other areas in which updating of existing mode-choice surveys is being considered.

The results reported are of course limited to the specific events in the Orlando area between 1973 and 1978. Due to the extremely limited data base related to stability of trip-making characteristics over time, particularly for the mode-choice relationship, additional research is required to further verify this stability. This research should, where possible, consider longer periods of time and ideally should come from areas in which existing or historic use of modes other than the automobile is significant.

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Evaluation of the Barnstable County Public Transportation Demonstration Project

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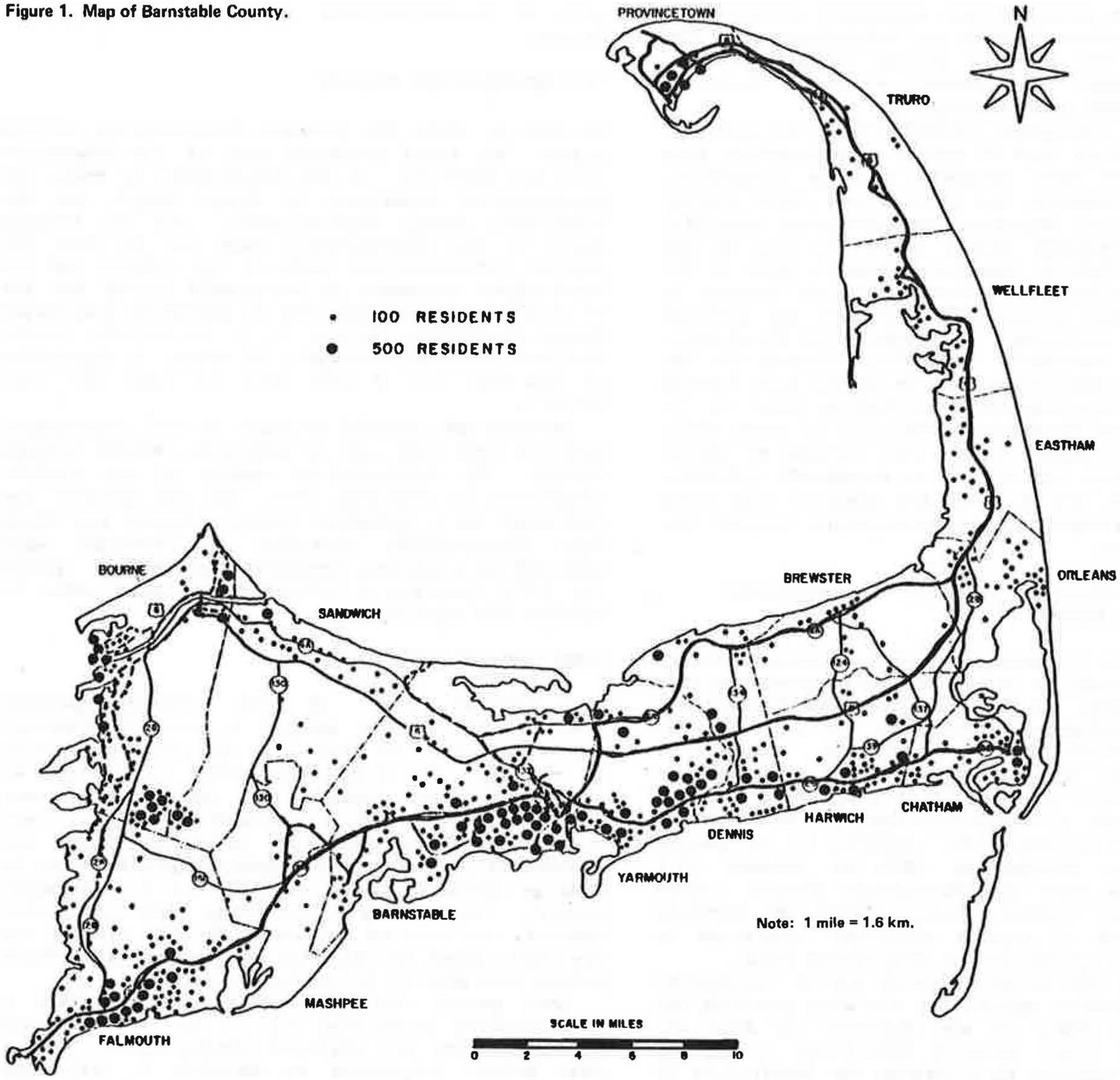
This paper evaluates the public transportation demonstration project in Barnstable County, Massachusetts [population, 130 000; area, 1008 km^2 (389 miles^2); 15 towns]. Service was provided with ten 12-passenger vehicles on a prearranged demand-responsive basis. The demonstration project operated for 22 months and was then continued on a permanent basis. The paper addresses various aspects of planning and design, which include preliminary project planning, program monitoring and evaluation, a rider-identification pass, data collection, user characteristics, system performance, financing, user attitudes, pricing, and simple supply-and-demand relationships. Major results and conclusions are that (a) some form of door-to-door public transportation service is necessary to meet the special needs of the elderly and the handicapped in small urban and rural areas; (b) consideration should be given to coordinating any new service of this type with similar existing services; (c) the system performance of such a service may need as much as 15 months to reach a stable condition; (d) the use of a rider-identification pass is a relatively low-cost simple mechanism by which to collect fares, market service, and obtain useful data; (e) attitudinal surveys may be helpful in determining user satisfaction and in identifying desired service changes; (f) consideration should be given to pooling various federal, state, and local funds to finance projects; and (g) any method used to apportion the local share of a deficit among towns may have to include a trip-length variable such as passenger kilometers if the desire of local officials is to base the apportionment on each town's level of use.

Section 313 of the Surface Transportation Act of 1978 amended the Urban Mass Transportation Act of 1964 by adding Section 18, which provides $75 million annually to finance the capital and operating costs of public transportation projects in rural and small urban areas. As a result of this federal action, a number of such projects will be implemented in the next few years. The general intent of this paper is to provide guidance to those involved in planning and designing such projects.

The paper provides an evaluation of a project that has been in operation for about two years in Barnstable County, Massachusetts. The first 22 months of the project were funded in part under the Federal Rural Public Transportation Demonstration Program (Section 147 of the Federal-Aid Highway Act of 1973). The paper focuses on this demonstration period and addresses various aspects of planning and design, which include preliminary project planning, program monitoring and evaluation, the use of a rider-identification pass, data collection, analysis of user characteristics and system performance, financing, the determination of user attitudes, pricing, and simple supply-and-demand relationships. We feel that the results of this paper will supplement the national Section 147 program evaluation currently being carried out by the Federal Highway Administration (FHWA) and several private consultants.

Figure 1. Map of Barnstable County.



DESCRIPTION OF BARNSTABLE COUNTY

Barnstable County is the governmental boundary of Cape Cod, a peninsula that extends seaward 128 km (80 miles) from the southeastern Massachusetts coastline. The Cape is in the shape of an elongated crooked arm that covers 1008 km^2 (389 $miles^2$) of flat or gently rolling terrain. There are 15 towns in the county; according to the 1975 official state census, they have a total population of approximately 130 000. The average population density is 130 persons/km^2. The areas of primary population density are in the Barnstable-Yarmouth and Falmouth-Bourne regions (Figure 1). Figure 1 also details geographically the population-density areas and the relationship of those regions to existing seasonally available transportation services of fixed-route carriers, which follow the major highways.

Those 60 years of age or older make up 26.5 percent of the total population of Barnstable County; this percentage is almost twice the national average as indicated in a report by the National Clearinghouse on Aging. The greatest concentrations of this age group are located from the town of Barnstable to Harwich along the south side of the Cape and across the Vineyard Sound side of Falmouth.

The permanent-resident population of Cape Cod is also characterized by low income levels. The median family income is now $9242, or 15 percent less than the state average. This problem is exacerbated by chronically high levels of unemployment. In February 1976, the unemployed totaled 18.4 percent of the population, or more than twice the national average, according to the Massachusetts Division of Employment Securities. Cape Cod's major highway, MA-6, stretches along the backbone of the peninsula and provides a limited-access four-lane road from the major routes on the mainland to South Dennis, two-thirds of the way out on the Cape. Roughly parallel on either side of this main artery are two state highways: MA-28 (commercial-resort zone) and MA-6A (residential, limited commercial zone). Both these roads service the high-density areas of the Cape and are fed by MA-6 through a connecting network of state and local roads. The focal points of transportation activity are the Hyannis, Falmouth, and Orleans areas. These three communities are the major employment and shopping centers within the county. Hyannis and Falmouth also maintain complete hospital facilities. It should be noted, however, that due to the elongated geography and decentralized community structure of the Cape, smaller shopping and employment districts do exist in the towns of Bourne (location of the county hospital and cancer clinic), Yarmouth, Dennis, Chatham, and Provincetown.

Today the geographic limitations of the Cape Cod peninsula and the lack of public transportation make it imperative that residents own an automobile. Employment, shopping, and medical and other similar services are all dependent on individual mobility, which in Barnstable County means the use of the automobile. This is especially true in light of the fact that existing fixed-route carrier service in this rural area is inadequate to meet the mobility needs of the residents. At present, the fixed-route carriers are extremely seasonally oriented for the high incoming populations of the months June through August. As the year-round population group of the elderly and the handicapped continues to grow, there is an ever-increasing number who, because of age or disability, find the use of an automobile difficult or impossible, and it is to the needs of this group that this transportation demonstration project has been addressed.

HISTORICAL DEVELOPMENT OF PUBLIC TRANSPORTATION IN BARNSTABLE COUNTY

In response to the need for public transportation in Barnstable County, a number of public-sector actions have been taken. In 1975, the Cape Cod Planning and Economic Development Commission, with a $40 000 technical studies grant from the Urban Mass Transportation Administration (UMTA), prepared a five-year public transportation program for the 15 towns that make up Barnstable County. This program was submitted in June 1976. Approval of the public transportation program by UMTA in January 1977 qualified the Cape Cod (Barnstable County) region for 80 percent federal funding toward the purchase or replacement of capital equipment identified in the five-year transportation development plan.

Under the UMTA grant, a rural public transportation demonstration application was also prepared and submitted to FHWA; it was approved on July 20, 1976. This grant enabled Barnstable County to purchase 10 vehicles to determine the feasibility of providing multipurpose demand-responsive transportation service on a countywide basis. During the two-year funding period, the experimental program was modified and improved as necessary to better suit the particular transportation requirements of Cape Cod residents.

