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Analysis of Maximum Load Data for an Urban Bus System

JAMES H. BANKS

ABSTRACT

Maximum load data are important indicators of transit route performance and are widely used in service planning. Maximum load data for the routes of the San Diego Transit Corporation were analyzed to provide an idea of the characteristics of such data and the range and patterns of variation they display. Major goals were to determine the general characteristics of the data, to analyze relationships between ridership and maximum loads, to compare variations in peak load factors among routes, and to compare successive data sets for the same route to assess the stability of the data over time. The most important characteristics of the San Diego data appear to be their overall variability and the high degree of randomness they display, the wide variation among routes in relationship between ridership and maximum loads, the relative stability over time of overall distributions of maximum loads and peak load factors, and the apparent instability of the exact times of day at which fluctuations in maximum loads occur.

Improvements in the performance of urban bus systems are usually achieved through a continuing process of monitoring and analyzing data about individual routes. Wilson and Gonzalez (1) refer to this process as "short-range transit planning" and identify two possible approaches. One of these, representing common current practice, focuses on identifying substandard route performance (whether it can be corrected or not); the other is based on identifying situations in which certain generic actions can be taken to improve performance. Both approaches involve systematic collection and evaluation of data about transit route performance. Consequently, one key to successful service planning is the ability to properly summarize and evaluate such data.

One important type of route performance data is that related to maximum loads. Peak load factors (ratios of maximum loads to seating capacity) are widely regarded as key indicators of the quality of transit service. In short-range planning, information about maximum loads has an important impact on decisions about scheduling, headway control procedures, and the assignment of equipment, especially where buses with different seating capacities are available. Maximum load data also have important implications for longer range planning decisions, particularly those related to the mix of bus sizes in the fleet.

Despite the evident importance of maximum load data, there is little published information on their characteristics or the best ways to summarize and use them. Discussions of the use of maximum load data [e.g., in the discussion of peak load factors in NCHRP Synthesis of Highway Practice 69 (2)] tend to be presented in general terms and without reference to the statistical characteristics of the data. Furthermore, little attention has been paid to the causes of variation in maximum loads. One study that does bear on this subject is a paper by Shanteau (3) who studied variations in loads at the maximum load point of a single high-frequency bus route and found them closely associated with variations in headway. Beyond this, there appears to be little or no published information; in particular, there do not appear to be any studies of variations in maximum loads for entire transit systems.

This lack of information is addressed here by presentation of an analysis of maximum load data for an entire urban bus system. This analysis involved two separate sets of data covering 27 of the 28 routes of the San Diego Transit Corporation (SDTC). Because the results obviously depend on the peculiarities of this system, they may not be representative of all urban bus systems; they are presented to suggest ways in which maximum load data can be analyzed and to give the reader a feel for the range and patterns of variation to be expected.

Analysis of the data involved comparisons of routes and, for the same route, of successive data sets. Major goals were to determine the general characteristics of the data, to analyze relationships between ridership and maximum loads, to compare variations in peak load factors among routes, and to compare successive data sets for the same route to assess the stability of the data over time.

DATA SOURCES

Primary data sources were summaries of boarding and alighting counts performed by the San Diego Association of Governments (SANDAG) on San Diego Transit Corporation routes. These summaries were available for 27 of the 28 routes in this system including 22 local routes and 5 express routes. In a few cases routes involved two or more branches; where this was the case, data for trips on the different branches were compared to determine whether the different branches should be analyzed separately. As it turned out, separate analysis appeared to be warranted in only one case.

The data summaries cover all scheduled one-way trips on the routes in question and include the dispatch time for the trip, the date the data were collected, the total number of passengers boarding and alighting, the maximum number of passengers on the bus at any point, and the seating capacity of the bus. It should be noted that the location of the maximum load point was not necessarily the same for every trip, so maximum load data in these summaries are not equivalent to load check data taken at maximum average load points.

Two sets of such summaries were analyzed. The first was derived from counts taken between February 1981 and December 1982, and the second from counts taken between September 1982 and April 1984. Surveys of individual routes in the two data sets were taken from 11 to 31 months apart, with an average difference of about 15 months. All data were taken on weekdays. Data for each route were taken over a period of several days and represent different days of the week; in particular, data for successive trips were normally not collected on the same day.

In addition to these summaries, time checks were used in some cases to determine whether headway control problems existed on particular routes, and summaries of the total number of passengers per day boarding, alighting, and remaining on board at each stop were used in selected cases to provide further insight into spatial peaking patterns.

GENERAL CHARACTERISTICS OF THE DATA

The data summaries described previously contain three basic items of information for each trip: the total ridership, the maximum load, and the seating capacity of the bus. Two additional measures, the peak load factor and the fraction of passengers on board at the maximum load point, may be derived from these. Let M represent the maximum load, R the number of passengers carried per trip, C the seating capacity, λ the peak load factor, and ϕ the fraction of passengers on board at the maximum load point. Then, $\phi = M/R$ and $\lambda = M/C$. The factor ϕ is an indicator of the degree to which loads peak in space, and λ is the basic measure of the operator's success in matching seating capacity with demand. Note also that R is not merely a function of the demand rate but also reflects the operator's scheduling policies, and that λ is a function of demand, frequency of service, and bus size.

The most striking characteristic of these data is their variability. Maximum loads are expected to vary with ridership and ridership to vary by route, direction, and time of day as demand rates and schedules vary. In addition to these variations, examination of the data showed that ϕ, the fraction of passengers on board at the maximum load point, also varies over a wide range, even for single routes, and that there are large irregular variations in all items of data between successive trips in the same direction on the same route. This suggests that there is a great deal of random variation superimposed on the time-of-day trends in the data.

If all scheduled trips in both data sets are considered, values of R range from 0 to 167, and M varies from 0 up to 81 for standard buses and 112 for 70-seat articulated buses. Values of ϕ are confined to a range of about 0.25 to 1.00 but tend to vary widely within that range, and values of λ range from 0.00 to 1.60. Figure 1, which shows the distribution of maximum loads for all one-way trips on one of the San Diego routes, provides some idea of the typical variation in maximum loads on individual routes.

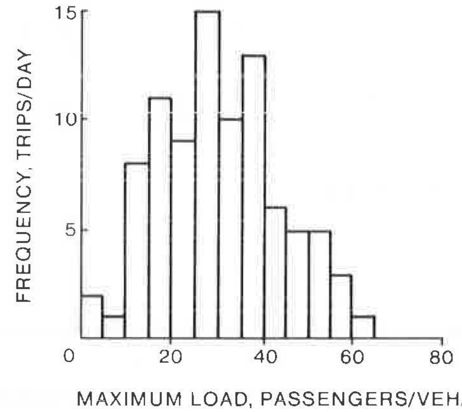

FIGURE 1 Distribution of maximum loads, SDTC Route 2, 1982 data.

RELATIONSHIPS BETWEEN RIDERSHIP AND MAXIMUM LOADS

Maximum loads are expected to vary with ridership. The results reported by Shanteau (3), for instance, appear to imply that maximum loads depend on ridership; that ridership, in turn, depends on the actual time separation between buses; and that all other influences make only minor contributions to variations in maximum loads. The San Diego data, on the other hand, appear to indicate that relationships between ridership and maximum loads may vary considerably, both between routes and for a single route. Figure 2 shows distributions of ϕ for two

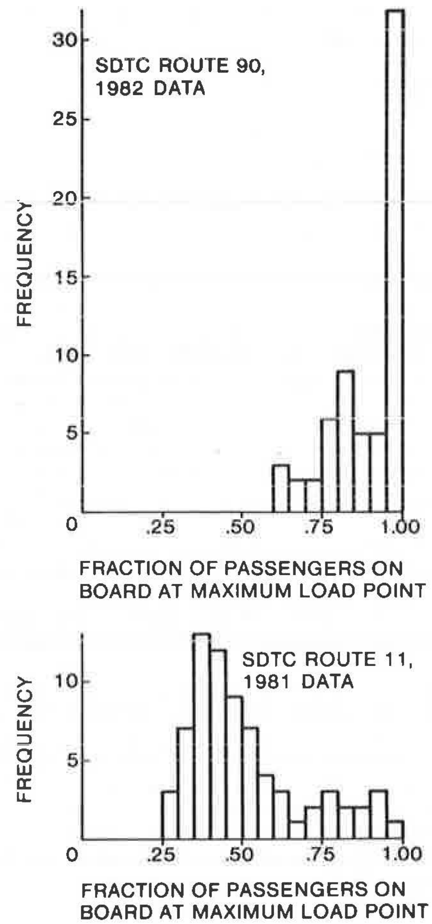

FIGURE 2 Comparison of distributions of fraction of passengers on board at the maximum load point for two San Diego bus routes.

San Diego routes that represent extreme cases. Note both the breadth of the distributions and the differences between them.

Values of ϕ for individual trips represent spatial load peaking and result from passengers' travel patterns. In particular, they depend on origin-destination patterns and, for highly dispersed origin-destination patterns, on average trip lengths. At one extreme, ϕ will be 1.00 when all passengers are on board at the maximum load point. For less concentrated origin-destination patterns, a minimum value may be estimated by considering, as an ideal case, the so-called steady-state many-to-many origin-destination pattern, the load profile of which is shown in Figure 3. For this case, all passengers

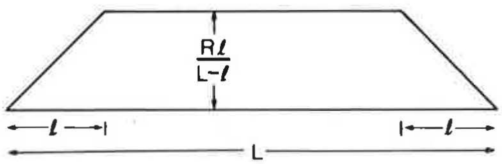

FIGURE 3 Load profile for steady-state many-to-many origin-destination pattern.

are assumed to have equal trip lengths of ℓ and boarding and alighting rates are assumed to be equal except within a distance ℓ of the ends of the route, leading to a trapezoidal load profile. If β represents the ratio of the trip length ℓ to the route length L, the value of ϕ for this case is $\beta/(1 - \beta)$. Assuming that minimum values of β are on the order of 0.20 in San Diego, this implies minimum values of ϕ of around 0.25. Figures 4 and 5 show plots of M versus R for the same routes the ϕ-distributions of which were compared in Figure 2, with the limits discussed previously superimposed for purposes of comparison. Note that the relationship between M and R is not necessarily linear, especially for small values of R, and that there is considerable scatter in the data.

