examined: private firms, city-owned companies, and a city transit agency. It was found that there are differences in all aspects discussed among these three types of companies.

The private firms are the most cost-efficient and productive, as judged by the output measures or indicators used in the study. The private firms also appear most responsive to changes in the travel market and adjust their level of service to market demand. Nonetheless, several of the private firms studied would benefit from closer attention to travel demand patterns and from more knowledge of the market they serve.

The publicly owned or operated firms and agencies appear to have another objective besides efficiency, productivity, and profitability: to maximize patronage and social service, not to minimize subsidy. This begs the question of what purposes and goals are aided by maximized patronage and service. The political pronouncements about inexpensive, accessible public transit are necessarily vague. The large costs of public transit coupled with attendant subsidies behoove that the transportation profession require a deeper and more thorough discussion about the aims and objectives of subsidized public transit to determine whether the same goal may be achievable without subsidies and attendant complex decision-making processes.

Other findings of this paper, that subsidies and even sponsored service contracts lead to increased costs and reduced efficiency, are supported by findings elsewhere. Yet another finding is that profitable public transit, at least in some parts of the Helsinki region, is possible at a good level of service in attractively appointed buses.

Finally, even though no data are shown to support it, a contention is made that economies of scale and productivity studies must consider not only the output measures that reflect the use of the factors of production and the service provided but also the effectiveness of management of the transit firm or agency.

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Passenger Service Times for a No-Fare Bus System

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ABSTRACT

Passenger service times for a no-fare bus system are examined to show how the service time per boarding passenger varies with the size of the boarding group and the number of passengers already on the bus. These relationships are developed for two different occupancy conditions: (a) when the number of passengers on the bus before reaching a stop is less than or equal to the seating capacity of the bus (about 30), and (b) when the number of passengers on board is greater than the seating capacity of the bus (over 30). Simple and multiple regression analyses were performed to examine the effects of bus occupancy and the rank of boarding passengers on the service time per passenger. Both factors were found to influence passenger boarding times. When the number of passengers on the bus exceeded the seating capacity, the service time was more than 2 sec per passenger. When the number of passengers already on the bus was less than the seating capacity, the service time was approximately 2 sec per passenger. The difference in service times stems from the crowded conditions that result when the seating capacity of the bus is exceeded and standing passengers are jostling for position.

The time that a bus spends at a passenger stop represents a significant amount of the total time of its journey. These dwell times affect the quality of service, operating costs, and modal choice, and they vary with the operating environment, the type of bus, and the type of route. The time buses spend at passenger stops in the United States accounts for about 0.50 min/mi in the suburbs, 1.20 min/mi in the city, and 3.00 min/mi in the central business district (CBD). Delays at passenger stops generally exceed traffic delays in non-CBD areas; both delays are equal in the CBD. Overall, delays at passenger stops account for 9 to 26 percent of the total time of a bus journey (1).

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The time that a bus spends at a stop depends on how many people board or alight and how fast they do so. Both the dead times (the time spent at a stop when no passengers are boarding or alighting) and passenger service times at bus stops have been researched extensively in the United States and Europe (2,3). These studies have found that the time required for passengers to board or alight is influenced by many factors, including the type of bus; the number, width, and configuration of doors; fare collection policies; and peak versus off-peak conditions. The service time for passengers boarding buses without having to pay fares, for example, averages about 2 sec.

Although the overall relationships between these factors and the number of interchanging passengers are well established, in-depth analyses of how service times are affected by boarding passenger queue sizes and crowded bus conditions have been limited. A free bus system operating at the Storrs campus of the University of Connecticut was chosen to analyze how the size of a boarding group and the number of people on a bus affects passenger service times. This analysis quantifies the relationships between boarding group size, bus load factors, and passenger service times that apply to the specific bus operation in Storrs and to other similar operations. However, it should be noted that the bus system in Storrs, which is operated mostly by student drivers, does not represent a typical U.S. bus transit system.

The salient characteristics of the Storrs bus system were as follows:

- The buses had two single-channel doors;
- The front door of the bus was used for boarding and the back door for alighting;
- The buses were 30 ft long and 8 ft wide;
- The buses had a seating capacity of 30 persons;
- No fare was collected; and
- The buses were operated mostly by student (nonprofessional) drivers.