In the fall of 1976, the county secured the assistance of the University of Massachusetts in Amherst to tabulate and analyze socioeconomic and travel-behavior data collection during the demonstration project. It is important to note that these data were collected for all riders through the use of a serially numbered identification card.

On October 12, 1976, at a meeting of the Barnstable County Selectmen's Association, 12 of the 15 towns in the county voted to form the Cape Cod Regional Transit Authority (CCRTA) under the provisions of Sections 2 and 14 of Chapter 1141 of the Acts of 1973 (Chapter 161B of the Massachusetts General Laws).

The Selectmen's Association on September 30, 1977, appointed a Transportation Advisory Board of five persons to advise the Barnstable County commissioners, CCRTA, the Selectmen's Association, and the county transportation administrator. CCRTA and the Selectmen's Association are made up of the same elected officials, and the Transportation Advisory Board provided significant input to CCRTA as the fledgling authority assumed a more-active role in transit-related activities in Barnstable County.

THE DEMONSTRATION PROJECT

On June 6, 1977, the 22-month demonstration service began. The total estimated cost of the demonstration was $623 625. It was cosponsored by FHWA, the Massachusetts Department of Public Works, and the Barnstable County commissioners. The two primary goals of the demonstration were (a) to meet the special transportation needs of the elderly and the handicapped residents of Barnstable County and (b) to determine the feasibility of providing countywide demand-responsive service in a low-density decentralized regional area with 15 towns, a population of 130 000, and a land area of 1008 km^2 (389 $miles^2$).

Service was provided by means of ten 12-passenger vehicles from 8:00 a.m. to 4:00 p.m., Monday through Friday. The demonstration status of the project terminated in February 1979, and the project was continued on a permanent basis. During the first four (three-month) quarters, the vehicles were operated by a private nonprofit corporation. During the fifth quarter, a private bus company began to operate the vehicles.

Rider-Identification Pass

An integral part of the demand-responsive demonstration is the use of a serially numbered rider-identification pass (1). The pass is acquired in advance at various Councils on Aging at designated times during the week. Each pass contains a four-digit identification number. Pass holders purchase quarterly stickers, which are affixed to the pass. The sticker allows a person to ride an unlimited number of times for a three-month period. During the first three quarters (nine months), the cost of a sticker for the elderly and the handicapped was $5. All others paid $7. These prices were doubled in the fourth quarter.

Each person who acquires a pass completes a questionnaire concerning his or her socioeconomic characteristics and physical disabilities. When a pass holder telephones to schedule a trip, the dispatcher records his or her identification number and the trip data. The use of pass, questionnaire, and driver log is relatively inexpensive. The annual operating costs associated with the pass were $2132, which amounts to less than 1 percent of the total operating costs. Some of the uses of the pass are discussed below.

Fare Collection

The pass is revalidated by CCRTA through the mail. After a person receives a pass, payment is made to the CCRTA office by check or money order. Three weeks prior to the end of the quarter, pass holders are sent a notice to remind them that the pass will become invalid and to encourage all pass holders to revalidate their passes. A self-addressed return envelope is provided to facilitate revalidation. Such a mailing process eliminates the need for the persons who distribute passes to handle cash or checks and reduces the potential of pilferage and theft of fare-box revenues.

Marketing

As mentioned previously, pass holders are sent a notice prior to the end of the quarter that encourages them to revalidate their passes for the upcoming three-month period. At the same time, brochures on the service and a survey questionnaire are enclosed. In sum, the mail-out, mail-in nature of the pass system provides a useful way to acquire information about user attitudes and to disseminate information on the program.

Evaluation of Vehicle Productivity and Efficiency

The daily driver logs and the operator's monthly cost invoices generate data that can be used to evaluate the productivity and efficiency of each vehicle. Typical vehicle-productivity measures are passenger trips per hour and passenger kilometers per hour. Efficiency measures include cost per vehicle hour and per vehicle kilometer.

These productivity and efficiency measures provide the operator and the CCRTA administrator with a means of continuously monitoring the performance of each vehicle. This will assist the CCRTA administrator in making recommendations to the rapid transit authority about potential operating changes. In addition, these measures could be used by state and federal departments of transportation to allocate operating subsidies.

Assessment of Local Deficit

CCRTA is presently addressing the following questions: How should the local share of the deficit be financed? Should a regionwide tax be imposed? Should town tax sources be used? If so, should each town pay on a per-capita basis or should some formula be developed based on each town's level of use? If so, should level of use be measured in terms of passenger trips, passenger kilometers, or some other parameter? The use of such formulas may require data that are provided by the pass-holder questionnaire and driver logs.

Identification of Social-Service Eligibles

Some persons are eligible for financial assistance for transportation purposes through various social-service agencies. The use of the pass-holder questionnaire allows CCRTA to identify potential social-service eligibles and inform them about available financial assistance. Steps have also been taken by the CCRTA administrator to make it easier for persons to receive such financial assistance. For example, CCRTA has prompted the Massachusetts Department of Welfare to reimburse eligible welfare recipients for the full price of a pass.

User Characteristics

Socioeconomic Characteristics

It is evident from Table 1 that the typical rider during the first 15 months of service was a woman who had no driver's license or automobile in her household. Table 1 also shows that the demonstration service was used at a disproportionately high rate by the county's female, retired, elderly, handicapped, and automobile-lacking populations.

Trip Characteristics

About half (50.4 percent) of all trips were made for work and shopping purposes. A higher proportion (60.2 percent) of work and shopping trips was made by the elderly and the handicapped riders. About one-quarter of all trips were made for social-recreational and health purposes.

The overall average trip length for all trips was approximately 15.4 km (9.61 miles). The average trip length for residents of each town ranged from 8.16 km (5.1 miles) for Barnstable to 33.92 km (21.2 miles) for Bourne. The relatively long trip lengths are due to the large percentage (44.0 percent) of trips between towns. These intertown trips accounted for 78.1 percent of all passenger kilometers.

Trip Frequency

The trip frequency of pass holders who had stickers increased steadily. From the first to the fifth quarters, the average number of trips made by pass holders with stickers was 6.28, 9.50, 9.90, 15.86, and 18.70. The relatively large increase from the third to the fourth quarter may be due in part to the doubling of the price of the sticker.

System Performance

Pass holders made 45 382 one-way trips in the first five quarters. Figure 2 gives a breakdown of one-way trips by month. It can be observed that afer 15 months, quarterly ridership had almost doubled, although the level of service had remained constant. More-specific measures of system performance, which include efficiency, productivity, and cost-effectiveness, are examined below.

System Efficiency

System efficiency can be defined as the relationship between system costs and input resources. Two measures of system efficiency are operating cost per vehicle hour and operating cost per vehicle kilometer. Operating costs for the purpose of this analysis include wages of drivers, dispatchers, and maintenance workers; gas, oil, tires, and parts; insurance; and administrative costs.

The monthly average operating cost ranged from $14.04/vehicle-h to $23.82/vehicle-h during the six-month start-up phase (June to November). The overall average for this period was $16.56/vehicle-h. This monthly average cost generally declined from December to August. It should be noted that the relatively high monthly average of $18.50/vehicle-h in February was due to several snow days on which no service was provided and drivers and other salaried employees were paid. The overall monthly average cost for this nine-month period was $13.67/vehicle-h. It is also interesting to point out that the overall monthly average cost in the fifth quarter (June, July, and August) was $12.77/vehicle-h. This is the first quarter during which the private bus company operated the system, and the decline in cost is due partly to the company's less-expensive in-house maintenance program. These operating costs are reasonable when compared with those of other systems. A recent analysis of 18 other demonstrations in rural areas reports a monthly average cost of $12.30/vehicle-h (2). These 18 demonstrations include a mix of service types (e.g., fixed-route and demand-responsive) and a variety of labor arrangements (e.g., paid drivers and volunteer drivers); consequently, direct comparisons between the Barnstable system and these other demonstrations are somewhat difficult to make. It is also worth noting that a study at the Massachusetts Executive Office of Transportation and Construction (3) suggests that systems that serve the elderly and the handicapped should operate at less than $14.00/vehicle-h.

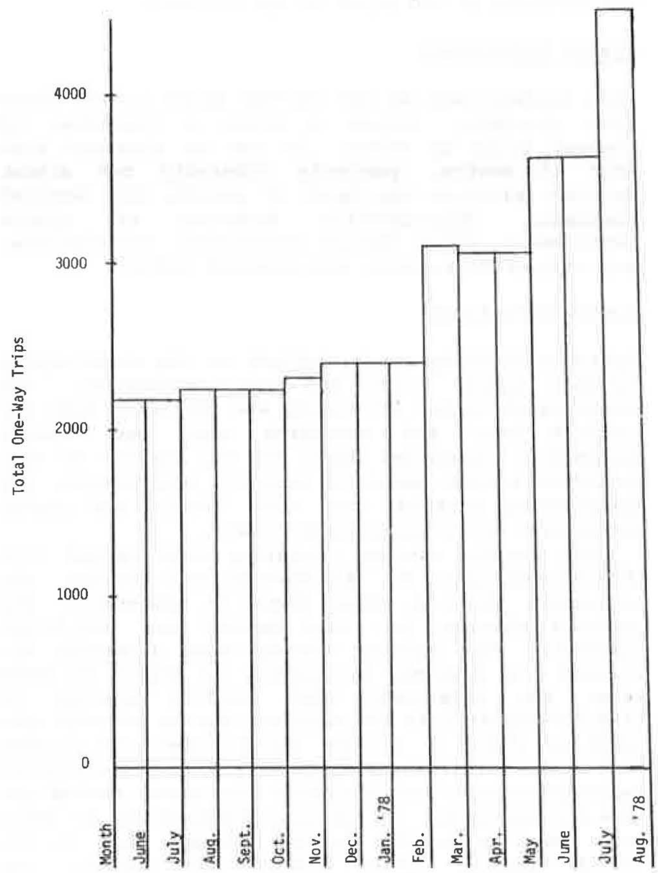
The monthly average cost varied from a low of $0.58/vehicle-km ($0.97/vehicle mile) to a high of $1.16/vehicle-km ($1.94/vehicle mile) in the six-month start-up period. From December to August

Table 1. Summary of socioeconomic characteristics of riders.