If relationships between ridership and maximum loads depend on passengers' travel patterns, they should vary by route, and these variations should depend on the functions of the various routes in the system and the types of trips they serve. To test this hypothesis, the San Diego routes were divided into four categories: express routes, local routes, terminating in the central business district (CBD), local routes passing through the CBD, and local routes not serving the CBD. To compare these, two alternative measures of the relationship between ridership and maximum loads were calculated for each route. One of these was a weighted value of ϕ, defined as $\hat{\phi} \equiv \Sigma M/\Sigma R$. The other was the regression slope for the line of best fit for M versus R. Because there is apparent nonlinearity in this relationship, especially for trips with small values of R, trips with R less than 10 were arbitrarily excluded. Note that both measures were designed to give more weight to heavily traveled trips than would the mean value of ϕ; this was done because spatial peaking on lightly traveled trips has little impact on the operation of the system.

A summary of the results is given in Table 1. Note that both measures yield similar results, although the regression slopes exhibit a somewhat greater range than the values of ϕ. Both measures are obviously much higher for express routes than for local routes (with the exception of one local route); for local routes, the ranges of both measures are broad and overlapping, although there appears to be some tendency for non-CBD routes to have higher values of $\hat{\phi}$ than CBD-oriented routes and for routes terminating in the CBD to have higher values of $\hat{\phi}$ than those that pass through. The variations among individual local routes do not appear to be closely related to any other route characteristic, such as route length, however.

Values of ϕ for individual routes may vary by time of day, depending on the types of trips served at different times of day, or randomly. If there are definite time-of-day trends, they may affect the timing and magnitude of peaks in maximum loads, depending on whether peaks in ϕ coincide with peaks

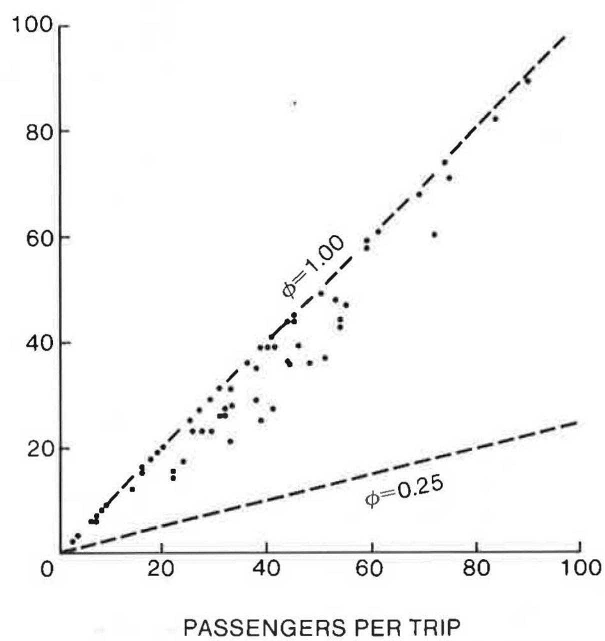

FIGURE 4 Maximum load versus passengers per trip, SDTC Route 90 (express route), 1982 data.

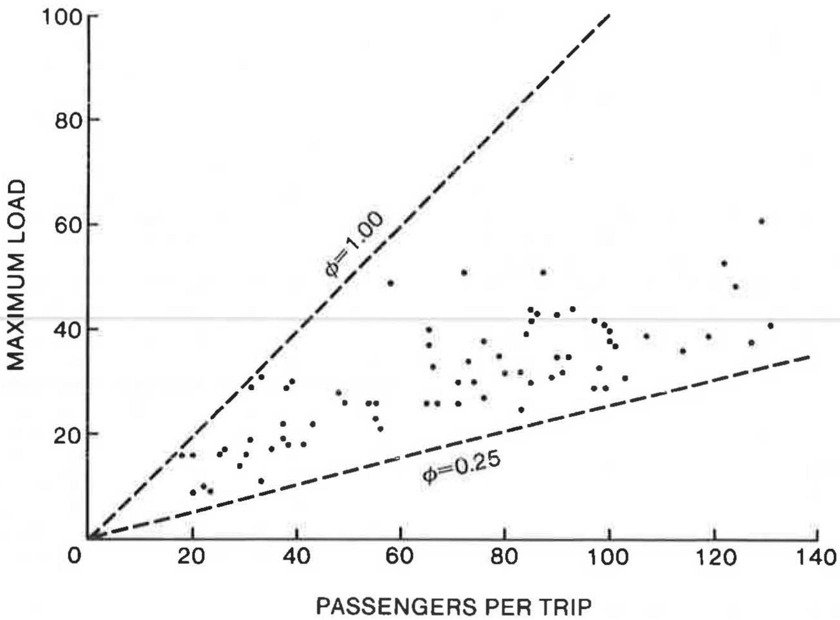

FIGURE 5 Maximum load versus passengers per trip, SDTC Route 11 (long local route passing through CBD), 1981 data.

TABLE 1 Values of $\hat{\phi}$ and Regression Slopes for Maximum Load Versus Ridership for San Diego Bus Routes, 1981-1982

Route	$\hat{\phi}$	Regression Slope
Express		
90	.93	.98
50	.83	.89
110	.75	.88
20	.72	.73
80	.70	.75
Local, non-CBD		
41	.64	.69
13	.57	.59
6	.54	.59
36	.53	.52
33	.53	.49
27	.51	.55
32	.51	.50
Local, CBD terminal		
35	.80	.93
7	.61	.59
15	.60	.47
1	.58	.52
25	.54	.50
43	.54	.53
34	.48	.42
Local, through CBD		
2	.58	.42
16	.53	.52
3	.53	.51
9	.53	.42
4	.49	.37
29	.43	.43
11	.43	.26
5	.42	.30

in R. Time-of-day trends were analyzed by plotting values of R, M, and ϕ versus the dispatch time of the trips in question. Because time-of-day trends were expected to be directional (for example, maximum loads peaking on inbound trips in the morning and outbound trips in the evening), separate plots were prepared for trips in opposite directions on the same route. Because there were large irregular variations between successive trips, moving averages over roughly 1.0 to 1.5 hr (three trips for 30-min headways, five trips for 15-min headways, and so forth) were used to smooth the data and extract the underlying time-dependent trends. Figures 6-8 show examples of such plots in which the solid lines represent the moving averages. As can be seen, the data fall into fairly broad bands about the moving averages. For maximum loads, for example, variations be-

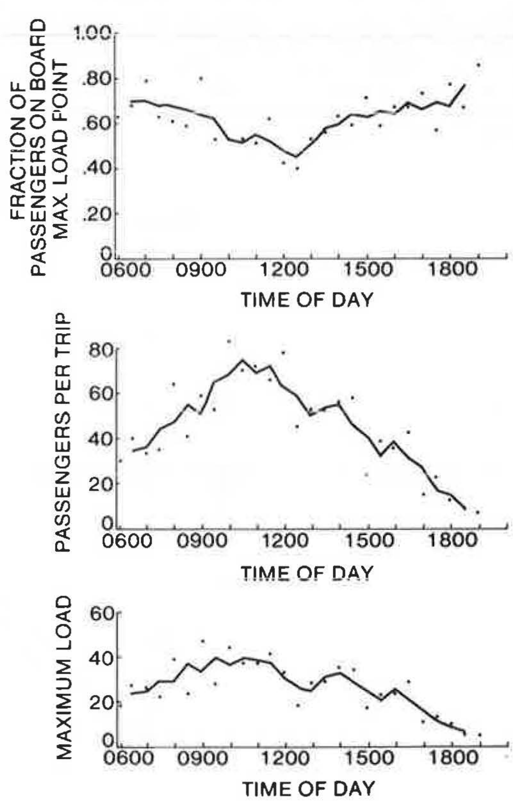

FIGURE 6 Time-of-day trends for SDTC Route 1, inbound, 1981-1982 data; solid lines indicate moving averages.

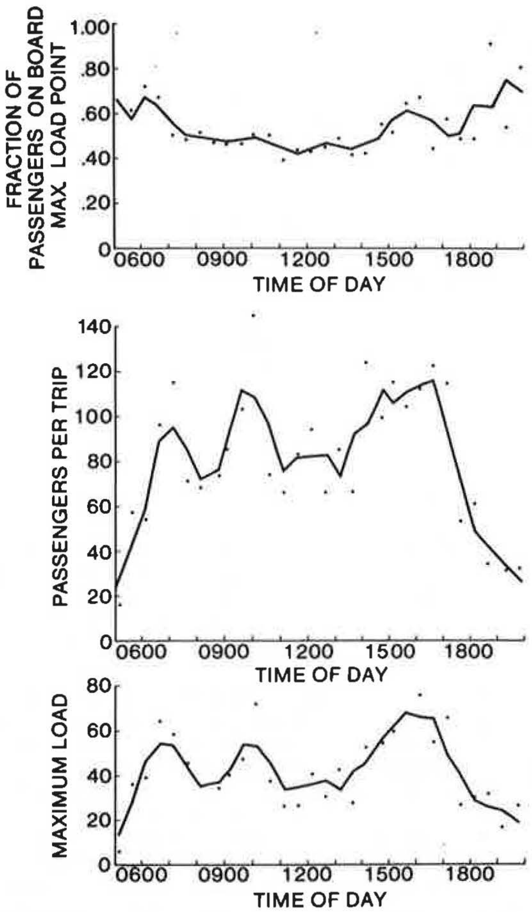

FIGURE 7 Time-of-day trends for SDTC Route 9, northbound, 1981 data; solid lines indicate moving averages.

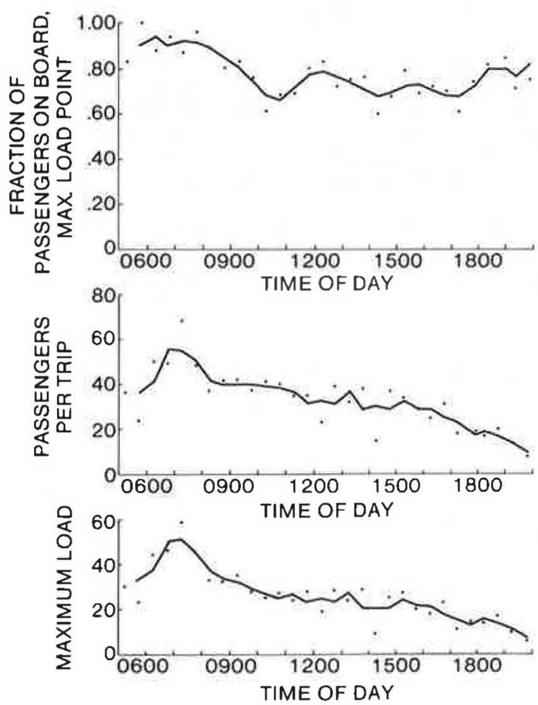

FIGURE 8 Time-of-day trends for SDTC Route 35, inbound, 1982 data; solid lines indicate moving averages.

tween successive trips of 10 to 20 passengers (representing 20 to 40 percent of the seating capacity of a standard bus) are not uncommon.