Field surveys of boarding passengers were conducted during May of 1984, when classes were in session. Two-person teams recorded passenger boarding times through the front doors of buses. The boarding time per passenger (in seconds) was defined as the time interval Δt, or $t_1 - t_2$, in which t_1 is the time when the passenger steps on the first step of the bus, and t_2 is the time when the same passenger steps on the top of the second step of the bus.

Fifty-eight passenger groups comprising a total of 364 passengers were surveyed. The frequencies of the boarding groups by size and by the number of passengers on board as buses entered stops are given in Table 1. Detailed passenger service time data are provided in Tables 2 and 3. A summary of passenger service time data for buses that had less than 30 passengers on board is provided in Table 2. Actually, data were only available for up to 20 passengers on board, but it is assumed that the same relationships would apply for up to a fully seated load. A summary of the data for buses that had more than 30 passengers on board is provided in Table 3.

TABLE 1 Frequency of Observed Boarding Groups by Size

Size of Boarding Group	No. of Passengers on Bus: 30 or Fewer	No. of Passengers on Bus: More Than 30	All Observations
1	3		3
2	5		5
3	5		5
4	5	2	7
5	2	4	6
6	2	4	6
7	3	5	8
8	1	5	6
9	1		1
10	1	6	7
11	1		1
12			
13	1		1
14			
15			
16	1		1
17			
18			
19	1		1
Total	32	26	58

ANALYSIS

The analysis was designed to show the direct effects of (a) the size of boarding group and (b) passengers who were already on the bus on (c) service times. To minimize the effects of alighting passengers, the data analyzed were limited to the following two cases when buses had seated loads:

1. The total boarding time was always greater than the total alighting time.

2. The size of the alighting groups was approximately the same in order to eliminate the effects on the time per boarding passenger because of differences between the number of boarding and alighting passengers.

The recorded data were analyzed in two phases. A preliminary analysis was performed on the aggregated data stratified only by the size of the boarding group. This preliminary analysis revealed two distinct clusters of data that corresponded to two different bus load conditions. A plot of the passenger service time against the number of passengers on board (Figure 1) shows that the first cluster of data covers the range of 4 to 20 passengers on board, whereas the second cluster covers the range of 32 to 42 passengers on board. Boarding groups ranged up to 19 passengers in size.

A further analysis stratified the data by boarding group size and by the number of passengers already on board. Two sets of boarding conditions were examined: when the number of passengers on the bus as it entered the stop was (a) less than and (b) more than the seating capacity.

The average boarding times, by passenger rank (equal to group size) when less than 30 passengers were on board, are provided in Table 4. It is shown that the number of passengers on the bus had no effect on passenger service times. The rank of the passenger in line had a slight effect on service time that became more pronounced when lines were longer.

A linear regression analysis produced the following relationship between passenger service times and each boarding passenger's rank in line:

$$t_p = 1.94 + 0.03\ r_p \qquad (1)$$

where t_p is the service time (in seconds) per boarding passenger, and r_p is the rank of the boarding passenger.

It was determined that Equation 1 was significant at the 95 percent level by using an F-test. The associated R^2 was .77. The rate of increase of the service time per boarding passenger was small; moreover, about 85 percent of the groups had less than 10 passengers. Therefore, for planning purposes, a service time per boarding passenger of 2 sec is appropriate.

TABLE 2 Observed Boarding Times per Passenger When Number of Passengers on a Bus Entering a Stop Is < 30