Characteristic	Percentage of All 1970 County Residents	Percentage of Riders per Quarter				
		First	Second	Third	Fourth	Fifth
Female	52.0	78.8	79.4	67.2	67.1	66.1
Aged 60 or older	22.9	59.5	59.4	48.7	48.1	44.4
Annual family income less than $5000	49.4	63.1	74.3	56.8	57.3	49.4
Retired[a]	11.8	47.6	45.1	36.1	32.8	33.2
Living alone or with one other person	31.7	68.6	67.2	55.9	55.2	50.5
Without automobile in household	8.7	66.8	75.5	58.1	58.9	62.0
Without driver's license	NA	76.5	82.2	67.8	71.1	71.3
With physical disabilities	9.0	30.8	44.5	34.0	32.2	32.8

[a]More than 60 years old and receiving Social Security.

Figure 2. One-way trips by month.



this cost ranged from $0.44/vehicle-km ($0.74/vehicle mile) to $0.63/vehicle-km ($1.05/vehicle mile). The overall monthly average cost during this nine-month period was $0.49/vehicle-km ($0.82/vehicle mile). The overall monthly averge in the fifth quarter was $0.46/vehicle-km ($0.76/vehicle mile). These operating costs are comparable with those of 15 rural systems in Pennsylvania in 1974 (4). The range for these systems was $0.02/vehicle-km ($0.04/vehicle mile) to $1.56/vehicle-km ($2.60/vehicle mile), and the average was $0.33/vehicle-km ($0.55/vehicle mile). The large variation is due in part to the fact that some of the systems in Pennsylvania receive volunteer service and donations. The average operating cost for the 18 other rural systems examined by Poka and others (2) was $0.35/vehicle-km ($0.59/vehicle mile). Again, it must be pointed out that these 18 systems include a mix of service types, and some use volunteer drivers.

System Productivity

System productivity can be defined as the relationship between output and input resources. Two common measures of productivity are passenger trips per vehicle hour and passenger kilometers per vehicle hour.

Passenger trips per vehicle hour increased more steadily and at a faster rate than did passenger kilometers per vehicle hour. During the first quarter, the overall monthly average of passenger trips was 1.51/vehicle-h; during the fifth quarter this average was 2.60/vehicle-h, an increase of 72 percent. The increase in passenger kilometers per vehicle hour from the first to the fifth quarter was 61 percent.

The average number of passenger trips per vehicle hour compares closely with those of other rural systems. During the fifth quarter of the Call-A-Bus system, it was 2.6/vehicle-h (5). This system served almost 200 km^2 (800 $miles^2$), which included the city of Syracuse and a considerable rural area. The average number of passenger trips on the Handibus system in Lincoln, Nebraska [service area, 203 km^2 (890 $miles^2$)] was 2.3/vehicle-h (5).

The average number of monthly passenger kilometers during the fifth quarter was 36.5/vehicle-h (22.6 passenger miles/vehicle-h), which was nearly twice that of the other two rural systems mentioned above. The number of passenger kilometers was 16.6/vehicle-h (10.3 passenger miles/vehicle-h) for the Call-A-Bus system and 21.3/vehicle-h (13.2 passenger miles/vehicle-h) for the Handibus system. The higher number of passenger kilometers per hour can be attributed to the longer trip lengths. The average trip length during the fifth quarter was approximately 14.3 km (8.8 miles).

Cost-Effectiveness

Cost-effectiveness is similar to productivity. It can be defined as the relationship between output and cost. Two measures of cost-effectiveness are cost per passenger trip and cost per passenger kilometer.

During the six-month start-up phase, the overall monthly average operating cost was $10.56/passenger trip; during the next nine months this overall average cost dropped to $6.17. It is also worth noting that this overall average during the fifth quarter (June, July, and August) was $4.97. These operating costs are comparable with those of other rural systems. Poka and others (2) reported that the average operating cost in 1977 ranged from $1.54 to $10.47/passenger trip for 18 other rural systems. Such costs have ranged from $3.50 to $7.50/passenger trip for van-type services in rural areas (2, p. 30).

The monthly average operating cost per passenger kilometer has also decreased steadily. During the first six-month period, the overall monthly average cost was \$0.60/passenger-km (\$1.00/passenger mile); this overall monthly average for the next nine months was \$0.39/passenger-km (\$0.23/passenger mile). During the fifth quarter, the overall monthly average dropped to \$0.34/passenger-km (\$0.20/passenger mile). The lack of passenger-kilometer data for a large number of rural systems makes it difficult to compare this measure with that of other systems.

Increasing the Price of a Pass

As mentioned previously, the prices of the sticker during the fourth and fifth quarters were \$10 for the elderly and the handicapped and \$14 for all others. During the first three quarters, these prices were \$5 for the elderly and the handicapped and \$7 for all others. After this price increase, sticker sales to elderly persons decreased at a greater rate (24.6 percent) than did sales to the nonelderly (13.4 percent). Other preliminary results of an ongoing analysis are as follows:

1. The number of male and female purchasers declined at similar rates;
2. Sticker sales to the nonhandicapped (27 percent) decreased at a greater rate than did sales to the handicapped (18 percent);
3. Sticker sales to those persons who had a driver's license decreased at about twice the rate of sales to those persons who did not have a driver's license; and
4. The sale of stickers to persons with an automobile available (44 percent) declined at a greater rate than did the sales to those without an automobile available (18 percent).

More-detailed results will be generated and used by CCRTA to develop future pricing policies.

Financial Analysis

The table below provides a breakdown of the costs for the demonstration. It is worth noting the different funding sources used in the project [which include Comprehensive Employment and Training Act (CETA) funds].

Expense	Funding Source	Amount Budgeted (\$)
Capital	FHWA	163 950
Operating	FHWA	82 150
	CETA	122 125
	County	60 000
	Pass sales	32 500
Subtotal		296 775
Programming	FHWA	121 900
	UMTA	41 000
Subtotal		162 900
Total		623 625

High initial costs were incurred for start-up reasons such as the need to purchase bulk supplies. After the first six months, this operating cost leveled off to about \$20 100 for the 10-vehicle system. Finally, it should be stated that the total capital, operating, and administrative costs of the demonstration over the 22-month period were slightly lower than the amounts budgeted.

As anticipated in the design of the system, there was an initial peak of revenue at the start of each three-month period. This initial high level of revenue was followed by a decline over an average six-week period to approximately \$200/week. A primary advantage to this method of revenue collection is the receipt within a four- to six-week period of the bulk of the revenue to be received over a three-month period. The large amount of prepaid bus revenue received early in the quarter assisted the management in judging cash flow from this source.

As previously mentioned, the quarterly sticker price was increased in the fourth quarter, which doubled the cost of quarterly pass renewal. Although there was some decline in the number of sticker holders, the revenue picture improved greatly. It is expected that there will be a continuing evaluation of the fare structure by CCRTA.

Simple Supply-and-Demand Relationships

The 10 vehicles operated in six basic service areas. Table 2 describes some of the service-area characteristics. The population of these service areas ranges from 6540 to 42 264, and the size of the areas ranges between 10 km^2 (3.8 $miles^2$) and 390 km^2 (141 $miles^2$). Each area was served by either one or two vehicles between the hours of 8:00 a.m. and 4:00 p.m. Figure 3 shows the relationship between one-way passenger trips per vehicle hour and population density (persons per square kilometer). The 60 points on the graph represent data for the six service areas over a 10-month period (July 1977 to April 1978). (The first month of service was excluded in the analysis because a full month of service was not provided, and dispatchers and drivers were still not totally familiar with the service areas.) The following linear regression equation was developed to further examine the relationship between trips per hour and density:

$$\text{One-way passenger trips/vehicle hour} = 0.001\,25\,(\text{population/area}) + 1.172 \quad (1)$$

The correlation coefficient was 0.84, which indicates a fairly high positive association between the two variables.

Another regression equation that helps explain the level of demand in each service area is

$$\text{Trips} = 0.037\text{ODU} - 217.53\text{COA} + 1.44\text{VEH-HRS} - 92.79 \quad (2)$$

where

trips = one-way passenger trips per month in each service area;
ODU = number of occupied dwelling units in service area;
COA = availability of Council on Aging bus service (no service, COA = 0; COA service available, COA = 1);
VEH-HRS = number of monthly vehicle hours of service in each service area; and
92.79 = constant.

This equation shows the level of positive association between trips and occupied dwelling units and vehicle hours, and the negative correlation between trips in a service area and the availability of a similar competing service. The multiple correlation coefficient for this equation is 0.95. All independent variables pass the t-test at the 10 percent level; the magnitude of the constant is 14.8 percent of the average number of one-way trips in a service area.

Attitudinal Surveys

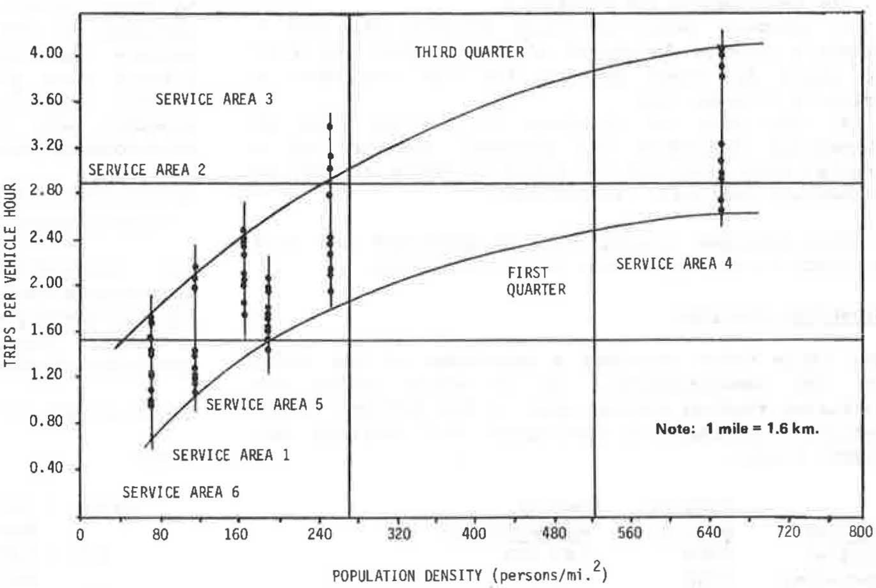
As mentioned previously, each pass holder is sent a letter three weeks prior to the end of a quarter. This letter encourages the person to purchase a sticker for the coming three-month period. In

Table 2. Service-area characteristics.