Table 2 gives a summary of some of the more important features of the time-of-day trends in the San Diego data. The times for the maxima and minima referred to in the table are those of the moving averages, not necessarily the maximum and minimum individual observations. Note that there were fairly large differences between the data sets in the numbers of routes experiencing peak values of R and M during particular time periods. In both cases, however, maximum loads on local routes were more likely to peak in the morning and evening work trip peaks than was ridership. This trend is explained in part by the fact that spatial load peaking is also subject to variations with the time of day, with minimum values of ϕ occurring during the midday period about 75 percent of the time in both data sets. Hence, for routes that have peak values of R during the midday period, there is a tendency for the trips carrying the maximum number of passengers to coincide with those with the least spatial peaking. For express routes, both M and R peak during the morning and evening work trip peaks, and values of ϕ tend to be minimum during the midday period.

TABLE 2 Summary of Time-of-Day Trends for One-Way Trips on San Diego Bus Routes

	Time of Day			
Event	0600-0900	0900-1200	1200-1500	1500-1800
Local routes, 1981-1982				
Maximum R	9	4	24	11
Maximum M	19	5	12	12
Minimum ϕ	7	16	19	6
Local routes, 1982-1984				
Maximum R	14	4	17	13
Maximum M	21	0	10	17
Minimum ϕ	6	18	18	6
Express routes, 1981-1982				
Maximum R	4	0	0	6
Maximum M	6	0	0	4
Minimum ϕ	0	2	8	0
Express routes, 1982-1984				
Maximum R	4	1	0	5
Maximum M	3	1	1	5
Minimum ϕ	1	3	5	1

COMPARISONS OF PEAK LOAD FACTORS

Peak load factors measure the relationship between maximum loads and seating capacity for individual trips. Distributions of peak load factors for individual routes are closely related to distributions of maximum loads but are also affected (sometimes crucially) by bus size. As do the other measures related to maximum loads, peak load factors vary over a considerable range for individual routes, and their distributions for different routes may differ a great deal. Figure 9 shows a comparison of distributions of peak load factors for two routes representing extremes in the San Diego data--one for which peak loads were rarely more than half the capacity of the bus, and another for which there were serious seating capacity problems.

In comparing distributions of peak load factors, it is useful to have a simple measure to summarize them, similar to those used in the preceding section to compare relationships between ridership and maxi-

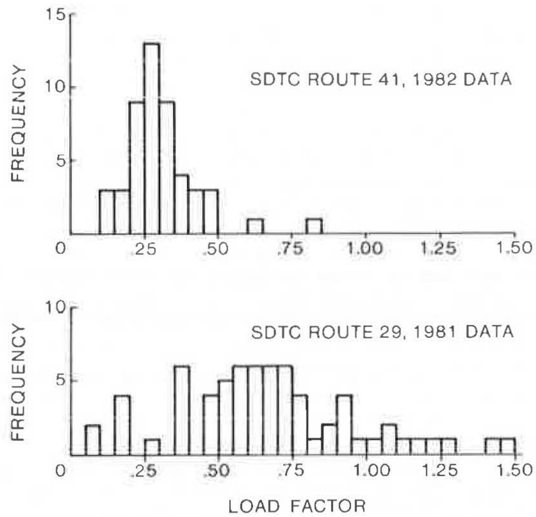

FIGURE 9 Comparison of load factor distributions for two San Diego bus routes.

mum loads. In this case, the ability to summarize the characteristics of the distribution also has practical value in service planning because the resulting measure may be used to set service standards and to identify the most serious seating capacity problems.

The most commonly used measures for summarizing peak load factors are average peak load factors. These are ratios of the sum of maximum loads on a route during some time period to the total number of seats dispatched. Both the time periods used to define average peak load factors and the standards with which they are compared vary among transit operators. In the case of SDTC, the time period is the hour for which the average peak load factor is greatest, whenever this occurs, and the standard is 1.00; a general idea of standards used elsewhere may be gotten from the recommended standards in NCHRP Synthesis of Highway Practice 69 (2).

Comparisons of average peak load factors, as defined by SDTC, with overall peak load factor distributions indicated that average peak load factors were a poor measure of the frequency and severity of standing loads. Specific problems were that they were inconsistent because they involved averaging over different numbers of trips where frequencies of service were different, and that they were dependent on the concentration in time of heavily loaded trips--in particular, they tended to understate the severity of problems where overloading resulted from irregular fluctuations in loads over comparatively long periods of time, such as exist on some San Diego routes where demand peaks during the midday period.

Consequently, an alternative measure of compliance with peak load standards was devised. Let Λ be the peak load standard, defined in terms of the peak load factor for an individual trip, and n be the number of trips surveyed. Then an overload index (ψ) may be defined as

$$\psi \equiv (100/n)\,\Sigma(\lambda/\Lambda - 1) \qquad \text{for all } \lambda > \Lambda$$

This index is sensitive to both the frequency and the severity of violations of the peak load standard and avoids the problems associated with using average peak load factors. It is not subject to an obvious intuitive interpretation, however, as is the average peak load factor; comparisons of the values of ψ with overall distributions for λ for San Diego routes indicated that values of ψ in excess of 2.00 represented significant violations of the standard, values less than 1.00 indicated only minor violations, and values between 1.00 and 2.00 represented borderline cases. Table 3 gives a summary of the frequency with which the various ψ-scores occurred in the two San Diego data sets.

TABLE 3 Distribution of Values of Overload Index (ψ), 1981-1982 Data Versus 1982-1984 Data

	ψ for Data Set				
	0.00	0.00-1.00	1.00-2.00	2.00-3.00	3.00-4.00
1981-1982	13	9	1	2	2
1982-1984	8	11	6	2	0

COMPARISONS BETWEEN DATA SETS

Two sets of data for each route were compared to assess the stability of the data over time. Specific comparisons involved total ridership, distributions of maximum loads and peak load factors, values of the overload index (ψ), and time-of-day trends for R, M, and ϕ.

Contingency tables were used to compare frequency distributions derived from successive data sets. This method is based on the hypothesis that the relative frequencies with which the data fall into given ranges are independent of the data set considered--in effect, that the distribution of the underlying population has not changed over time. If the hypothesis is true, the joint probability that event j is observed in data set i is the product of the marginal probabilities that event j occurs and that the observation belongs to data set i. If x_{ij} represents the number of times event j is observed in data set i, then the expected value of the number of times it is observed is given by

$$E(x_{ij}) = \Sigma_i x_{ij} \Sigma_j x_{ij} / \Sigma_i \Sigma_j x_{ij}$$

These expected frequencies may be compared with the actual frequencies by means of a chi-square test to determine the probability that differences as large as those observed occurred by chance. Table 4 is an example of a contingency table to compare a route's maximum load distributions for two successive data sets.

Use of contingency tables, as opposed to direct comparisons of the distributions by means of chi-square tests, was considered appropriate because neither sample could be said to represent the "true"

TABLE 4 Contingency Table for Comparisons of Maximum Load Distributions for SDTC Route 2, 1982 Versus 1983

	Data Set						
	0-10	11-20	21-30	31-40	41-50	>50	Total
Maximum Load (observed)							
1982	3	19	24	23	11	9	89
1983	15	21	31	14	14	6	101
Total	18	40	55	37	25	15	190
Maximum Load (expected)							
1982	8.43	18.74	25.76	17.33	11.71	7.03	89.00
1983	9.57	21.26	29.24	19.67	13.29	7.97	101.00
Total	18.00	40.00	55.00	37.00	25.00	15.00	190.00

Note: Chi-square = 11.428. Significant difference for $\alpha < .05$.

distribution and because the contingency tables allowed the comparison of samples of different sizes. There was some concern about the statistical validity of the comparisons, however, because the real null hypothesis in the chi-square test is that the two data sets represent randomly drawn samples from the same population. In the case of the San Diego data, it was clear that the trips were not sampled at random with respect to time of day because each scheduled trip was surveyed once. If the probabilities that the data fall into given ranges vary a great deal with time of day, the chi-square test would tend to overstate the probability that two samples were drawn from the same population. This possibility was checked after the fact by comparing the actual chi-square scores with their expected distributions. These proved to be reasonably similar, so it was concluded that contingency tables did provide statistically valid tests for differences in distribution.

In general, the data in the two sets were found to be quite similar. Overall ridership had declined by about 2 percent, which is not significant, being well within the normal variation in daily ridership for the system as a whole. Of the 27 routes surveyed, 10 experienced increases in ridership and 17 experienced decreases. In all but three cases the increase or decrease in ridership for individual routes was less than 20 percent; there were increases of 24 and 34 percent, respectively, on two lightly traveled routes and a decrease of 58 percent on one route (Route 9) where there had been major routing and scheduling changes due to cancellation of a service contract with a suburban jurisdiction.

Contingency table comparisons detected five cases in which distributions of maximum loads were significantly different at the 5 percent level. Of these, three were lightly traveled routes where the changes were of no practical significance, one (Route 2) was the result of increased night service (which resulted in a comparatively large increase in lightly loaded trips), and one (Route 9) was due to a large decrease in ridership, as discussed previously.

Differences in peak load factor distributions that were significant at the 5 percent level were also found in five cases. Of these, two (Routes 2 and 9) were associated with differences in maximum load distributions that were significant at the same level; the others involved cases in which differences in maximum load distributions were significant at the 10 to 25 percent levels. Of these three routes, one (Route 25) was a lightly traveled route that had experienced a comparatively large increase in ridership; a second (Route 32) had experienced a comparatively large decrease in ridership that resulted in downward shifts at the lower ends of the distributions of maximum loads and peak load factors; and the third (Route 34) had experienced a large increase in trips for which maximum loads exceeded seating capacity.

Where routes had peak load factors exceeding 1.00 for a total of 10 or more trips (counting both data sets), contingency tables were also used to compare the frequencies with which this event occurred. In two cases the difference was significant at the 5 percent level: Route 9 had experienced a significant drop in the number of trips for which λ exceeded 1.00 and Route 34 had experienced a significant increase.