Observation No.	No. of Passengers On Board (n_p)	Rank of Boarding Passenger (r_p)																		
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
1	4	2.00	1.80																	
2	4	2.00	2.00	2.0	2.0	2.0	2.0	2.1												
3	5	2.0	2.0	2.0																
4	5	2.0	2.0	2.0	2.1															
5	5	1.9	2.0	2.0	1.9	2.0	2.0	2.0												
6	6	2.0	2.0	2.1	2.1	2.0	2.0													
7	7	1.8	2.0																	
8	7	2.0	1.8	2.0	2.0															
9	8	2.0																		
10	8	1.9	2.0																	
11	9	2.0	2.0	1.8	2.0															
12	9	2.0	2.0	2.0	2.1															
13	10	2.0																		
14	10	2.0	2.0																	
15	10	2.0	2.0	1.9																
16	10	2.0	2.0	2.1																
17	10	2.0	2.0	2.0	2.0															
18	10	1.7	1.9	2.0	2.0	2.0														
19	10	2.0	2.0	2.0	2.0	1.9	1.9	2.0	2.0	2.0	2.1									
20	10	2.0	2.0	2.0	2.0	2.0	2.1	2.1	2.0											
21	10	1.5	2.0	2.0	2.1	2.0	2.1	2.0	2.1	1.9										
22	10	2.0	2.0	2.0	2.1	2.1	2.1	2.0	2.1	2.2	2.2	2.2								
23	10	1.8	1.9	2.0	1.9	2.0	2.0	2.0	2.0	2.1	2.0	2.1	2.2	2.2						
24	10	2.0	2.0	2.0	2.0	2.1	1.9	2.0	2.0	2.0	2.2	2.2	2.1	2.2	2.3	2.3				
25	10	2.1	1.9	1.9	2.0	2.0	2.1	2.0	2.0	2.1	2.0	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5
26	11	2.0	2.1	2.0																
27	13	2.0	2.0	2.1	2.0															
28	13	2.0	2.0	2.1																
29	14	2.0	2.0																	
30	14	2.0	2.0	2.0	2.1	2.1	2.7													
31	15	2.0																		
32	20	2.1	2.0	2.0	2.1	2.2	2.2	2.2												

TABLE 3 Observed Boarding Times per Passenger When Number of Passengers on a Bus Entering a Stop Is > 30

Observation No.	No. of Passengers on Board (n_p)	Rank of Boarding Passenger (r_p)									
		1	2	3	4	5	6	7	8	9	10
1	32	2.0	2.1	2.0	2.1						
2	32	1.9	2.0	2.1	2.1	2.2	2.2				
3	32	2.0	2.0	2.0	2.2	2.1	2.2	2.20	2.30		
4	32	2.0	2.0	2.1	2.0	2.1	2.10	2.30	2.40	2.50	2.70
5	34	2.0	2.0	2.1	2.1						
6	34	2.0	2.1	2.0	2.2	2.3					
7	34	1.9	2.0	2.1	2.1	2.2	2.30	2.40			
8	34	2.1	2.0	2.0	2.0	2.1	2.20	2.30	2.50	2.70	2.90
9	36	2.1	2.0	2.1	2.20	2.30					
10	36	2.0	2.1	2.1	2.20	2.30	2.60	2.80			
11	36	2.0	2.2	2.0	2.20	2.20	2.50	2.60	2.80		
12	36	2.0	1.9	2.0	2.30	2.40	2.70	2.70	2.80	2.90	3.10
13	38	2.2	2.1	2.1	2.20	2.40					
14	38	1.9	2.0	2.2	2.30	2.40	2.60				
15	38	2.1	2.0	2.0	2.20	2.30	2.60	2.70			
16	38	2.0	2.0	2.1	2.40	2.50	2.80	3.00	3.10		
17	38	2.0	2.2	2.2	2.30	2.50	2.60	2.80	3.00	3.20	3.40
18	40	2.1	2.2	2.2	2.50	2.80					
19	40	2.0	2.1	2.3	2.60	2.80	3.00				
20	40	2.0	2.2	2.3	2.50	2.70	2.90	3.20			
21	40	2.1	2.2	2.4	2.70	2.90	3.00	3.20	3.60		
22	40	2.0	2.0	2.2	2.60	2.90	3.10	3.30	3.60	3.80	4.00
23	42	2.0	2.2	2.2	2.50	2.80	3.10				
24	42	2.1	2.2	2.4	2.70	2.90	3.20	3.50			
25	42	2.0	2.2	2.3	2.60	2.90	3.10	3.60	3.90		
26	42	2.0	2.0	2.2	2.70	3.00	3.20	3.50	3.80	4.0	4.10