Characteristic	Service Area 1	2	3	4	5	6
No. of vehicles	2	1	1	1	2	2
Location	Falmouth, Bourne, Mashpee, Sandwich	West and south ends of Barnstable Town	North and east ends of Barnstable Town, also Yarmouth	Hyannis	Dennis, Brewster, Harwich, Chatham	Provincetown, Truro, Eastham, Wellfleet, Orleans
Population	41 163	23 899	39 143	6540	42 264	13 124
Land area (km^2)	390	148	161	10	205	200
Density (persons/km^2)	106	162	243	654	208	65
Percentage of population older than 60 years	18.8	23.6	27.9	23.6	32.2	26.7
No. of persons older than 60 years	7739	5640	10 921	1543	13 609	3504
No. of towns in service area	4	1	2	1	4	5
No. of towns in service area that had transportation available from Councils on Aging	3	0	0	0	1	1
No. of towns in service area that had car transportation available	4	1	2	1	4	3

Notes: 1 km = 0.6 mile.
Monthly hours of service for each service area ranged from 160 to 368, depending on (a) the number of days of service in a month and (b) the number of vehicles that operated in the service area.

Figure 3. Relationship between trips per vehicle hour and population density.



addition, a survey questionnaire is enclosed that pass holders are asked to complete and return. The questionnaire acquires information on the attitudes of the pass holder concerning the service. Some major results of one survey were as follows:

1. Approximately 90 percent were satisfied with the service;
2. Approximately 83 percent have recommended the service to others;
3. The largest area of complaint (36 percent) was that service hours were too restricted;
4. The service was an important form of public transportation on Cape Cod for 98 percent of those surveyed; and
5. Approximately 50 percent were willing to pay more for a quarterly sticker, and 95 percent indicated that they would take direct action if there was a threatened stop to the service.

The results of these surveys have led to proposed system changes. For example, steps are being taken by CCRTA to extend daily hours of service from 8:00 a.m. to 4:00 p.m. to 6:30 a.m. to 6:30 p.m. It was felt that these new hours will allow CCRTA to penetrate new markets, particularly the work trip. Alternatives that are being considered are subscription commuter-bus service and employer-based vanpools. Due to the preliminary results of the analysis on the increase in the price of the quarterly sticker (discussed previously), CCRTA is considering charging a higher user rate for this new service, since the majority will be nonelderly who travel at significantly higher trip rates.

CONCLUSIONS

A number of conclusions may be drawn from the foregoing evaluation of the Barnstable County public transportation project.

1. The project demonstrated that there is a need

for some form of door-to-door service to meet the special needs of certain segments of the population in small urban and rural areas. As shown in Barnstable County, these population groups, which include the elderly and the handicapped, are those who are unable to walk the relatively long distances characteristic of fixed-route services in low-density areas.

2. When any new service directed toward meeting the transportation needs of these population groups is being designed, consideration should be given to coordinating this service with similar services provided by agencies such as private nonprofit organizations. It was observed in the demand analysis that in demonstration service areas that had competing services provided by the Councils on Aging, the demand for the demonstration service was, on the average, lower. At present, CCRTA is consolidating the services of the demonstration project and similar public transportation services in the county. CCRTA has estimated that this consolidation plan will reduce total annual operating costs by 18 percent and will lead to steady increases in overall system productivity and cost-effectiveness (6).

3. When new services in small urban and rural areas are begun, it should be realized that system performance may vary considerably during the first year. Trends in productivity, cost-effectiveness, and efficiency show that, in the case of Barnstable County, it took about 15 months for the system to reach a stable condition.

4. The use of a rider-identification pass is a relatively low-cost simple mechanism with which to collect fares and obtain data. Uses of these data include monitoring vehicle productivity, efficiency, and cost-effectiveness; assessing local deficit; charging social-service agencies; and analyzing user characteristics.

5. Attitudinal surveys can be useful in determining user satisfaction with the system and identifying desired service changes. As cited, efforts are currently under way to provide new and expanded services to meet other public transportation needs for county residents. To meet the demand for work trips, employee- and employer-based vanpools and subscription-bus service are being considered.

6. Any method used to apportion the local share of a deficit among towns may have to include a trip-length variable such as passenger kilometers if local officials feel that the method should be based on each town's level of use. In the case of Barnstable County, results showed that the average trip length varies considerably among the residents of each town, which may prompt some local officials to question a method that employs only the number of trips made by each town's residents.

7. Consideration should be given to using a number of sources of funding available to finance public transportation services in rural and small urban areas. Limited funds from any one available source and periodic fiscal constraints being placed at all levels of governments make the use of one funding source difficult. As discussed, the demonstration used funds from FHWA, UMTA, CETA, and local tax sources. It should also be noted that after the demonstration phase, CCRTA also received funding from the State Executive Office of Transportation and Construction and entered into agreements with agencies under Titles III, VII, and XX. CCRTA also expects to receive assistance from FHWA under the new Section 18 program.

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Concept of Transportation Need Revisited

K. C. KOUTSOPOULOS

A new approach in considering the concept of transportation need is suggested based on the notion that need can be determined by considering the inverse of one's ability to adjust, for a given trip purpose, aspects of this trip in response to mobility constraints. By using this criterion, two indices of need (effectiveness and efficiency) can be constructed. The application of this approach to data on the handicapped in four areas (two urban and two rural) in Iowa indicates that that the needs of the handicapped are equally met in all four areas; however, the rural systems are less efficient than the urban ones in meeting that challenge. These results are in contrast to the results of the traditional approach (existing demand met), which show great spatial discrepancies between urban and rural areas.

The subject of travel and access for the transportation disadvantaged is based on the assumption that this group actually is in need. As a result, the transportation literature is full of studies that have decried, discussed, and described their needs and that argue that the handicapped should be provided with more transportation than they now use (1). None of these studies, however, has produced concrete measures of transportation needs nor has anything of substance been written on precisely how much transportation is needed. That is, important questions related to this problem have yet to be answered. For example, how much transportation does a person need? If someone needs more transportation than he or she now uses, should his or her unsatisfied needs be supplied in full? Therefore, the concept of need (as distinct from that of travel demand) has yet to be defined and made operational. Moreover, the approaches now in use to determine transportation needs (namely, the normative, the comparative, and the perceived-need approaches) have serious conceptual and operational, as well as logical, deficiencies (2,3), which suggests that a new approach to the concept of transportation need is necessary.

NEW APPROACH TO THE CONCEPT OF NEED

A new approach to the concept of need requires reexamining what constitutes need. To say that a person needs something or needs to do something is to say that that object or that act is necessary for that person. Need indicates a relationship, namely, that of a certain kind of necessity, between an object or an act (which is said to be what is needed) and a situation that consists of a set of circumstances (constraints) and an end state (4). Logically, then, the concept of need evolves around three separate yet interrelated dimensions--those of the end state, the act or the object needed, and the constraints.

End State

The end state is what is needed to obtain an object or to do something. The necessity expressed is therefore a prospective necessity, i.e., a necessity for something. The concept of need is inseparable from a reason or reasons. There has to be a purpose for needing something. Thus the understanding of travel as a derived demand can establish a basis for determining transportation needs, not only because travel-related activities are inherently imbedded in the notion of traveling, but mainly because they represent the reason or reasons why travel is needed (the end state) (5,6).

Trips to different travel-related activities assume different roles in the consumer's goal of getting satisfaction or fulfilling needs. Therefore, it is suggested that three major classes of travel-related activities can be defined based on the different ways in which they can satisfy the needs of someone living in a modern society (7): (a) subsistence activities that are necessary to generate income for the household (mainly work and business trips); (b) maintenance activities that are related to the purchase and consumption of goods and services (shopping and personal trips); and (c) leisure activities, or voluntary activities that take place during the remainder of the time not devoted to the first two activity classes (recreational and social trips).

Act or Object Needed

Given that need may vary according to the many aspects of the act needed (and conversely for the same aspect of the act needed), need may vary with respect to different end states and need can be qualified with regard to the act (or object) by which it is related to the end state; thus a two-dimensional matrix is created between end states and aspects of the act needed.

There are three important aspects of travel: (a) the spatial attributes, related to the spatial extent of the trip (range in terms of miles or minutes is the best example of such an attribute); (b) the temporal attributes, concerned with the rate of repetition of a given activity and the time that the various types of trips were taken; and (c) the linkage, which reflects the efficiency and flexibility of travel arrangement and includes multipurpose, multimodal, and multiperson trips (7).

Constraints

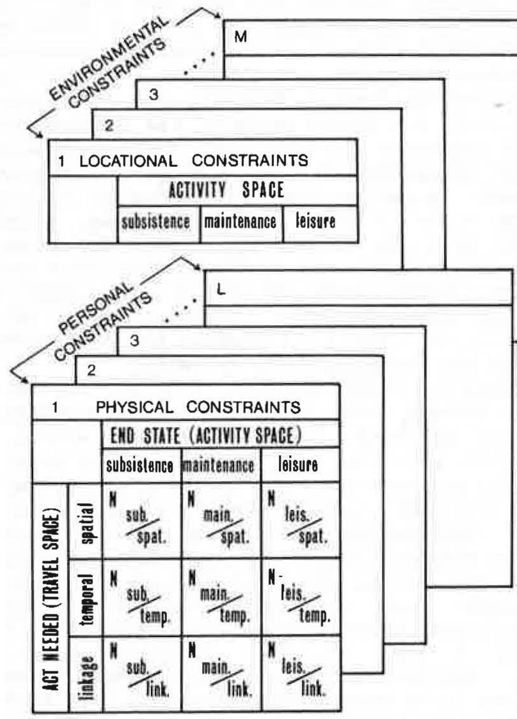
To say that a person does something because of necessity suggests a constraint. Need can therefore be further qualified with respect to the constraints related to the act needed and consequently to the end state.

The literature on transportation abounds with descriptions of factors that adversely influence (or constrain) travel. Based on a classification scheme presented by Koutsopoulos and Schmidt (8), we can divide that multitude of constraints into two groups: (a) environmental constraints imposed on a person by the physical and social environment, which could include locational constraints that result from the spatial distribution of various travel-related activities in relation to home location as well as planning and administrative shortcomings that impede travel, and (b) personal constraints, which result from a person's condition (physical or mental disabilities) as well as socioeconomic restrictions that adversely influence a person's ability to make a trip. By defining the travel constraints, the framework for determining transportation needs is now completed. Figure 1 schematically presents the three-dimensional matrix that focuses on basic factors that delineate transportation needs.