Summaries of the distributions of values of the overload index (ψ) for the two data sets were given in Table 2. Despite the overall decrease in ridership, there was a small increase in the number of routes with peak load factors exceeding 1.00; values of the index increased for 13 routes, decreased for 6, and remained the same (zero both times) for 8 routes. For a variety of reasons, however, all but one of the four highest ψ-scores in the 1981-1982 data set had declined, so that, even with the addition of Route 34, only two routes in the 1982-1984 data set had ψ-scores greater than 2.00, compared with four in the 1981-1982 set.

Comparison of plots of time-of-day trends showed that overall peaking patterns tended to remain stable but that there were fairly substantial shifts in the exact times and magnitudes of fluctuations in ridership and maximum loads, even where there were no significant differences in the overall distributions of M, R, and ϕ. Figure 10 shows a comparison of time-of-day trends in maximum loads for a route that appeared to have no significant changes in the overall distribution of M; as can be seen, the magnitude of the fluctuations in the moving averages is similar, but the times of occurrence do not correspond very well, except during the morning peak.

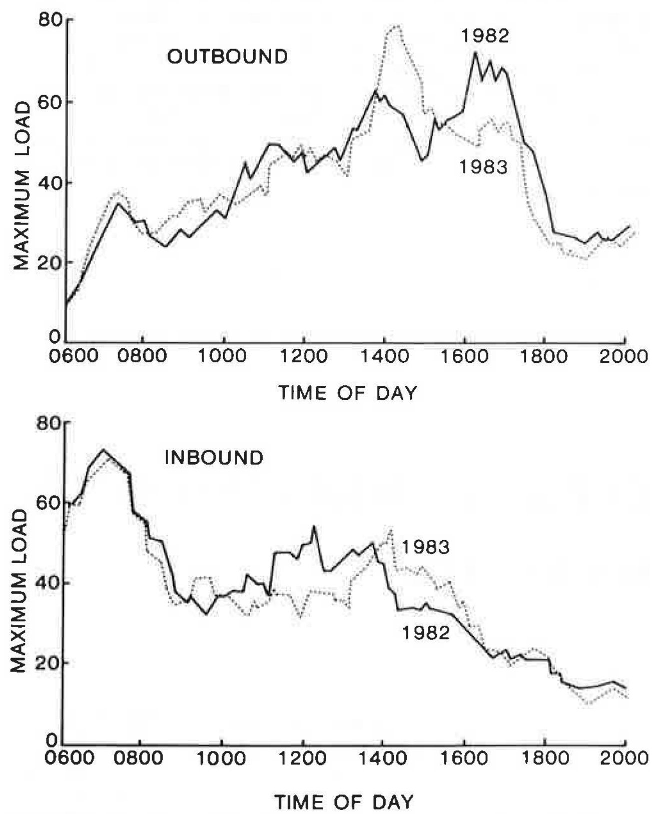

FIGURE 10 Time-of-day trends in maximum loads on SDTC Route 7 for successive data sets; plots represent moving averages over seven trips.

CONCLUSION

The most important characteristics of the San Diego maximum load data appear to be their overall variability and the high degree of randomness they display, the wide variation among routes in relationships between ridership and maximum loads, the relative stability over time of overall distributions of maximum loads and peak load factors, and the apparent instability of the exact times of day at which fluctuations in maximum loads occur.

These characteristics suggest that, for most planning purposes, overall distributions of maximum loads, peak load factors, and the like should be used instead of data for individual trips or data averaged over short time periods. In addition, the high degree of variability and randomness suggests that caution should be exercised in interpreting maximum load data; statistical analyses of such data are unlikely to alert planners to problems and changed conditions they would otherwise miss, but they are likely to cast doubt on the reality of apparent problems and changes. The variability of the data also implies that it will always be impractical to achieve close matches between seating capacity and demand, because considerable overcapacity must be provided to prevent serious overcrowding. For instance, if all scheduled one-way trips are considered, no route in either San Diego data set had more than 74 percent of its seats occupied at its maximum load point, despite several cases of fairly serious overloading.

When viewed from the standpoint of the system as a whole, the causes of variations in maximum loads appear to be quite complex. Variations in ridership are obviously the most important influence, but there are also wide variations, both for individual routes and between routes, in spatial peaking patterns and time-of-day trends in total ridership and the fraction of passengers on board at the maximum load point. Although some of the reasons for these variations are fairly obvious (for instance, the marked differences between express routes and most local routes), much of this variation remains unexplained.

ACKNOWLEDGMENT

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O-Bahn: Description and Evaluation of a New Concept

VUKAN R. VUCHIC

ABSTRACT

The O-Bahn system, developed in the Federal Republic of Germany in recent years, consists of conventional diesel buses equipped with a special guidance mechanism that can be extended or retracted. The vehicles thus can run on regular streets or on special guideways that have two simple vertical guidance surfaces. The O-Bahn concept is intended to combine the advantages of low-investment bus operation on streets in low-density areas with the advantages of narrower right-of-way and greater highway safety of guided-mode operation on higher density route sections. However, because the basic vehicle is the standard (or articulated) diesel bus, the most important advantages of guided modes--high-capacity vehicles, ability to form trains, electric traction with a number of superior aspects, and fail-safe running--are not captured. A systematic analysis of all characteristics shows that the O-Bahn is much more similar to semirapid bus (bus lines that use busways and other separated ways on individual sections) than to light rail transit (LRT). In comparison with semirapid bus, the O-Bahn offers the advantages of narrower right-of-way, somewhat greater comfort and safety, guaranteed permanent retention of the exclusive right-of-way for buses only, and greater suitability (O-Bahn with dual-traction vehicles) for operation in tunnels. These advantages must be weighed against the higher investment cost and lower capacity and operating flexibility of the O-Bahn, which is due to the inability of O-Bahn vehicles to overtake or bypass each other on the guideway. O-Bahn represents a higher cost, higher quality system than semirapid bus, which may be advantageous for use in such special cases as areas with narrow rights-of-way. It is not suited for lines that require high-capacity, low-cost transit systems, which are typical of cities in developing countries.

Attempts to develop a transit system that can operate in steered and guided modes are not new. During the 1920s and 1960s there were several attempts to develop railbus--a bus that could also operate on standard rail track. Because of major mechanical problems and basic structural differences between highway and rail vehicles, these attempts were not successful and they were abandoned.

The Barrett Corporation (USA) demonstrated in the early 1960s that a specially equipped bus can be electronically guided quite precisely by an underground cable. That concept has recently been pursued and further improved by Maschinenfabrik Augsburg-Neurnberg (M.A.N.) Corporation in the Federal Republic of Germany under the sponsorship of the BMFT (German Ministry for Research and Technology).

By far the most successful development of a bus that can also travel in guided mode has been the O-Bahn system, developed recently by Daimler Benz AG, also under sponsorship of the BMFT. This system has been brought to the operational stage and has been in operation on test lines in Essen, Germany, since 1981; it is also being built as a complete new transit line in Adelaide, Australia. In addition to the basic guided bus, several other vehicle types and related components have been developed as possible complementary elements to improve some of the O-Bahn's features and make it a more diversified transit system. These include a dual-mode diesel bus-trolleybus; a four-axle, 24-m-long double-articulated bus for guideway operation only; an exhaust-collecting mechanism for tunnel operation of diesel buses; and several others.

A number of articles have been published about the O-Bahn (1-4). Most of them focus on its description and advantages; few evaluate it completely or compare it with other modes.

The purpose of this paper is to briefly describe the O-Bahn concept and its technical features, to evaluate its operational characteristics, and to compare it with similar conventional transit modes. This will lead to a conclusion about the potential of the O-Bahn for applications in cities and its place in the family of urban transit modes.

SYSTEM DESCRIPTION

Vehicle

The basic vehicle for the O-Bahn system is a regular diesel bus equipped with a retractable guidance mechanism. The mechanism consists of special arms with small horizontal solid rubber rollers that, when extended, lie in front of the front axle wheels, as shown in Figure 1.

When the O-Bahn vehicle operates on streets and highways, the guidance mechanism is retracted and there is no visible difference between it and a regular bus. Before entering a guideway, the driver extends the guidance mechanism and drives through a funnel-shaped entrance (Figure 2). The rollers come in contact with the guidance surfaces and take over the steering function while the driver continues to control vehicle speed.

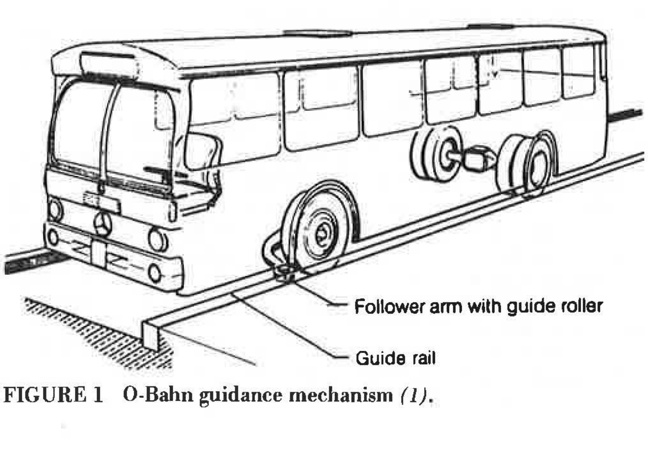

FIGURE 1 O-Bahn guidance mechanism *(1)*.

Infrastructure

The guideway consists of two horizontal concrete running surfaces for regular, running wheels and two small (25-cm-high) vertical surfaces on the outside of the running surfaces, at a distance (gauge) of 2.60 m (the bus is 2.50 m wide), against which the guiding rollers run, providing horizontal guidance (Figure 3). The guideway is supported by concrete cross beams, which are anchored to a series of 2.50-m-deep and 60-cm-wide bore concrete piles. This special foundation is necessary to ensure extremely precise horizontal and vertical alignment of the guideway because riding comfort is sensitive to the alignment.

Switching is done by alternate rising and lowering of the two mutually crossing guiding surfaces within the area of the switch.

Concept

The basic intent in the development of the O-Bahn system is to create a transit mode that will be capable of taking advantage of the benefits of operating on streets as well as those of guided technologies. In other words, the O-Bahn is intended to combine the lower investment and nearly unlimited mobility of the bus--its ability to operate on lines anywhere on the street and highway network--with such advantages of guided modes as narrower right-of-way, greater riding comfort and safety, and a stronger image. Its technology allows the O-Bahn to operate under either of the modes on any section of a transit line.

Thus the dual-mode feature of the O-Bahn could make this mode suitable for providing economical service in low-density suburban areas as a bus on streets (right-of-way category C) as well as for serving higher capacity lines converging toward a city center where, similar to light rail transit, it would use a separated guideway with street crossings at grade (right-of-way category B) or, if some sections allow it, even full separation (category A).