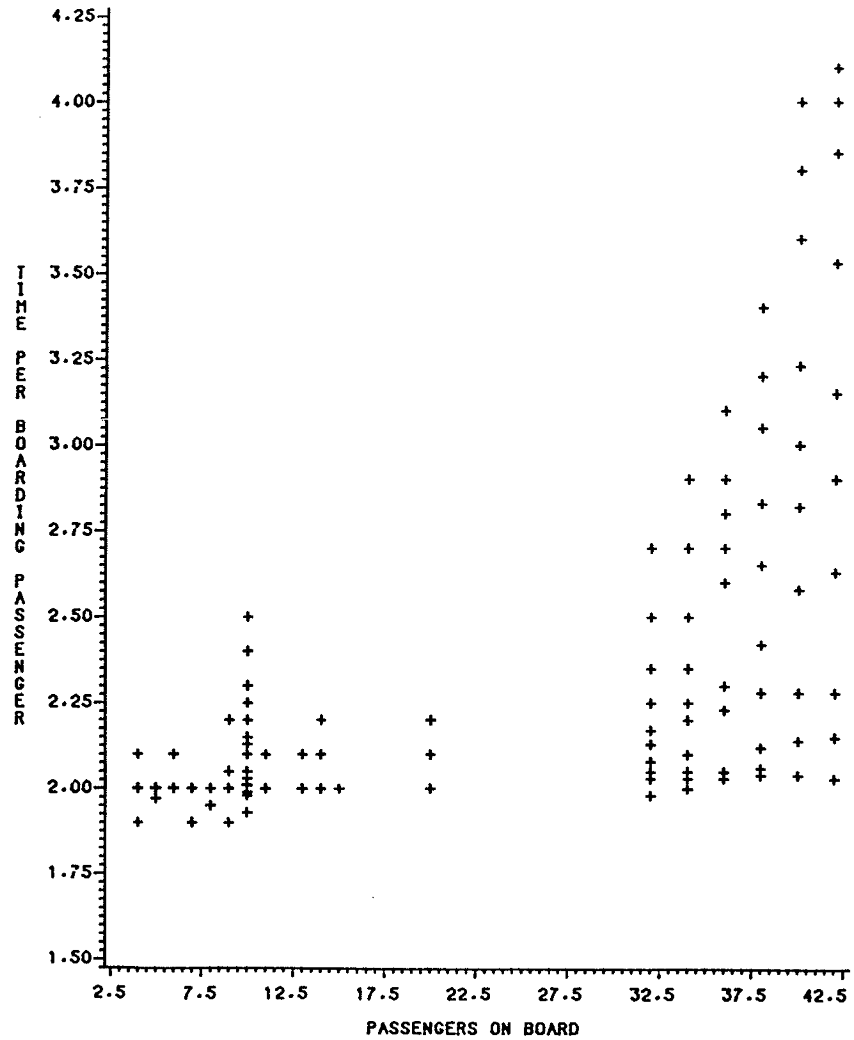

FIGURE 1 Time per boarding passenger (in seconds) versus number of passengers on board.

TABLE 4 Average Boarding Time per Passenger When Number of Passengers on a Bus Entering a Stop Is < 30

Passenger Rank (r_p)	Passengers on Board (n_p)												Avg Range of Service
	4	5	6	7	8	9	10	11	13	14	15	20	
1	2.0	1.97	2.0	1.70	1.95	2.0	1.93	2.0	2.0	2.0	2.0	2.1	0.20
2	1.90	2.00	2.0	1.90	2.0	2.0	1.98	2.1	2.0	2.0		2.0	0.20
3	2.0	2.00	2.1	2.0		1.9	1.99	2.0	2.1	2.0		2.0	0.20
4	2.0	2.00	2.1	2.0		2.05	2.01		2.0	2.1		2.1	0.10
5	2.0	2.00	2.0				2.01			2.1		2.2	0.20
6	2.0	2.00	2.0				2.01			2.2		2.2	0.20
7	2.1	2.0					2.01					2.2	0.20
8							2.03						
9							2.05						
10							2.10						
11							2.13						
12							2.15						
13							2.20						
14							2.25						
15							2.30						
16							2.30						
17							2.40						
18							2.40						
19							2.50						
Range	0.20	0.03	0.10	0.10	0.05	0.15	0.57	0.10	0.10	0.70		0.10	

TABLE 5 Average Boarding Times per Passenger When Number of Passengers on a Bus Entering a Stop Is > 30