Adjustment

The conceptual framework just presented basically

Figure 1. Matrices of need.



holds that individuals in any area live in physical and social environments over which they can exert little control. These environments, however, are often changing due to exogenous complex-aggregate-level forces, which create what have been termed environmental constraints. In addition, during the course of the life cycle, as individuals grow older, get married, and have children or as their employment status or income changes, the personal constraints under which they operate also change. In the process, travel needs change or adjust to better match the new circumstances. Both environmental and individual changes invariably result in imbalances between existing ways of trip making and the ways that are necessary in order to compensate for the imposed constraints, which reflects the existence of transportation needs. Therefore, in order to determine transportation needs, it is necessary to examine how the act of traveling adjusts to modify trip-making imbalances (9).

The forms that the adjustments of the act of traveling can take include (a) spatial adjustments, which may include taking shorter trips as well as taking trips to activity nodes in different locations; (b) temporal adjustments, which may involve taking fewer trips or taking the trips at different times; and (c) linkage adjustments, which may involve combining trips for different purposes, carpooling, changing the number and type of vehicles used (also changing mode), and changing the destination or route.

Common sense dictates that a hierarchy and differences exist in these forms of adjustment. Therefore, in order to assess and quantify the various transportation needs, a criterion is required and a mechanism that can be made operational through the use of existing or obtainable data. The following criterion is suggested: Need can (and should) be determined by considering the inverse of someone's ability to adjust, for a given trip-related activity, aspects of his or her travel space in response to mobility constraints.

If one's ability to adjust the linkage aspects of his or her travel space (the act needed), which are characterized by a multitude of easily substitutable alternatives, is greater than, say, one's ability to adjust the spatial aspects (it is relatively difficult to find substitute nodes of the activity space at a shorter distance), then one's needs are far greater from a spatial point of view than they are from the point of view of the linkage characteristics. In a similar manner, if one's ability to adjust the aspects of travel space is greater for leisure activities, which are associated with highly price-elastic trips, than, say, to adjust for maintenance activities, which are characterized by price-inelastic trips, then transportation needs in terms of trips to subsistence activities are far greater than for trips to leisure activities. As a result, for a given mobility constraint, there exist at least nine groups of transportation needs, differentiated in terms of trip-related activities and travel-space aspects.

INDICES OF TRANSPORTATION NEEDS

The scheme proposed to identify, determine, and consequently differentiate transportation needs is shown in Figure 2, which is basically an enlargement of every individual square from the matrix of needs (Figure 1). For a given mobility constraint and for a specific activity and trip characteristic, this scheme classifies a group of persons as to their ability to adjust the specific aspect of their travel space and the availability of public transportation as a viable adjustment alternative. In terms of their ability to adjust, the group is subdivided into persons for whom the public transportation system is available and can provide a viable alternative in the adjustment process and those for whom the system is not available or cannot be a viable adjustment alternative. As a result, A and B in Figure 2 represent persons who in response to a constraint cannot adjust without the help of public transportation. These are the persons who have a public transportation need. Conversely, A and C represent persons for whom the system is a viable adjustment alternative. These are the persons for whose needs society provides transportation.

Based on this framework, two indices can be constructed. Need effectiveness is the proportion of persons who have a transportation need (cannot adjust on their own) and who are provided with a viable adjustment alternative (or alternatives) by public transportation: This is expressed as $T = A/(A + B)$. Need efficiency is the proportion of persons who do not have a transportation need (can adjust by using other means than public transportation) and who are not provided with a public transportation alternative or alternatives; this is expressed as $M = D/(C + D)$. Conceptually, these indices are identical to the sensitivity and specificity measures applied to medical tests (10). Therefore, in the same way that effectiveness and efficiency of various medical tests, for a given condition, are compared in terms of their relative sensitivity and specificity values, the need indices can be indicative of the effectiveness and efficiency, for a given mobility constraint, of a public transportation system or systems (in providing for the needs of a group of the transportation disadvantaged).

The important concept in this scheme is that an increase in the proportion of persons who have a

Figure 2. Criteria for identifying needs.

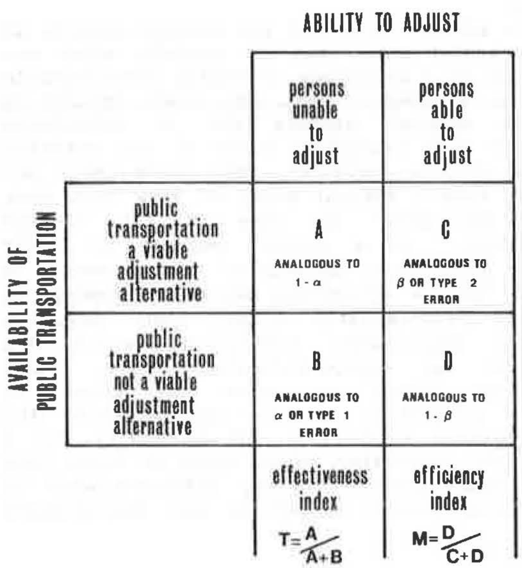


Table 1. Empirical results.

Area	Need Indices: Effectiveness (%)	Need Indices: Efficiency (%)	Demand Met (%)
Cedar Rapids	68.3	10.3	73.5
Ottumwa	58.1	10.0	71.5
Boone County	60.0	7.1	45.9
Area XV	56.3	4.5	42.3

transportation need and for whom the public transportation system is a viable alternative will result in a decrease in the proportion of persons who do not have a transportation need and are not provided with one (or more) viable public transportation alternative. Raising the need-effectiveness index requires lowering the need-efficiency index. The ramifications of this concept for transportation planning and policy decision making are paramount in that equity considerations advocate increases in the need-effectiveness indices, whereas concerns for fiscal austerity support increases in the need-efficiency index (11).

The need-effectiveness index can and should be used for comparing different public transportation systems, for federal monitoring and subsidizing, and for evaluating the transportation services offered to various transportation-disadvantaged groups within a specific service area. The need-efficiency index may be used to compare various transportation systems within the same community or across communities and over time to measure change. The need-efficiency index can also function as a performance criterion for federal monitoring and subsidizing and for evaluating the transportation services offered to various transportation-disadvantaged groups. The same index can be used in a transit system to compare the efficiency of subregions of a service area within the system. Thus, the need-effectiveness and need-efficiency indices provide an empirical basis for program evaluation of transportation needs.

EMPIRICAL RESULTS

From June 1, 1977, through May 31, 1978, staff members from the University of Iowa's Institute of Urban and Regional Research and the Iowa Department of Transportation participated in a joint research project concerned with the transportation situation for handicapped persons in Iowa. Basically, a two-part survey was used to determine the incidence, characteristics, and travel needs of the handicapped (12). With regard to the last task, the traditional approach of comparing existing demand with supply was followed. Based on the data collected on the four target areas of Cedar Rapids, Ottumwa, Boone County, and Area XV, it was found that the urban systems of Cedar Rapids and Ottumwa supply 73.4 and 71.5 percent, respectively, of the existing demand; in the rural areas of Boone County and Area XV, however, only 45.9 and 42.3 percent of the demand for trips by the handicapped are satisfied.

These figures, which indicate a great spatial discrepancy between urban and rural areas, although they are in agreement with conventional wisdom, become suspect when the data are reexamined under the framework proposed earlier. By using these same data, the two need indices were calculated (for reasons of comparability, all trip purposes and travel-space characteristics were condensed into one category). The results (Table 1) indicate that all four systems are equally effective (their need-effectiveness index ranges from a low of 56.3 percent to a high of 68.3 percent). Their efficiency, however, differs widely (the Cedar Rapids system is 50 percent more efficient that that of Area XV), which suggests that, although the needs of the handicapped are equally met in all four areas, the rural systems (as might be expected) are less efficient than the urban ones in meeting that challenge. Therefore, traditional approaches to determining transportation needs are inadequate in explaining and pinpointing the areas of concern. As a result, before we embark into service changes and improvements to meet such transportation needs, we should be extremely cautious. The fact remains that adding equipment or routes, especially to systems that are reasonably effective and that might marginally increase their effectiveness, would inevitably result in large decreases in their efficiency, a trade-off that might not be desirable given the present economic environment.

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Near-Side or Far-Side Bus Stops: A Transit Point of View

NADIA S. A. GHONEIM AND S. C. WIRASINGHE

The optimum location of a bus stop near an intersection is defined as that which minimizes the sum of the cost of time to passengers and the operating cost of buses. Two cases, controlled and signalized intersections, are presented in this paper. A theoretical approach is adopted. A near-side and a far-side bus stop are assumed in the vicinity of the intersection under consideration. The relevant costs are calculated and compared. The location that minimizes these costs is chosen. The optimum location is shown to be dependent on the demand for boarding and alighting from the bus at the near side or the far side and on the expected delay to the bus. Some simple rules are suggested. The method is illustrated by a numerical example to show the validity and practicality of the theory developed.

In the vicinity of an intersection, a bus stop may be located at the near side or at the far side. The two sides are defined by the Highway Capacity Manual (1) as follows:

> Near-side curb stops--located at the curb on the intersection approach in advance of the intersection proper.
> Far-side curb stops--located at the curb immediately beyond the intersection proper on the straight-through exit from the approach under consideration.

The Institute of Traffic Engineers (2) has issued guidelines and recommendations for locating stops. Terry and Thomas (3) conducted a field study on a portion of a major arterial street. Their analysis indicated that far-side stops tend to be more favorable in terms of reducing queuing, providing additional maneuvering space for vehicles, and avoiding delay to right-turning vehicles. However, Feder (4) recommended the near-side stop, since it allows the bus to achieve a shorter travel time over its route. For the case in which more vehicles turn right than left at the intersection, the far-side location was recommended. Bodmer and Reiner (5) summarized the advantages and disadvantages of both locations.

The choice depends on the different factors that have been discussed in the literature. However, in all the studies carried out, no attention was given to the effect of the location on the cost of travel time to passengers and on the operating cost of the bus system. In general, the near-side, far-side studies (3-4) have considered only choosing one of the two alternatives for the complete series of intersections along a specific route; intersections have not been considered separately. These studies are either simulations or field studies. No theoretical work has been carried out as far as we can ascertain.

The objective of this paper is to investigate the optimal location of bus stops in the vicinity of some of the most-common intersection configurations. The optimum location is defined as that which minimizes the sum of the cost of travel time to passengers and the cost of operating the buses. Other factors, not included in this study, are delay to traffic, effect on right-turning vehicles, parking conditions, effect on the capacity of the intersection, and safety, which is also a primary concern.

The procedure followed in the analysis is as follows. At each intersection, a near-side location and far-side location are assumed. The related costs are calculated and compared, and the location that minimizes these costs is chosen. General rules are given when it is possible.