Characteristics of Dual-Mode Systems

All transport systems with dual-mode features (i.e., modes that can operate in two different ways) have the advantages of a broader range of applications or uses but also the disadvantages of greater complexity. They usually also combine some disadvantages of each of the two modes they incorporate (5, section 6.2.1). One of the best examples of this is the trolleybus. It combines some advantages of buses over rail systems (greater compatibility with street traffic, better adhesion) with some advantages of rail modes over buses (electric traction with better performance and environmental aspects, stronger public image due to overhead wires). But the trolleybus also incorporates some disadvantages of the two: smaller capacity of buses and somewhat higher investment costs and dependence on fixed guideway of the rail modes.

The relationship of a transit mode with the other modes most similar to it depends on the significance of its advantages and disadvantages compared to

FIGURE 2 O-Bahn guideway entrance *(1)*.

FIGURE 3 O-Bahn guideway and articulated vehicle in Essen *(1)*.

those of each other mode. This relationship determines the potential a mode has for applications in urban transportation.

The O-Bahn, which combines highway and guided technology and uses rights-of-way C, B, and sometimes A, obviously falls between bus and rail or, more precisely, between semirapid bus [bus operating partially on busways or high-occupancy vehicle (HOV) lanes] and light rail transit (LRT). Its comparison with these two modes is therefore fundamental in evaluating the feasibility and the potential for use of the O-Bahn in urban transportation.

Before this comparison, however, an analysis of the generic features of the O-Bahn system will be presented.

GENERIC FEATURES OF O-BAHN

Characteristics of Guidance

Compared to steered (highway) modes, guided modes have the following major advantages and disadvantages:

Advantages

1. Ability to use larger vehicles that have greater capacity and a more comfortable ride;
2. Ability to operate trains, resulting in much higher line capacity and lower unit operating costs (greater driver productivity);
3. Possibility of using electric traction with its numerous advantages over diesel motors (performance, cleanliness, less noise, no exhaust, safety of operation in tunnels, and so forth);
4. Narrower right-of-way, particularly useful in high-density urban areas, on viaducts, and in tunnels; and
5. Greater safety due to positive guidance and possible fail-safe signaling.

Disadvantages

1. Requires higher investment; therefore network extensiveness is more limited;
2. Less compatible with other traffic in street operation;
3. More difficult (often impossible) rerouting (e.g., temporary detours); and
4. Vehicles cannot pass each other unless off-line stations are provided [a stalled transit unit (vehicle or train) cannot be bypassed; it must be pushed].

These differences exist between exclusively steered and exclusively guided modes--each one is designed to take full advantage of the respective technology. Examples are LRT (or rapid transit) compared with bus (regular or semirapid, standard or articulated vehicles). Modes between these two, such as trolleybus, O-Bahn, and Railbus, have some but not all of these advantages and disadvantages.

O-Bahn is actually a standard bus with the added capability of guided operation. This capability gives it some of the previously listed advantages and disadvantages, but its basic vehicle design as a bus--imposed by its street operation--prevents other distinctions, both advantageous and disadvantageous. A review of the previously listed items produces the following results.

Advantages 1 and 2, operation of larger vehicles and trains, are not used because the vehicle is a standard (or articulated) bus; manpower is not reduced--drivers continue to drive, but without the steering function on the guideway.

With respect to riding comfort, O-Bahn is considerably better on the guideway than on streets because of better surface quality and alignment geometry, but the difference in comfort between O-Bahn and bus on busways with similar construction quality and alignment is quite small.

Advantage 3, electric traction, is not used in the basic O-Bahn version; an optional version of dual-mode or trolleybus vehicles will be discussed later.

Advantage 4 is a distinct feature of the O-Bahn: due to the guidance, its right-of-way and free profile are narrower than those for a bus on a street. The inside gauge of the guideway is 2.60 m and overall width of the guideway structure (such as built in Adelaide) is approximately 3.00 m, compared to street or highway lanes of 3.25 to 3.75 m (plus shoulders, if any). In general, there is a saving in width of approximately 0.80 to 1.20 m per direction. Tunnel profile for O-Bahn is foreseen as a 4.40-m-diameter circular tube that is similar to rail system tunnels, which vary from the minimum of 3.85 m for the London "tube" system to 4.88 m for the Toronto rapid transit. This comparison is shown in Figure 4(A). Standard (unguided) buses need wider rights-of-way than LRT or rapid transit, particularly for high-speed operation for which O-Bahn is proposed. As shown in Figure 4(B), the width of aerial structures of O-Bahn is somewhat greater than the widths for rail systems. O-Bahn is shown with 3.90 m for 2.50-m-wide vehicles, LRT with 3.75 m for 2.65-m-wide vehicles, and rapid transit with 4.00 m for 2.90-m-wide vehicles.

Advantage 5, safety, is greater with O-Bahn on guideway than with standard bus on busway because of the positive guidance; it is not as high as it is for rail because O-Bahn does not have signals or fail-safe mechanisms.

Disadvantage 1, high investment, is a major disadvantage of the O-Bahn guideway compared to street lanes. As they are for all separate transit ways, acquisition and construction of right-of-way are usually the main investment cost items of the system. Guideway construction for the O-Bahn is more complicated than for a conventional roadway due to the high precision of alignment required to avoid shocks through the guidance mechanism.

Disadvantages 2 and 3, mixing with other traffic and possibility of reroutings, do not apply to the O-Bahn; with their dual-mode ability, buses can simply be diverted from the guideway to other streets.

Disadvantage 4, no passing on the guideway, is a distinct disadvantage of O-Bahn compared to buses. O-Bahn is more sensitive to this problem than are rail modes because of the lower capacity of its units and the resultant higher frequency of operation. To achieve higher capacity, off-line stations must be built, requiring additional space, switches, construction cost, and some operational disturbance.

In review, the guidance feature of the O-Bahn gives this system some of the advantages and disadvantages of the fixed guideway mode, but the most important features of that mode of operation (higher capacity, labor productivity, electric traction, lack of noise and exhaust, and so forth) are not captured by the O-Bahn.

Vehicle Variations and Additional Components

O-Bahn designers have developed several other versions of vehicles and components that are intended to improve some aspects of O-Bahn's performance or reduce some of its shortcomings.

Dual-Traction Vehicle

An articulated O-Bahn vehicle with diesel and electric propulsion has been developed. This vehicle is a combination of the conventional diesel bus and trolleybus and can switch between the two types of propulsion. Given the recent development in Germany of automatically rising trolley poles, this change of propulsion is rather simple.

Several such diesel-electric propulsion vehicles without the guidance option have been tested in recent years. These tests have shown that this type of dual-mode vehicle allows the use of each type of propulsion where it is advantageous: diesel on lightly traveled line sections in suburbs, electric on heavily traveled lines, in environmentally sensitive areas, and even in tunnels. The costs associated with this diversity are a more expensive vehicle, more complex maintenance, and somewhat more complicated operations.

The same advantages and disadvantages are valid for the O-Bahn dual-powered vehicles, with an additional advantage that O-Bahn's guidance and trolleybus mode (electric propulsion) eliminate some of the major obstacles to operation of diesel buses in tunnels--problems of wide right-of-way, exhaust, and noise--and make limited tunnel operation possible.

Double-Articulated Electric-Only Vehicle

Daimler Benz has also developed a bidirectional four-axle double-articulated vehicle with guidance mechanisms for all axles. The vehicle resembles two articulated buses connected back-to-back. Its middle section, between articulations, however, has no wheels--it is supported by the two outside two-axle bodies. The vehicle has only electric traction and it cannot be operated in steered mode: it can travel on guideway only. Supposedly, such vehicles could be coupled in trains.

The basic intention of this type of vehicle is to overcome the low capacity of standard and articulated buses and to create an image that O-Bahn is an expandable system.

However, this concept has virtually no practical value because it lacks the main positive feature of the O-Bahn--its ability to operate in both steered and guided modes. This four-axle vehicle could be operated only on right-of-way category A (i.e., in rapid transit mode). Thus it would not be in the class of medium-investment semirapid transit (semirapid bus, O-Bahn, and LRT); instead, it would be a kind of rapid transit, requiring a much higher investment. Actually, except for similar technology (vehicle construction and type of guidance), such a system would have little in common with the basic O-Bahn concept--dual-mode operating capability.

M.A.N. developed a different type of high-capacity vehicle: a double-articulated regular diesel bus. It looks like an articulated bus with an additional joint and rear section attached to it. With the O-Bahn guidance mechanism this vehicle represents a higher capacity O-Bahn, retaining its basic dual-mode capability. For street operation, however, this vehicle is somewhat bulky.

Exhaust Gas Extraction System

A special mechanism for collecting exhaust gases in tunnels has also been recently developed. It consists of an overhead tube, which is installed on tunnel ceilings, with a slot on its bottom; a specially designed bus exhaust pipe located on the roof sends exhaust into the tube, facilitating exhaust extraction. This system may be useful where opera-