Passenger Rank (r_p)	Passengers on Board (n_p) 32	34	36	38	40	42	Range
1	1.98	2.00	2.03	2.04	2.04	2.04	0.06
2	2.03	2.03	2.05	2.06	2.14	2.15	0.12
3	2.05	2.05	2.05	2.12	2.28	2.28	0.23
4	2.08	2.10	2.23	2.28	2.58	2.63	0.55
5	2.13	2.20	2.30	2.42	2.82	2.90	0.77
6	2.17	2.25	2.60	2.65	3.00	3.15	0.98
7	2.25	2.35	2.70	2.83	3.23	3.53	1.28
8	2.35	2.50	2.80	3.05	3.60	3.85	1.50
9	2.50	2.70	2.90	3.20	3.80	4.00	1.50
10	2.70	2.90	3.10	3.40	4.00	4.10	1.40
Range	0.72	0.90	1.07	1.36	1.96	2.07	

The average boarding times by passenger rank when more than 30 passengers were on board are provided in Table 5. It is shown that both the number of passengers on board and the rank of the boarding passenger had a pronounced effect on service times. This is also apparent in Figure 2, in which a graph is provided of the service time per boarding passenger (t_p) against the rank of the boarding passenger (r_p) for different values of the number of passengers on board (n_p).

The effect of the rank of the boarding passenger on service time becomes more pronounced when there are more than two passengers in line and when there are more than 36 passengers on board. A multiple linear regression was performed to predict the service time (in seconds) per boarding passenger from the rank of the boarding passenger and the number of passengers on board. The equation that resulted is as follows:

$$t_p = -1.56 + 0.16\ r_p + 0.09\ n_p \qquad (2)$$

where

t_p = service time per boarding passenger,
r_p = rank of boarding passenger, and
n_p = number of passengers on board.

It was determined that Equation 2 is significant at the 95 percent level by using the F-test. The R^2 is .86. Equation 2 is a good predictor of the service time per boarding passenger when, and only when, it results in service times of over 2 sec. Therefore, for combinations of r_p and n_p that give service times of less than 2 sec, a 2-sec value should be used. Accordingly, Equation 2 was found to apply under the following conditions:

- When the number of passengers on board is greater than 38 and for any group size (i.e., $n_p > 38$ $r_p > 1$).
- When the number of passengers on board is greater than 32 ($n_p > 32$, $r_p > 4$) and the group size is greater than 4.

The areas of applicability for Equation 2 are shown in Table 6. Any combination of r_p and n_p that results in a cell to the right of the dashed line in Table 6 defines the domain of applicability. Any combination of r_p and n_p that results in a cell to the left of the dashed line defines the area where Equation 2 does not apply; a time of 2 sec per boarding passenger should be used for this area.