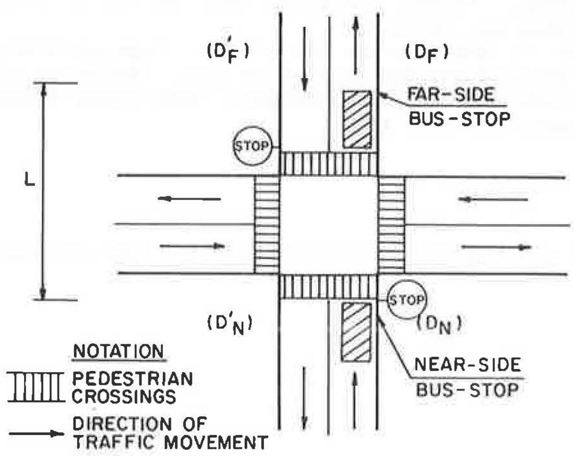
Other intersection configurations not discussed here can be analyzed in a similar manner (6). The general conclusion drawn from this analysis (which represents the transit point of view) and from other studies related to the near-side, far-side problem should provide a useful guide to transit planners and traffic engineers.

CONTROLLED INTERSECTIONS

Consider a four-leg intersection at which one of the streets (i.e., two opposite approaches) is controlled by stop signs (Figure 1). Buses operate on one or both approaches of the controlled street. The following analysis deals with either of the two approaches.

First, consider a near-side bus stop. It is assumed that the near-side bus stop is close enough to the stop sign so that the bus does not have to stop twice. Thus, if the bus stop was located on the near side, a bus would decelerate from its cruising speed to a stop in time t_B, load and unload passengers in time t_S, wait time t_G for a suitable gap to occur in the uncontrolled street, and then accelerate to its cruising speed in time t_A. The variables t_S and t_G are random

Figure 1. Controlled intersection.



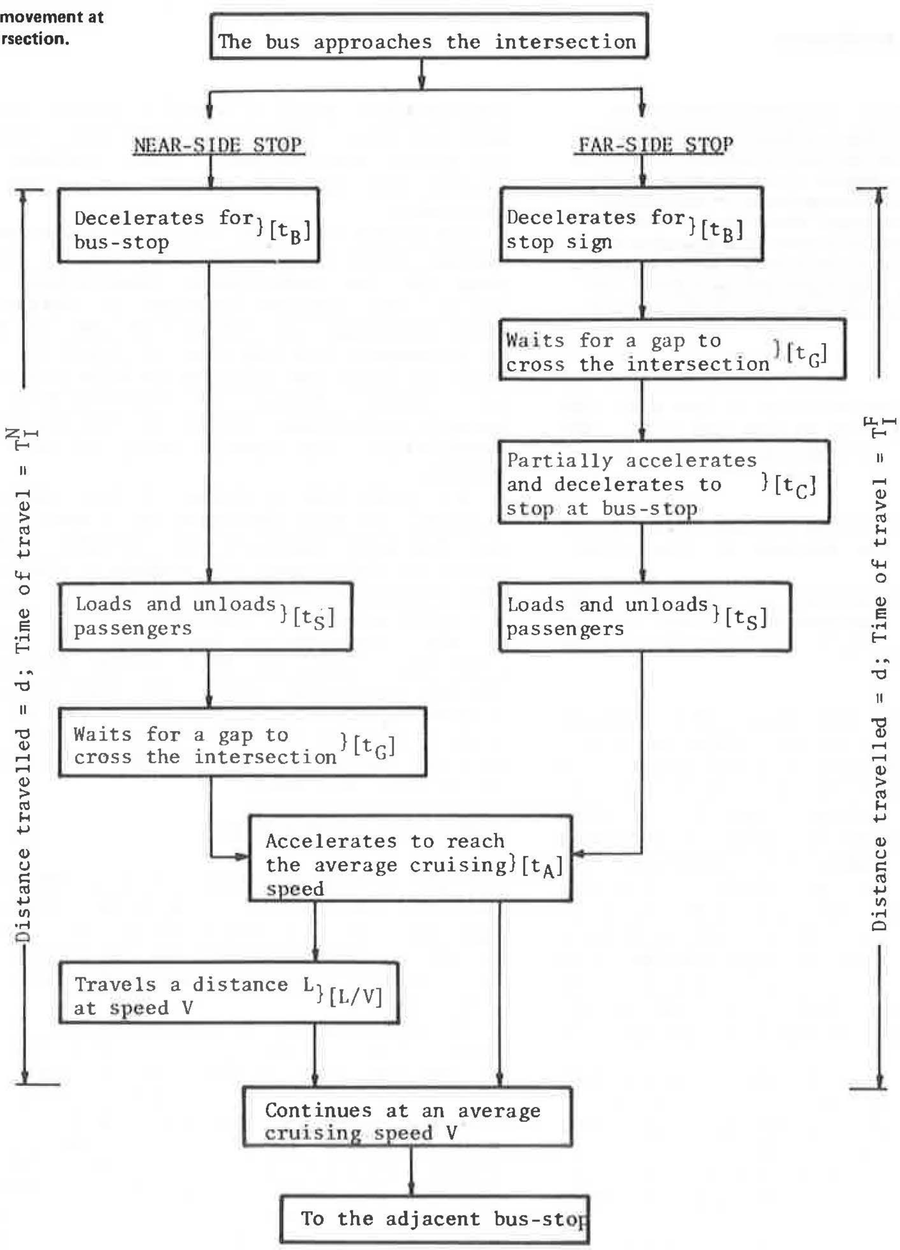
variables for which the expected values may be used for calculations. The dead time is included in t_S. This sequence is illustrated in Figure 2.

Second, consider a far-side bus stop. There a bus would decelerate from its cruising speed to a stop in time t_B, wait time t_G for a suitable gap in the uncontrolled street, cross the uncontrolled street by partially accelerating and decelerating to a stop at the far side in time t_C, load and unload passengers in time t_S, and then accelerate to its cruising speed in time t_A (Figure 2).

Thus, the only real difference between near-side and far-side bus stops as far as the movement of the bus is concerned is that the bus has to lose some time while it crosses the uncontrolled street.

Assume a far-side bus stop as shown in Figure 1. Distance L between the far-side and near-side stops may be obtained from field measurements. Assume that the maximum speed the bus reaches while it travels distance L during the partial acceleration and deceleration is V_0. Then

Figure 2. Bus movement at controlled intersection.



$$t_C = (V_0/A) + (V_0/B) \quad (1)$$

where A and B are the average acceleration and deceleration rates of a bus and

$$L = (V_0^2/2)[(1/A) + (1/B)] \quad (2)$$

From Equations 1 and 2,

$$V_0 = \{2L/[(1/A) + (1/B)]\}^{1/2} \quad (3)$$

and consequently

$$t_C = \{2L[(1/A) + (1/B)]\}^{1/2} \quad (4)$$

The actual time loss for a bus due to the acceleration and deceleration maneuver is the difference between t_C and the time (L/V) that it would take to cross the uncontrolled street at the cruising speed, i.e., $\{2L[(1/A) + (1/B)]\}^{1/2} - (L/V)$. This amount is relatively small and is possibly of theoretical interest only.

The costs associated with the location of the bus stop at the near side are the time for passengers to walk between the far side of the intersection and the bus stop, the additional riding time T_I^N for passengers inside the bus, and the bus operating costs related to T_I^N. The costs related to t_A, t_B, and t_S are independent of the location of the bus stop at the near side or the far side of the intersection. Therefore, these costs will not be included in the analysis.

The cost per unit of walking time for passengers who originate or have their destinations at the far side of the intersection is given by

$$(D_F + D_F')t_w\gamma_w \quad (5)$$

where

- D_F = combined far-side demand for boarding and alighting from a bus per unit of time on the right side of the intersection,
- D_F' = combined far-side demand for boarding and alighting from a bus per unit of time on the left side of the intersection,
- t_w = time for a passenger to find a gap and cross the uncontrolled street, and
- γ_w = average value of a unit of walking time to a passenger.

The relevant cost per unit of riding time for passengers inside the bus is expressed by

$$(P_0 + P - Q)[t_G + (L/V)]\gamma_R \quad (6)$$

where

- P_0 = total number of passengers inside a bus before it stops at the bus stop per unit of time,
- P = total demand for boarding a bus at the bus stop per unit of time,
- Q = total demand for alighting from a bus at the bus stop per unit of time, and
- γ_R = average value of a unit of riding time to a passenger.

The relevant cost per unit of bus-operating time at the intersection is given by

$$N[t_G + (L/V)]\gamma_B \quad (7)$$

where N is the number of buses that arrive at the stop per unit of time and γ_B is the operating cost of a bus per unit of time.

The total relevant cost (C_N) per unit of time for the location of the stop at the near side is then obtained by adding expressions 5, 6, and 7:

$$C_N = (P_0 + P - Q)[t_G + (L/V)]\gamma_R + [(D_F + D_F')t_w\gamma_w] + N[t_G + (L/V)]\gamma_B \quad (8)$$

Similarly, the different costs associated with the far-side bus stop are as follows.

The cost per unit of walking time for passengers who walk between the near side of the intersection and the bus stop is given by

$$(D_N + D_N')t_w\gamma_w \quad (9)$$

where D_N,D_N' is the combined near-side demand for boarding and alighting from the bus on the right and left sides of the intersection, respectively, per unit of time.

The relevant cost per unit of additional riding time for passengers inside the bus is given by

$$P_0(t_G + t_C)\gamma_R \quad (10)$$

and the relevant cost per unit of bus-operating time is given by

$$N(t_G + t_C)\gamma_B \quad (11)$$

By adding expressions 9, 10, and 11, the total relevant cost (C_F) per unit of time for the far-side stop is obtained:

$$C_F = P_0(t_G + t_C)\gamma_R + (D_N + D_N')t_w\gamma_w + N(t_G + t_C)\gamma_B \quad (12)$$

In order to evaluate the near-side and the far-side locations, the total costs C_N and C_F are compared. The best location from a transit point of view is that which minimizes the sum of the time costs for passengers and the bus-operating costs. The necessary condition for choosing the near-side location is $C_N < C_F$; i.e.,

$$(P_0 + P - Q)[t_G + (L/V)]\gamma_R + (D_F + D_F')t_w\gamma_w + N[t_G + (L/V)]\gamma_B < P_0(t_G + t_C)\gamma_R + (D_N + D_N')t_w\gamma_w + (t_G + t_C)N\gamma_B \quad (13)$$

Rearranging inequality 13, we obtain

$$(D_F + D_F' - D_N - D_N')t_w\gamma_w + (P - Q)[t_G + (L/V)]\gamma_R < (P_0\gamma_R + N\gamma_B)[t_C - (L/V)] \quad (14)$$

It is clear that inequality 14 is always true if the left-hand side is zero or negative, i.e., if the following conditions are satisfied concurrently:

$$(D_N + D_N') \geq (D_F + D_F') \quad (15)$$

i.e., the demand at the near side for boarding and alighting from the bus is greater than or equal to that at the far side, and

$$Q \geq P \quad (16)$$

i.e., the demand for alighting from the bus at the stop is greater than or equal to that for boarding.