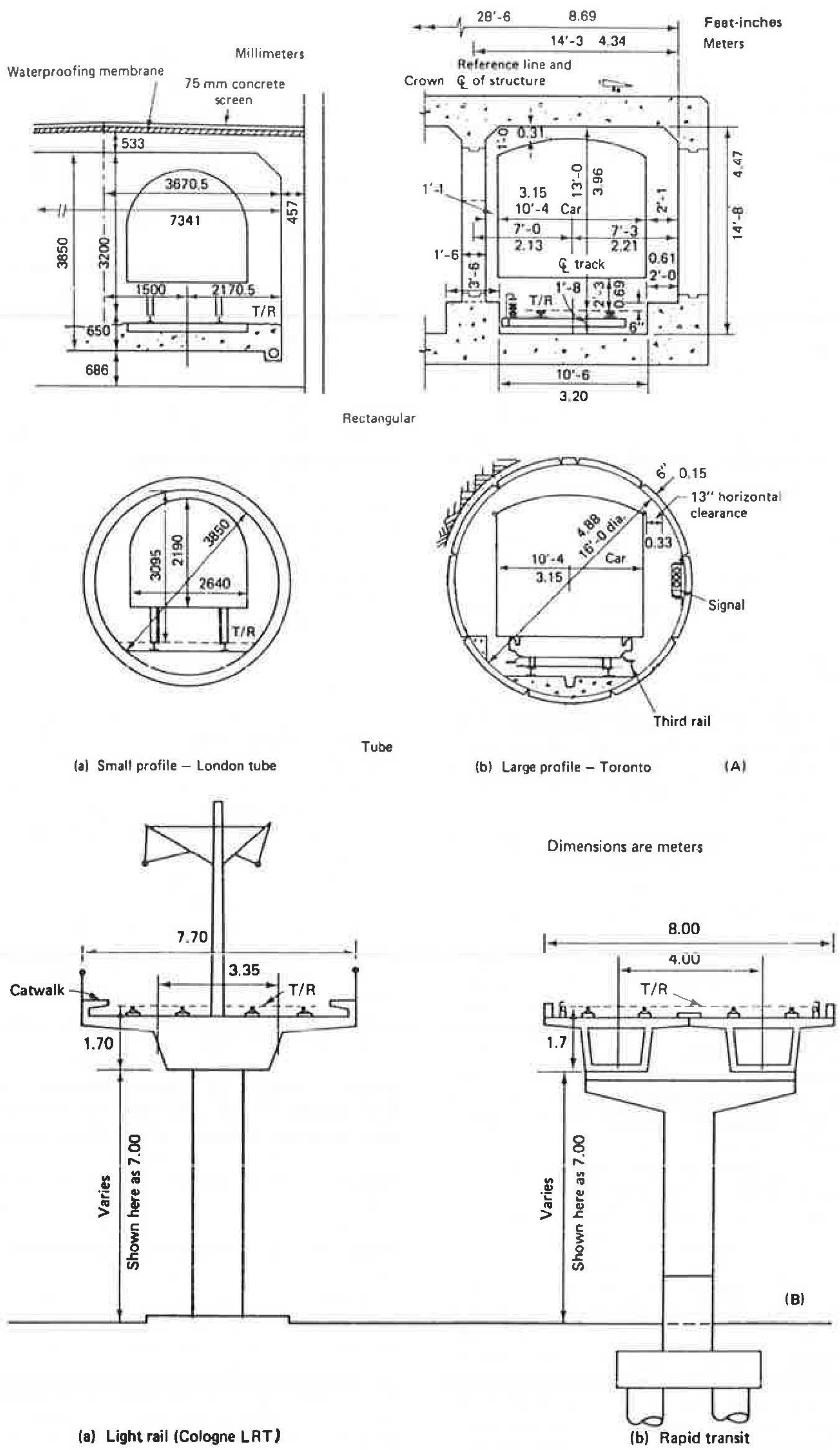

FIGURE 4 Comparison of right-of-way structures for O-Bahn, LRT, and rapid transit.

tion of diesel buses through short tunnels cannot be avoided.

Prefabricated Elements for Guideways

Developed for the O-Bahn guideway, this type of structure is claimed to result in cheaper and faster construction. This is not, however, an exclusive feature of the O-Bahn; it could be applied to construction of any other guideway or roadway type.

COMPARISON OF O-BAHN WITH OTHER MODES

On the basis of the previously defined characteristics of the O-Bahn, it will be compared in this section with its "neighbors" in the family of transit modes.

O-Bahn Versus Semirapid Bus

First, clarification of the term "semirapid bus" will be useful. The commonly used term "buses on busway" is a misnomer. Most lines to which it refers use not only busways but also HOV lanes and bus lanes on streets as well as regular street lanes. The term "express bus" refers to bus lines with limited stopping, not necessarily with any right-of-way separation. Therefore, bus lines with substantial portions of their lengths on partly or fully separated rights-of-way (category B or A, respectively) will be designated here as "semirapid bus" (5, Chapter 2).

O-Bahn compared with conventional semirapid bus, has the following advantages:

1. Narrower right-of-way,
2. Greater safety (full lateral control), and
3. Somewhat better riding quality.

The disadvantages of O-Bahn are

1. Higher investment (more complicated and precisely built guideway, more complex vehicles);
2. Lower capacity; express operation not possible (no overtaking); to correct these problems, all stations must be off-line, which involves additional costs; and
3. Lower reliability: a stalled vehicle cannot be bypassed, it must be coupled and pushed.

The O-Bahn guideway cannot be used by other vehicles. This is an advantage with respect to pressures to convert busways into HOV roadways, which have prevailed in most of our cities but which are clearly damaging to transit services. The guideway is a disadvantage with respect to use by emergency vehicles (police, ambulances, and so forth). The former is usually more important than the latter.

This comparison clearly shows that the O-Bahn is not distinctly different--superior or inferior--from semirapid bus. Mainly, the guidance brings this system the advantage of narrower right-of-way and safer operations; however, these advantages are countered by higher investment costs, lower capacity, and lower reliability. The relative importance of these factors under specific conditions determines which mode is superior to the other in each individual case.

O-Bahn Versus Light Rail Transit

The differences between these two modes are summarized in this section.

Advantages

O-Bahn has the following advantages in comparison with LRT:

1. Requires fewer transfers;
2. Requires somewhat lower investment; and
3. For new lines, involves considerably less complex new technology.

Disadvantages

1. Has much lower capacity;
2. Has higher operating costs for larger passenger volumes (more labor intensive);
3. Is less comfortable (less spacious vehicles, less stable ride during operation on streets where O-Bahn guidance is physically impossible);
4. Has lower performance due to diesel traction;
5. Has stronger negative environmental impacts (greater noise, exhaust, aesthetics of guideway);
6. Has lower reliability (electric vehicles have fewer breakdowns; if stalled, rail vehicles can be coupled and pushed more easily than buses); and
7. Is appropriate for tunnel operation only with special technology and auxiliary systems.

By far the most important advantages of the O-Bahn are its ability to branch out into regular streets (therefore fewer passenger transfers) and its somewhat lower investment costs and construction complexity (change of technology from buses to O-Bahn is small; change to LRT is drastic). The exact difference in investment costs depends greatly on the type of right-of-way and various auxiliaries. For the same type of right-of-way (at-grade in open field, aerial, and so forth), the difference, if any, is actually quite small and most of it is due to LRT electrification, which results in superior performance, or signaling, which increases safety. Major differences come if O-Bahn sections running on the street are compared with LRT in tunnels, as was the case in Adelaide (6,7); however, in such cases the tunnel brings with it much higher system performance. Indications are, therefore, that investment costs for comparable rights-of-way are somewhat but not drastically lower for the O-Bahn.

Reviewing the disadvantages of the O-Bahn compared to LRT, it can be seen that they are similar to those of semirapid bus compared to LRT. Smaller transit units (the price of street-running capability) and diesel propulsion limit the comfort (spaciousness) and performance of the O-Bahn (capacity even lower than for standard buses), and O-Bahn retains the problems of noise and air pollution.

Summary of Comparisons

To give a complete overview of the relationship of these modes, all major features in which they differ are given in Table 1 and compared using regular bus on streets as the basis (this resembles the typical planning situation of analyzing alternatives for upgrading an existing bus line).

By its very nature, this type of comparison cannot be absolutely exact; it depends heavily on underlying assumptions and, in a few items, on some-

TABLE 1 Semirapid Transit Modes (Semirapid Bus, O-Bahn, and Light Rail Transit) Compared with Regular Buses

Item	Semirapid Bus	O-Bahn	Light Rail Transit
System and operation			
Capacity	+	0	++
Right-of-way width	0	+	+
Dynamic performance	0	0	+
Permanence of right-of-way exclusivity	+	++	++
Tunnel operation ability	0	+	++
Safety	+	++	++
Need for new technology	0	–	– –
Level of service			
Need to transfer	0	0	– –
Reliability of service	++	+	++
Comfort (seats, riding)	+	+	++
Costs			
Investment cost	–	–(–)	– –
Operating cost	+	+	++
Impacts			
Image, land use impacts	0	+	++
Noise	0	0	+
Exhaust	0	0	++

Note: – – = very much inferior, – = inferior, 0 = no difference, + = superior, and ++ = very much superior.

what subjective judgments. In the present comparison the following underlying assumptions were made:

- All these modes would use similar rights-of-way and stations (except for specific physical characteristics of each mode); in other words, the portions of right-of-way categories C, B, and A for all these modes are similar.
- Design passenger volumes are substantial (otherwise semirapid transit modes would not be considered).
- Operations are as practiced on modern systems of each type (e.g., LRT has signals for sections with speeds greater than 70 km/hr).
- Quality of technology of each mode is typical of well-designed and maintained systems.

To avoid an unjustified impression of great precision, minus signs, zeros, and plus signs are used in the comparison. The more desirable characteristics are marked by plus signs and the less desirable ones by minus signs. Thus, higher costs, because they are less desirable, are designated by a minus sign. The ratings are based on the preceding analyses and comparisons of the three modes.

The comparison given in Table 1 shows quite clearly that the O-Bahn is quite similar in most characteristics to the semirapid bus: there are only a few differences in evaluations (counting these should be resisted because of their different relative weights). Comparing O-Bahn with LRT, on the other hand, shows many differences that resemble the differences between semirapid bus and LRT.

It can be concluded that the O-Bahn concept is much more similar to (and therefore competitive with) semirapid bus than to LRT.

PROSPECTS FOR O-BAHN APPLICATIONS

A review of present applications of the O-Bahn system will be useful for evaluating the prospects for its further use.

Present and Proposed O-Bahn Applications

Three cases of O-Bahn applications will be reviewed: in Essen, Federal Republic of Germany; Adelaide, Australia; and Regensburg, Germany.

Several different installations have been built in Essen to test various features and variations of the O-Bahn system. One O-Bahn line section (Fulerumer Strasse) has been in operation since 1981; joint operation of diesel and dual-traction vehicles with LRT on the same right-of-way has been tested [joint operation of conventional buses and LRT has existed for many years in Amsterdam, Hannover, Munich, Pittsburgh (tunnel) and many other cities]; operation of dual-traction vehicles in LRT tunnels will also be tested. The installations in Essen have thus been quite useful for testing and development of various physical and operational elements of the O-Bahn system.

Adelaide has under construction a long radial line along an unused freeway corridor into the center city; in the suburbs and in the center city buses branch out on streets. The line is heavily line-haul oriented with only three stations (off-line) and two guideway entrances for collector routes.

In arguing for the O-Bahn system compared to semirapid bus and LRT (the debate was finally aligned with political parties and the O-Bahn was adopted when the party supporting it won elections), its proponents quoted several advantages. O-Bahn has a narrower right-of-way than a conventional busway would have required; O-Bahn is safer because of guidance, particularly at the planned speed of 100 km/hr; it is quieter; and it requires a substantially lower investment than does LRT (although higher than semirapid bus).