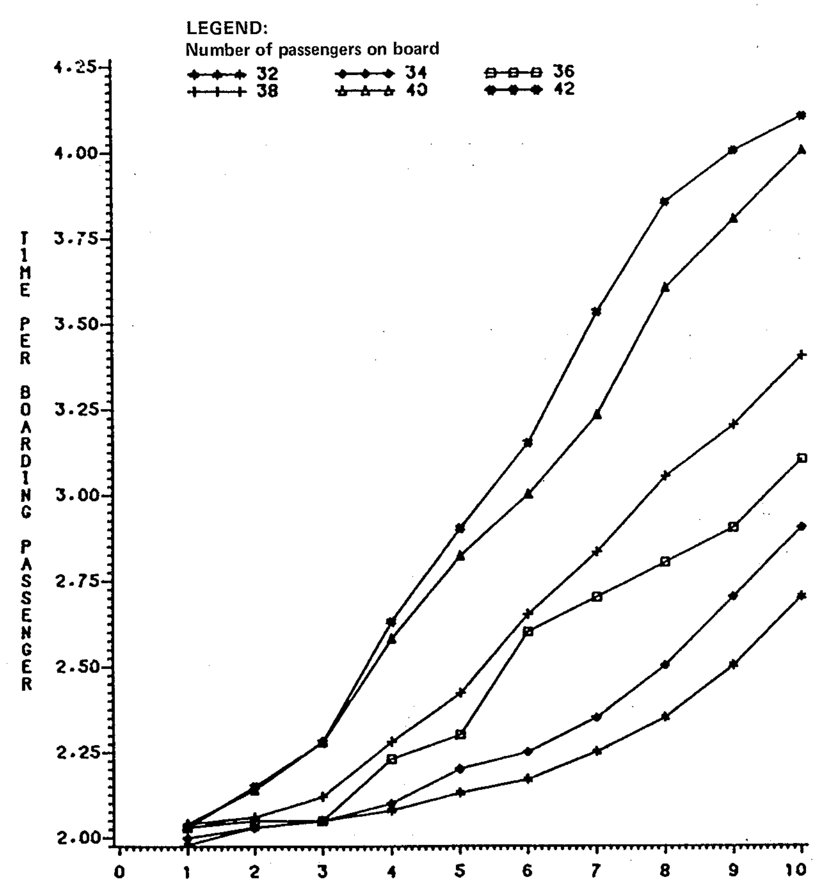

FIGURE 2 Time per boarding passenger (in seconds) versus passenger rank.

TABLE 6 Determination of the Area of Applicability for Equation 2

Passenger Rank (r_p)	Passengers on Board (n_p) 32	33	34	35	36	37	38	39	40	41	42
1	1.98	1.57	2.00	1.75	2.03	1.93	2.04	2.11	2.04	2.29	2.03
	1.98		1.66		1.84		2.02		2.20		2.38
2	2.03	1.73	2.03	1.91	2.05	2.09	2.06	2.87	2.14	2.45	2.15
	1.64		1.82		2.00		2.18		2.36		2.54
3	2.04	1.89	2.05	2.07	2.05	2.25	2.12	2.93	2.28	2.61	2.28
	1.8		1.98		2.11		2.34		2.52		2.70
4	2.08	2.05	2.10	2.23	2.23	2.41	2.28	2.59	2.58	2.77	2.63
	1.96		2.14		2.32		2.50		2.68		2.86
5	2.13	2.21	2.20	2.39	2.30	2.57	2.42	2.75	2.82	2.93	2.90
	2.12		2.30		2.48		2.66		2.84		3.02
6	2.17	2.37	2.25	2.55	2.60	2.73	2.65	2.91	3.00	3.09	3.15
	2.28		2.46		2.64		2.82		3.00		3.18
7	2.25	2.53	2.35	2.71	2.70	2.89	2.83	3.07	3.23	3.95	3.53
	2.44		2.62		2.80		2.98		3.16		3.34
8	2.35	2.69	2.50	2.87	2.80	3.05	3.05	3.23	3.60	3.41	3.85
	2.60		2.78		2.96		3.14		3.32		3.50
9	2.50	2.85	2.70	3.03	2.90	3.21	3.20	3.39	3.80	3.57	4.00
	2.76		2.94		3.12		3.30		3.48		3.66
10	2.70	3.01	2.90	3.19	3.10	3.37	3.40	3.55	4.00	3.73	4.10
	2.92		3.10		3.28		3.46		3.64		3.82

Note: The first number in each cell corresponds to the observed values of passenger service time, whereas the second number corresponds to values calculated by using Equation 2. When there is only one number per cell, this number corresponds to values calculated by using Equation 2. Cells to the right of the dashed line define the domain of applicability. Cells to the left of the dashed line define the area where Equation 2 does not apply; a time of 2 sec per boarding passenger should be used for this area.

A comparison of Equation 1 and Equation 2 shows the effect of crowded conditions on the bus on service time. For instance, the 10th passenger has a service time of 2.24 sec when the bus has less than 30 passengers on board, and a service time of 3.82 sec when the bus has 42 passengers on board. This difference is due to the jostling of crowded passengers as they attempt to make room for new passengers.

The combined effects of crowded bus conditions and the rank of a boarding passenger on the service time per boarding passenger were further analyzed through a series of simple linear regression models. A summary of these equations for a number of different bus load conditions is provided in Table 7. As indicated in Table 7, the rate of increase of passenger service time (t_p) is substantially higher when there are 42 passengers on board than when there are 32 passengers on board.

TABLE 7 Regression Equations Used to Predict Service Time per Boarding Passenger for Various Group Sizes and Numbers of Passengers On Board

Equation	R^2	Condition of Applicability
$t_p = 1.83 + 0.07\ n_p$	.87	POB = 32
$t_p = 1.78 + 0.10\ n_p$	.89	POB = 34
$t_p = 1.77 + 0.13\ n_p$	.96	POB = 36
$t_p = 1.71 + 0.16\ n_p$	.97	POB = 38
$t_p = 1.68 + 0.23\ n_p$	.99	POB = 40
$t_p = 1.65 + 0.26\ n_p$	.98	POB = 42

Note: t_p = time per boarding passenger; r_p = rank of boarding passenger; POB = passengers on board.