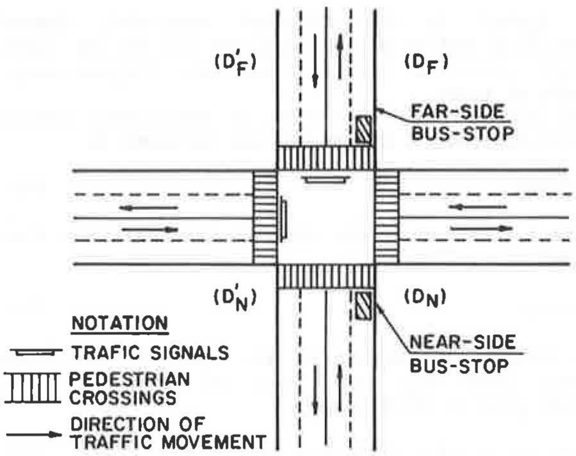
If any or both of conditions 15 and 16 are not satisfied, inequality 14 should be evaluated. It is also clear that the likelihood of a near-side bus stop increases as the frequency of service (N) increases and also as the number of people in the bus (P_0) increases.

ISOLATED SIGNALIZED INTERSECTION

Expected Signal Delay to Bus

Consider the isolated signalized intersection shown in Figure 3. Buses are assumed to arrive at the intersection at random times. When a stop is located at the near side, the time T_I^N may be described as shown in Figure 4, i.e., the sum of the deceleration time t_B to stop at the bus stop, the loading and unloading time t_S, the running time L/V, and, if the bus faces a green light after

Figure 3. Signalized intersection.



loading and unloading passengers, the acceleration time t_A; i.e.,

$$T_I^N = t_B + t_S + t_A + (L/V) \quad (17)$$

However, if the bus faces a red light,

$$T_I^N = t_B + t_S + T_N + t_A + (L/V) \quad (18)$$

where T_N is the interval of time (delay) between the moment the bus closes the doors after loading and unloading passengers and the moment the light changes to green.

When the stop is located at the far side of the intersection, T_I^F may be used to describe the case of encountering a green light or a red light on arrival at the intersection, as shown in Figure 4. If the bus encounters a green light, T_I^F is composed of the running time L/V, the deceleration time t_B to stop at the bus stop, the loading and unloading time t_S, and the acceleration time t_A. If the bus encounters a red light, T_I^F is equal to the sum of the deceleration time t_B to stop for the red signal, the delay T_F until the light turns green, the time t_C during partial acceleration and deceleration before the stop at the bus stop, the loading and unloading time t_S, and the acceleration time t_A.

The probability that a bus may encounter a green light or a red light on arrival at the intersection may be expressed by

$$P_G = G/C \quad (19)$$

$$P_R = R/C \quad (20)$$

Figure 4. Bus movement at signalized intersection.

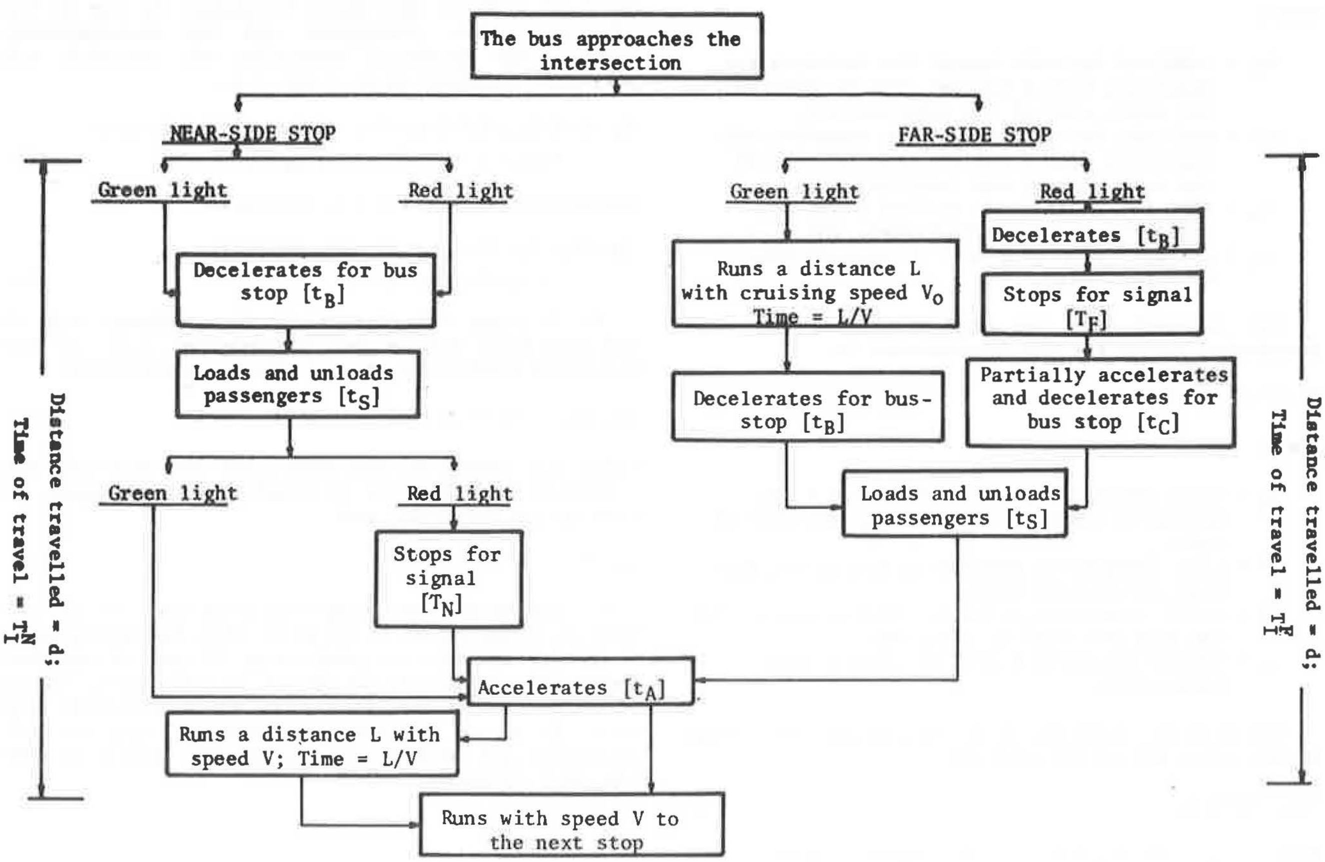
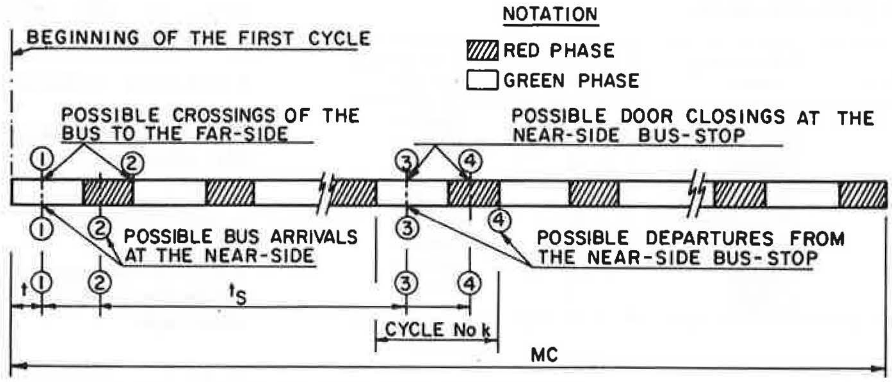


Figure 5. Possible moments of arrival and departure of bus within time period MC.



NOTE: ACTUAL ARRIVAL AT AND DEPARTURE FROM THE FAR-SIDE BUS-STOP IS NOT SHOWN.

respectively, where

C = cycle length,
G = green time plus yellow time, and
R = red time.

Alternatively, some proportion of the yellow time may be included in both the green and the red times.

The expected delay T_N associated with the location of the bus stop at the near side depends on the moment of arrival of a bus within a cycle, the loading and unloading time t_S, the cycle length C, and the signal split. However, the expected delay T_F for a far-side stop depends only on the signal at the moment of arrival, the cycle length C, and the signal split. The expected delays T_N and T_F may be determined for a near-side or a far-side stop, respectively, as follows.

Delay at a Near-Side Stop

Consider M consecutive cycles as shown in Figure 5. Assume that the bus arrives at the bus stop after a time t measured from the beginning of the first cycle. Let the loading and unloading time be t_S and let the bus be ready to depart within the kth cycle, where $k \geq 1$. In most cases, k is likely to be equal to 1 or 2. At the ready-to-depart time $t + t_S$, the bus might face a green light or a red light.

We assume that the probability density $f(t_S)$ of t_S is known. Since the intersection is isolated and buses arrive at random, the probability density of t is assumed to be uniformly distributed. A bus that is ready to depart within the green phase of any cycle will not be delayed. If the bus encounters a red light after the doors have closed, the expected delay associated with the possibility that a bus may arrive at any moment within the first cycle and be ready to depart at any moment within the red phase of the kth cycle may be calculated as follows.