However, the information about that project (6,7) and some observers point out that saving 1 or 2 m of right-of-way width in a 50-m-wide unused freeway right-of-way is insignificant; safety against head-on collision is greater, but it may be questionable whether manual-visual operation of guided vehicles at 100 km/hr is safe against rear-end collisions; vehicle noise actually cannot be changed much because the same diesel engine and wheels produce it regardless of guidance; capacity and flexibility of operation are lower for O-Bahn than for bus; and finally, the massive guideway structure (Figure 5) is much less aesthetically pleasing than either a blacktop roadway with attractive pavement markings or LRT tracks that can be constructed as a green surface with four rails and a pair of overhead wires only. (Other aspects of a bus and LRT comparison for the Adelaide line exceed the scope of this paper.)

Consequently, the case of O-Bahn in this particular application is so weak that this specific project may damage not enhance O-Bahn's chances for other adoptions.

Regensburg, a small city (140,000 population) in Germany with a high density of activities and narrow streets, has many buses converging on its central area. A 1.6-km-long tunnel has been proposed to take several bus lines through the center, thus increasing their speed and reliability.

This is a case in which the narrower right-of-way of the O-Bahn would be a major advantage. If the cost and the historic nature of the area permit construction of the tunnel and purchase of special vehicles and if the problem of exhaust gas extraction can be technically solved, this application of the O-Bahn may be more appropriate than those in outlying areas of cities, such as in Adelaide.

Review of Deciding Factors

The basic question in considering the O-Bahn for any specific application should be its differences with respect to semirapid bus. Because the differences in riding quality and safety are usually of secondary importance, the basic trade-off is that of the narrower right-of-way and guaranteed right-of-way exclusivity of the O-Bahn versus lower cost, higher capacity, and flexibility that favor semirapid bus. Comparison of LRT with semirapid bus will in most cases be similar to that of LRT with O-Bahn.

Thus, the two most important factors that may justify use of the O-Bahn are

- Narrower right-of-way, and
- Need to ensure a permanent exclusive transit facility.

This leads to the following conclusions about prospects for the O-Bahn system.

CONCLUSIONS

In developing countries there is a pressing need to provide high capacity on a substantial network with reasonable reliability, speed, and comfort with rugged and economical operation. Because it has the lowest capacity of the three modes, higher investment cost than semirapid bus, and higher operating cost than LRT, O-Bahn does not appear to be a com-

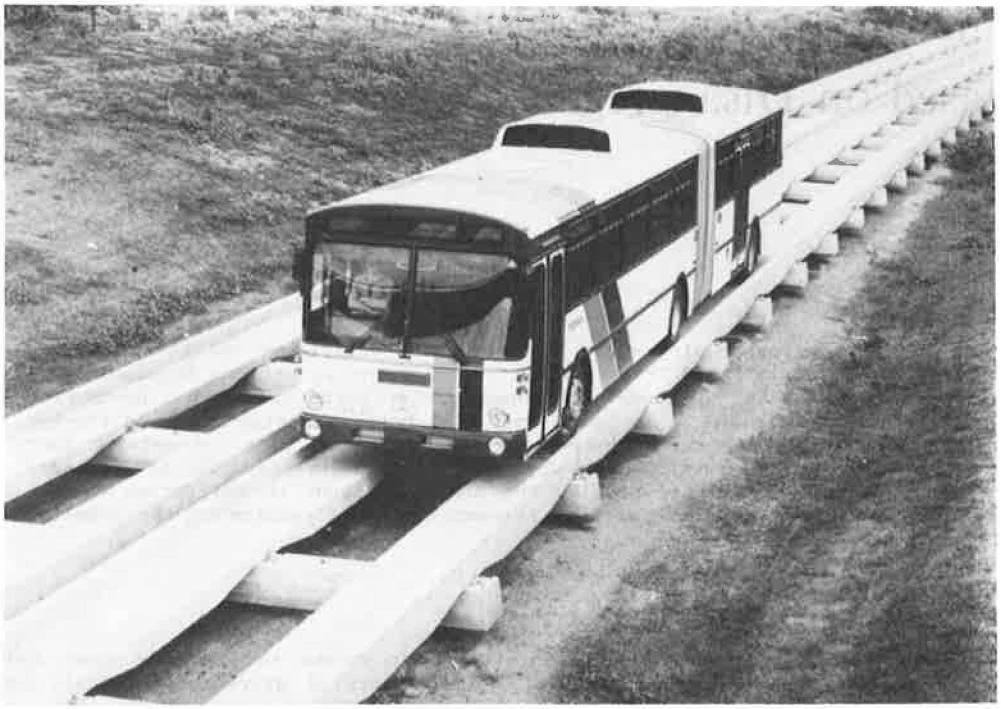

FIGURE 5 O-Bahn guideway in Adelaide: questionable aesthetics *(6)*.

petitive system. There is no way that O-Bahn could handle the volumes buses carry in Bogotá, Bangkok, or São Paolo.

In West European countries there are cases where narrower right-of-way is extremely important because of restricted space. A typical case would be convergence of several lines on a separated right-of-way section (guideways cannot be used on streets) similar to the situation in Regensburg. O-Bahn may be the optimal mode for such corridors.

In the United States the importance of ensuring permanently exclusive right-of-way may appear as a more important factor favoring O-Bahn than narrower right-of-way. Safety may also be important, but mostly on lines with moderate frequencies of operation because O-Bahn is less suited to short headways than is conventional bus.

It can be concluded that the O-Bahn system represents an option or accessory of the bus transit mode that provides higher quality (although not higher capacity) of service at a higher cost than semirapid bus. If evaluated on its technical and functional merits, the O-Bahn appears to be applicable only to special conditions such as convergence of many bus routes in one or two corridors in downtown areas.

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Development of a Bus Operating Cost Model Based on Disaggregate Data

REX GEPHART

ABSTRACT

As part of a major ongoing study to assess the efficiency and equity of the Southern California Rapid Transit District's current as well as proposed pricing policies, a set of models designed to estimate marginal line-by-line operating costs has been developed. Operating costs associated with different times of day (peak versus off-peak periods), different types of service (express versus local), and different days of operation (weekdays versus weekends) can be identified by these models. The approach taken in the design of the models is presented and the methods, assumptions, and results of the modeling process are described.

Traditionally, transit operating cost models were developed through a cost allocation procedure that attributed each and every operating and capital expense to the specific measurement of service that was believed to have primarily caused it. Under this unit cost approach, subcategories of operating expenses have typically been associated with one of four service variables: (a) vehicle-miles, (b) vehicle-hours, (c) revenue passengers, or (d) peak buses. Fuel, tire, maintenance, and repair costs, for example, have usually been associated with vehicle-miles. Driver wages and fringe benefits have usually been associated with vehicle-hours. Expense items related to the size of the peak fleet, on the other hand, have typically been related to a peak vehicle factor. Administrative overhead, clerical staff, and storage facilities are commonly attributed to the peak vehicle variable. The revenue passenger variable has usually been assumed to account for expenses associated with accident payment and liability premiums. Not all expenses, however, can be clearly tied to a single explanatory variable. Some transit agencies, for example, make the case that maintenance and repair expenses relate not only to the distance traveled but also to the vehicle-hour factor to reflect the effect of congestion along the route. To the degree that route congestion equates with greater numbers of vehicle stops, a close association between vehicle-hours and maintenance expenses can be inferred.

The unit cost approach represents an attempt to apportion transit operating expenses among all lines, using cost parameters generated from systemwide data. An implicit assumption of this aggregate approach is that neither driver labor agreements nor the distribution of an agency's services (between the peak and base periods) has any effect on the variations in estimated line costs. To the extent that these factors do not directly or indirectly vary among lines, the computation of line-by-line cost estimates from systemwide data appears to be reasonable. Realistically, however, the cost characteristics of lines should be expected to differ as the "peaking" of lines varies. An inner-city local route requiring a nearly equal spread of service throughout the day, for instance, would be expected to experience relatively lower unit costs compared to a peak-hour-only service, on the basis of the overtime and premium pay penalities stated in the labor agreements.

In contrast to the unit cost approach, direct assignments of driver wages, fuel, repairs, and so forth provide the optimal solution. Direct linkage of operating expenses to individual lines, nevertheless, necessitates an elaborate accounting system and would probably yield insufficient marginal gains in cost estimate accuracy to justify the additional accounting expenses. Ideally, a cost allocation method that strikes a balance between the unit cost and direct assignment approach is preferred.

COST CENTERS APPROACH

As part of a major ongoing study to assess the efficiency and equity of the Southern California Rapid Transit District's (SCRTD) pricing policies, a model that would address marginal line-by-line operating costs was desired. In an attempt to offer a better alternative to the unit cost and direct assignment modeling approaches, a disaggregate approach to identifying line-by-line operating costs was developed. Because the basic operating characteristics of various types of SCRTD services could be generally associated with the divisions (garages) from which the services originated, a disaggregate or "cost centers" modeling approach based on divisional data was chosen. To the extent that variations in divisional expenses could be explained by variations in divisional service, increases in the accuracy of line-by-line cost estimates were considered potentially significant.

In addition, because nearly half of SCRTD's expenses are incurred as operator labor costs, it was decided that an appropriate modeling objective would be to accurately identify the peak versus off-peak operator pay-hour differentials associated with the current labor agreement of SCRTD's United Transportation Union (UTU). Given that a cost centers approach could identify service-related expenses that differ from the system average expense, and given that divisional operator wages played an important role in explaining these differences, an increase in the model's accuracy in estimating line-by-line costs seemed possible.

The attraction of this approach is its ability to reflect the relative differences in the cost characteristics of service types on the basis of quantitative analysis of divisional expenses and service-related data. As opposed to the unit cost approach, where the selection of the model variables and their respective cost coefficients is subjective, the cost centers approach will allow the most appropriate model variables to be chosen objectively and will statistically determine each variable's appropriate cost coefficient. To avoid incorrect or artificial results, steps discussed in the following sections were incorporated into the modeling design.