CONCLUSIONS AND APPLICATIONS

The service times of passengers boarding a no-fare bus were examined as a function of the number of passengers already on the bus and the rank in line of the boarding passenger. The following conclusions were made:

- The commonly accepted value of 2 sec per boarding passenger applies to uncrowded buses and to small groups of boarding passengers.
- Passenger service times appear to be greater when the bus is operating beyond its seating capacity and when there are more than two people boarding per stop. Under these conditions, the service time per boarding passenger increases linearly with the number of people already on the bus and the passenger's rank in line. The increase in service times reflects the crowded condition of the bus. These conclusions appear to be consistent with the findings of earlier studies that boarding and alighting times increased when passengers were standing because the seating capacity of the bus was exceeded (4).
- When buses were overcrowded, most of the jostling for position occurred in the space between the driver's seat and the alighting door in the middle of the bus.

Because the circulation space inside the bus depends on the square feet available per standing passenger, a bus designed to allow more space for standing passengers would tend to reduce passenger service times. Additional space is especially desirable when frequent stops, high load factors, and short trips are common. Some buses that operate in high-density routes provide this extra space. Aisles could be widened by eliminating one row of seats between the front and center doors or by providing transverse seating along one side of the bus.

It is also important to provide adequate reception space between the driver's seat and the boarding door. In this study, even when the bus was full, the time per boarding passenger did not increase for the first two or three passengers, because the reception space was adequate.

This pilot study was conducted for 30-passenger, no-fare buses with student drivers on a university campus. Similar studies should be performed on more typical urban bus systems with varying door arrangements, seating configurations, passenger mixes, vehicle sizes, and fare structures. The results of these studies could be transferred to current bus transit systems.

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Developing a Cost Model for Privately Contracted Commuter Bus Service

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ABSTRACT

Provision of public transportation services by the private sector is often cited as a strategy for reducing transit costs and required subsidies. Attempts to compare public agency and private contractor service costs for transit operations of a significant size are complicated, however, by the small number of comparable services now being provided and by the difficulty of comparing estimates of public and private costs when only a portion of the service delivery system is being contracted. An approach is presented in this paper to remedy one aspect of this cost comparison problem by developing a cost model for privately contracted commuter bus service. This model permits the full service costs of a privately contracted commuter bus operation to be estimated. The model utilizes a fixed-variable expense approach to estimate cost, and is based on information obtained from actual commuter bus contractors for two large transit systems. Capital charges, which depend on vehicle use as well as vehicle cost and contract length, represent a major portion of service costs. The model was applied to three situations and the results were satisfactory; it estimated route costs within 2 to 12 percent of the average actual values in each case. The model performed much better than two previously developed models and appears satisfactory for its intended purpose.

Provision of public transportation services by contracting with the private sector has become an important process for urban mass transit. UMTA recently published a formal policy on private enterprise participation in public transit service delivery, and the current UMTA leadership is vigorously promoting the concept of private-sector service contracting. Although many large transit agencies have resisted service contracting and the concept is strenuously opposed by transit labor unions, it is an increasingly prevalent method of transit service delivery. In a recent nationwide survey conducted by one of the authors, it was found that 25 percent of all individual transit services, which represents 8 percent of all revenue vehicle miles, is provided through private-sector contracting.

The primary motivation for private-sector contracting is economic in nature. Public agencies that contract for transit service almost invariably do so because they believe that it saves money. The evidence on cost savings is limited in scope, however, because of difficulties in finding comparable public and private services and the problem of accurately estimating public agency service costs when only a portion of the service delivery system is being contracted. These problems have motivated attempts to construct improved cost models to estimate the differences in costs between public and private service.

Most research efforts to date have focused on developing cost models for public agency service and have directed their attention to peak-period services in particular (1-3). With a single exception (4), analysts who have used cost models to compare public and private service costs have given only cursory treatment to the latter, and have typically relied on price quotations from private operators as the basis for their private-sector cost estimates (5). This approach is understandable in view of the difficulty of obtaining detailed data from private operators, who are reluctant to make such information available because they are concerned about competition. However, the lack of a structural basis

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