Since t and t_S are random variables and if we assume that $t + t_S = t'$, we can write

$$F(t') = \int_0^{t'} \int_0^{(t'-t_S)} f(t) f(t_S)\, dt\, dt_S \quad \text{for } t > 0 \text{ and } t_S > 0 \tag{21}$$

where F(t') is the cumulative density function of the random variable t'. Then the probability density function of t' is given by

$$f(t') = dF(t')/dt' \tag{22}$$

If a bus is ready to depart from a near-side stop at a time t', it will be delayed by a period equal to kC - t'. Consequently, the expected delay associated with the possibility that a bus may arrive at any moment within the first cycle and be ready to depart at any moment within the red phase of the kth cycle is given by

$$E(\text{delay})_k = \int_{kC-R}^{kC} (kC - t') f(t')\, dt' = T_k \tag{23}$$

However, a bus may be ready to depart within any of the M cycles; therefore, the expected delay over all cycles is given by

$$E(\text{delay}) = \sum_{k=1}^{M} T_k = T \tag{24}$$

Delay at a Far-Side Stop

As described in Figure 4, no signal delay is associated with a bus arrival at the intersection within a green phase. If a bus encounters a red light on arrival at time t (as shown in Figure 5), the expected signal delay is C - t. The expected delay per bus is then R/2 and the expected signal delay T_F associated with the location of the stop at the far side is given by

$$T_F = (R/2)(R/C) \tag{25}$$

Expected Signal Delay to Passengers Walking to and from the Stop

Assume that the cycle for pedestrians at the intersection under consideration is given by

$$C = G_P + R_P \tag{26}$$

where G_P and R_P are green time and red time, respectively, for pedestrians. Obviously, a passenger who arrives at the intersection within G_P walks without delay to the opposite side. But for a passenger who arrives within R_P, the expected signal delay is

$$D_P = R_P/2 \tag{27}$$

Therefore, the total expected delay per unit of time for passengers who walk between the far side of the intersection and a bus stop located at the near side is

$$D_N^{P_1} = (D_F + D_F')(R_P/2)(R_P/C) = (D_F + D_F')(R_P^2/2C) \tag{28}$$

Table 1. Values of parameters.

Parameter	Value Used in Example	Parameter	Value Used in Example
A	0.4 m/s^2	γ_w	\$5.00/h
B	0.4 m/s^2	C	60 s
N	6 buses/h	G	35 s
t_w	10.0 s	R	25 s
P_0	150 passengers/h	M	2 cycles
P	19 passengers/h	L	37 m
Q	44 passengers/h	t_C	13.6 s
V	25 km/h	R_P	20 s
γ_B	\$15.00/h	t_p	17 s
γ_R	\$2.50/h		

For passengers who walk between the near side of the intersection and the bus stop located at the far side, it is

$$D_F^{P_1} = (D_N + D_N')(R_P/2)(R_P/C) = (D_N + D_N')(R_P^2/2C) \quad (29)$$

The signal delay for passengers who cross the street on which the buses operate is not included in Equations 28 and 29, since it is independent of the location of the bus stop.

In addition to the signal delay, a passenger spends time t_p to cross the street from one side of the intersection to the other side, at which the bus stop is located. The total crossing time per unit of time for $(D_F + D_F')$ and for $(D_N + D_N')$ passengers is given respectively by

$$D_N^{P_2} = (D_F + D_F')t_p \quad (30)$$

$$D_F^{P_2} = (D_N + D_N')t_p \quad (31)$$

As a consequence, the total cost per unit of time for $(D_F + D_F')$ passengers and for $(D_N + D_N')$ passengers between the moment of arrival at one side of the intersection and the moment of arrival at the opposite side, respectively, is

$$D_N^P = (D_F + D_F')[(R_P^2/2C) + t_p] \quad (32)$$

$$D_F^P = (D_N + D_N')[(R_P^2/2C) + t_p] \quad (33)$$

Total Cost

The total relevant cost is composed of the cost of additional riding time for passengers inside the bus, the cost of walking time and of delay for passengers who cross the intersection, and the additional operating cost for the bus at the intersection. For a near-side stop, the total cost is expressed by

$$C_N = (P_0 + P - Q)[T + (L/V)]\gamma_R + (D_F + D_F')[(R_P^2/2C) + t_p]\gamma_w + [T + (L/V)]N\gamma_B \quad (34)$$

For a far-side stop, the total cost is given by

$$C_F = P_0\{[(R/2) + t_C](R/C) + [(L/V)(G/C)]\gamma_R\} + (D_N + D_N')[(R_P^2/2C) + t_p]\gamma_w + [(R/2) + t_C](R/C) + [(L/V)(G/C)]N\gamma_B \quad (35)$$

Comparison of the Total Relevant Costs

The near-side location of the bus stop is preferred if

$$(P_0\gamma_R + N\gamma_B)\{T + (L/V) - [(R/2) + t_C](R/C) - [(L/V)(G/C)]\} + [(R_P^2/2C) + t_p](D_F + D_F' - D_N - D_N')\gamma_w + (P - Q)\gamma_R[T + (L/V)] < 0 \quad (36)$$

i.e., if the following conditions are satisfied concurrently:

$$T < [(R/2) + t_C - (L/V)](R/C) \quad (37)$$

i.e., if the expected signal delay for a bus when the stop is at the near side is less than that expected for a far-side bus stop;

$$(D_F + D_F') < (D_N + D_N') \quad (38)$$

i.e., if the demand at the far side for boarding and alighting from the bus is less than that at the near side; and

$$P < Q \quad (39)$$

i.e., if the demand for boarding the bus at the stop is less than that for alighting from it. If any of the above conditions is not satisfied, inequality 36 should be evaluated.

CONCLUSIONS

It may be concluded from the previous analysis that, in general, a near-side stop minimizes the sum of the travel-time costs to passengers and the bus-operating costs if the following simple conditions are satisfied concurrently:

1. The demand for boarding and alighting at the far side of the intersection is less that that at the near side;
2. The demand for boarding is less than that for alighting; and
3. The expected delay to a bus caused by a near-side bus stop is less than that caused by a far-side stop.

NUMERICAL EXAMPLE

Assume that the demands for boarding and alighting from buses per hour at a bus stop near an isolated signalized intersection are as given below:

Corner of Intersection	No. That Board	No. That Alight
Far side, left	5	15
Far side, right	7	10
Near side, left	4	7
Near side, right	3	12

Assume also that the values of the parameters are as given in Table 1.

Based on data from Chapman (7), the probability density $f(t_S)$ of t_S may be approximated by the gamma distribution shown in Figure 6 and given by

$$f(t_S) = [0.138/\Gamma(2.49)]\,0.138t_S^{1.49}[\exp(-0.138t_S)] = 0.0055t_S^{1.49}[\exp(-0.138t_S)] \quad (40)$$

Assume that $f(t) = \text{constant} = 1/C = 1.60$.

By following a numerical procedure to derive $f(t')$, the probability density function of t' is shown to be approximately normal (as shown in Figure 7) and is given by

$$f(t') = (1/\sigma\sqrt{2\pi})\exp\{-[(t' - \mu)/2\sigma]^2\} = (1/21.85\sqrt{2\pi})\exp[-(t' - 44.4)^2/2(21.85)^2] \quad (41)$$

Thus, the expected delay for a bus ready to depart from a near-side bus stop within the first cycle is

$$E(\text{delay})_1 = \int_{35}^{60} (60 - t')f(t')dt' \approx 6\text{ s} \quad (42)$$

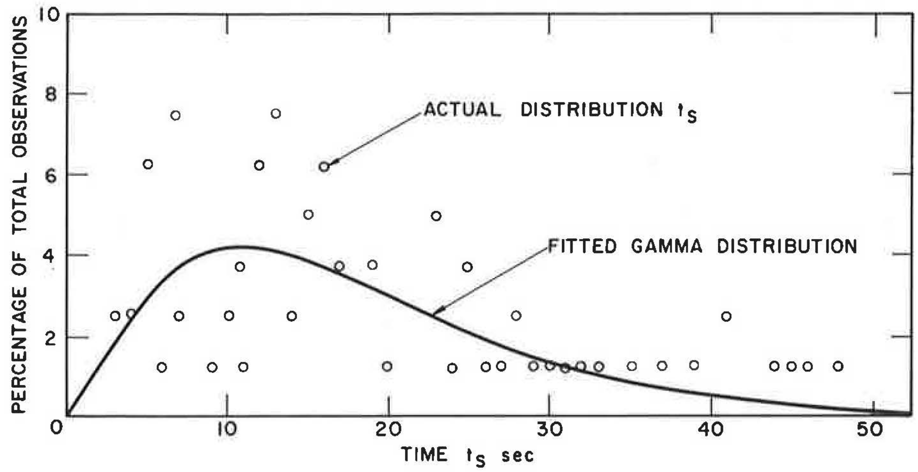


Figure 6. Probability density of t_S.

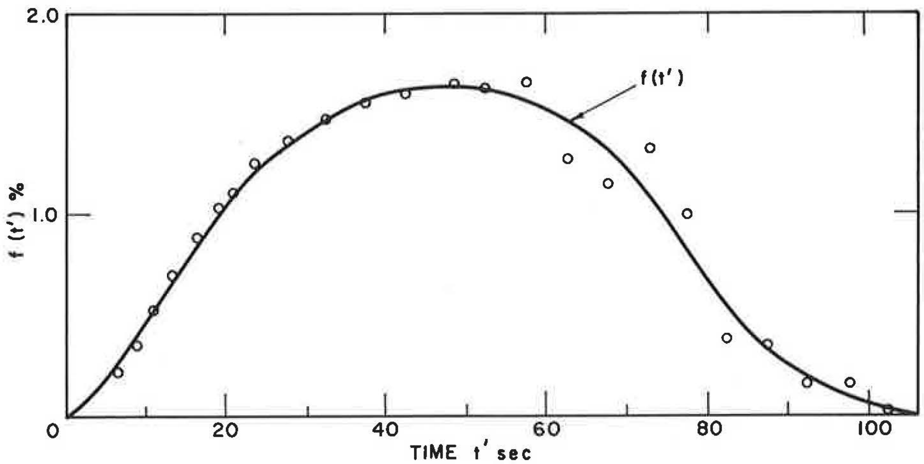


Figure 7. Probability density of t'.

The expected delay for a bus ready to depart within the second cycle is

$$E(delay)_2 = \int_{95}^{120} (120 - t')f(t')dt' \approx 0.0 \text{ s} \quad (43)$$

Thus, the expected delay for a near-side stop is 6 s.

If the bus stop is located at the far side of the intersection, the value of the expression $[(R/2) + t_C - (L/V)](R/C)$ in inequality 37 is given by

$$[(25/2) + 13.6 - (37 \times 6.94)] \times (25/60) = -96.1 \quad (44)$$

Since 6 is not less than -96.1, i.e., inequality 37 is not satisfied, inequality 36 should be evaluated to decide whether the near-side or the far-side stop is better: The left-hand side of inequality 36 = \$13.33/h.

Since 13.33 is not less than 0 (i.e., inequality 36 is not satisfied), the far-side stop is chosen. The saving obtained over the near-side stop, as far as the cost of time for passengers and the operating cost of buses are concerned, is equal to \$13.33/h.

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