EVALUATION OF DIVISIONS AS COST CENTERS

Operating cost models are typically constrained by the level at which expenses are accounted. Although operator wages, mechanic wages, fuel costs, and so forth are frequently incurred at less than the total system level (e.g., trip by trip), the accounting records of these expense items are usually maintained only at the system level. Although SCRTD also maintains system-level expense accounts, the origin of a majority of SCRTD's expenses is at the division level. Between 50 and 60 percent of SCRTD's total operating expenses are tallied among 12 operating divisions. The first step in the design of a disaggregate modeling approach, therefore, was to test whether SCRTD's divisional unit costs differed from the system average. If significant variations could be quantified, as well as subjectively explained, a statistical approach could be developed that would objectively explain the variations in divisional unit costs. Given that a number of service-related variables were found to closely correlate with variations in divisional expenses, the service variables with the "closest fit" could be used as the framework for the modeling process. However, if little or no variation between divisional unit costs could be quantified, justification for the use of a traditional unit cost model based on systemwide expenses (for line-by-line applications) would be confirmed.

To test the degree of variation between SCRTD's divisional unit costs, an analysis of SCRTD's cost per vehicle-mile and cost per vehicle-hour was made for each of the 12 operating divisions. Total expenses incurred and accounted for by division were divided by each division's respective total vehicle-miles and total vehicle-hours to produce the results given in Tables 1 and 2. A list of the expense accounts maintained for each division follows: An asterisk (*) indicates the expense accounts chosen for inclusion in the basic modeling design.

- * UTU operator normal pay
- * UTU operator nonwork pay
- * UTU operator scheduled overtime and premium pay

TABLE 1 SCRTD Mileage Unit Costs by Division (FY 1982-1983)

Division No.	Name	Cost per Vehicle-Mile ($)
9	El Monte	1.67
12	Long Beach	1.71
15	Sun Valley	1.79
8	Chatsworth	1.94
16	Pomona	2.02
1	Alameda	2.13
18	South Bay	2.23
5	South Central L.A.	2.25
3	Cypress Park	2.28
2	Los Angeles	2.32
6	Venice	2.46
7	West Hollywood	2.59
Mean		2.12
Standard deviation		0.29

TABLE 2 SCRTD Hourly Unit Costs by Division (FY 1982-1983)

Division No.	Name	Cost per Vehicle-Hour ($)
1	Alameda	26.65
2	Los Angeles	27.79
5	South Central L.A.	27.88
7	West Holywood	27.91
3	Cypress Park	27.98
9	El Monte	28.69
15	Sun Valley	29.01
6	Venice	30.21
12	Long Beach	30.39
18	South Bay	32.80
8	Chatsworth	32.90
16	Pomona	41.97
Mean		30.35
Standard deviation		4.16

- * UTU operator unscheduled overtime and premium pay
- * UTU operator part-time pay
- UTU nonoperator normal pay
- * UTU nonoperator nonwork pay
- * Noncontract normal pay
- * Noncontract nonwork pay
- Noncontract overtime and premium pay
- * Noncontract straight time and overtime pay
- Contract working as noncontract pay
- * Amalgamated Transit Union (ATU) revenue equipment mechanic normal pay
- * ATU revenue equipment mechanic nonwork pay
- * ATU revenue equipment mechanic overtime and premium pay
- * ATU revenue equipment nonmechanic normal pay
- * ATU revenue equipment nonmechanic nonwork pay
- * ATU revenue equipment nonmechanic overtime and premium pay
- ATU nonrevenue equipment mechanic normal pay
- ATU nonrevenue equipment mechanic nonwork pay
- ATU nonrevenue equipment mechanic overtime and premium pay
- * Brotherhood of Railway, Airline and Steamship Clerks, Freight Handlers, Express and Station Employees (BRAC) employee normal pay
- * BRAC employee nonwork pay
- * BRAC employee overtime and premium pay
- * Uniform and tool allowances
- * Training programs
- * Other fringe benefits
- Professional and technical services
- Contract maintenance services
- Custodial services
- Contract maintenance services of revenue vehicles
- * Other services
- * Fuel for revenue equipment
- Fuel for nonrevenue equipment
- * Lubricant for revenue equipment
- Lubricant for nonrevenue equipment
- * Tires and tubes for revenue equipment
- Tires and tubes for nonrevenue equipment
- * Other materials and supplies for revenue equipment
- * Other materials and supplies for nonrevenue equipment
- Buildings and grounds materials and supplies
- * Office supplies and equipment
- Promotional and informational materials
- * Tools and expendable equipment
- * Other materials and supplies
- * Water
- Gas (natural)

* Electricity
  Telephone and telegraph
  Other facilities
* Vehicle license and registration fees
* Fuel and lubrication taxes of revenue equipment
  Fuel and lubrication taxes of nonrevenue equipment
  Other taxes
  Dues and subscriptions
  Travel and meetings
  Schedule checkers travel expenses
* Petty cash expenditures
  Other miscellaneous expenditures
  Passenger station leases and rentals
  Passenger parking facilities leases and rentals
  Service vehicle leases and rentals
  Operating yard and station leases and rentals
  Other general administration facilities leases and rentals
  Public liability

For each unit cost analysis, the audited expense accounts for FY 1982-1983 were used. That the total operating expenses maintained for the 12 operating divisions as a whole account for approximately 55 percent of SCRTD's total FY 1982-1983 operating budget is noteworthy.

From the data in Tables 1 and 2, significant variations in divisional costs per vehicle-mile and costs per vehicle-hour are apparent. Divisional costs per mile vary by as much as $0.92 (55 percent) per mile, whereas the divisional costs per hour vary by as much as $15.32 (58 percent) per hour. As expected, divisions that operate relatively more high-speed freeway service tend to accumulate lower costs per mile but, because of the nature of their services (generally peak period services with relatively higher operator pay-hour-to-vehicle-hour ratios), they also tend to have higher costs per hour. The statistics given in Tables 1 and 2 generally illustrate that divisions farthest from the Los Angeles central business district (CBD) have the lowest costs per mile and the highest costs per hour (Figure 1).

From a modeling perspective, the data in Tables 1 and 2 clearly show that system average unit costs do not present an accurate picture of SCRTD's variety of services. An operating cost model based on a division cost centers approach, therefore, can indeed improve the accuracy of line-by-line cost estimates.

DESIGN OF BASIC MODELING FRAMEWORK

To define the service-related variables that explain the variations in the divisional unit costs noted in Tables 1 and 2, a correlation matrix between divisional expense accounts and divisional service statistics was developed. The expense accounts that were thought to have "logical" relationships with various service-related variables were statistically analyzed using a Pearson Correlation Matrix. [The expense accounts that were chosen are noted by an asterisk (*) in the previous list.] The service-related statistics that were tested include

- Total vehicle-miles
- Revenue vehicle-miles,
- In-service vehicle-miles,
- Total vehicle-hours,
- Revenue vehicle-hours,
- In-service vehicle-hours,
- Number of bus pullouts, and
- Peak buses.

An analysis of the correlation matrix indicated that, of the eight service variables chosen, virtually all had relatively significant correlations with each of the tested expense accounts. In general, any one of the service variables would have made a good estimator of divisional expenses. On the other hand, various combinations of service variables appeared to provide even better explanations of division expenses, indicating that variations in divisional expenses can only be partly explained by one service variable. A combination of the total vehicle-hour and peak bus variables, for example, indicated a better correlation with the various expense accounts than either of the variables individ-

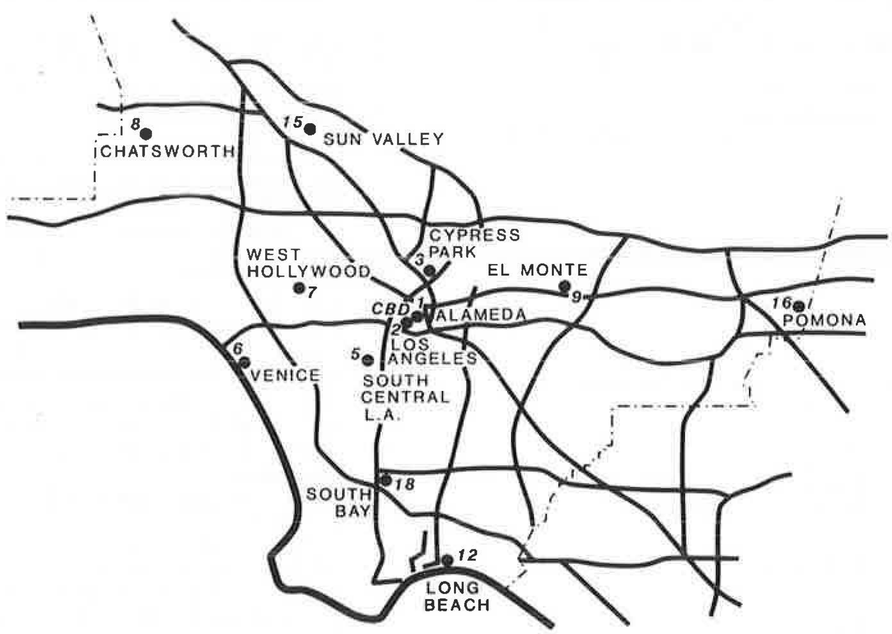

FIGURE 1 Division location map.

ually. A multivariate regression analysis, therefore, was used to define which variables in tandem produced the best estimate of divisional expenses. To avoid the development of a model with high intercorrelation between the independent variables (multicollinearity), and as an aid in identifying the specific variables that explain the variations in operating expenses, a nontraditional approach to multivariate modeling design was developed.

Instead of one model in which all expense accounts are correlated with each service variable at the same time, three separate models were developed. The expense accounts that consistently maintained a high correlation with each of the hourly service variables (total, revenue, and in-service hours) made up the dependent variable of the first model. Individual correlations between these hourly expenses and each of the three hourly service variables indicated which service variable was capable of making the best estimate of hourly expenses. The same process was used to define the "best" mileage and peak service variables. The resultant models took the following forms:

FY 1982-1983 divisional hourly expenses =
$507,639 (constant) + SIG T = .09
$14.50 (total vehicle-hours) SIG T = .00, R^2 = .993 (1)

FY 1982-1983 divisional mileage expenses =
$505,822 (constant) + SIG T = .12
$0.54 (revenue-miles) SIG T = .00, R^2 = .958 (2)

FY 1982-1983 divisional peak service expenses =
$691,704 (constant) + SIG T = .07
$45.89 (bus pullouts) SIG T = .00, R^2 = .982 (3)

Because each of these three models estimated a unique and separate share of divisional expenses, the three models together represented the best estimate of total divisional expenses. Through simple addition of the models, a multivariate model was prepared. The following equation represents the final, summed format of the initial modeling process:

FY 1982-1983 total divisional expenses =
$1,705,165 + $14.50 (total vehicle-hours)
+ 0.54 (revenue-miles)
+ 45.89 (bus pullouts) (4)

Of interest at this stage in the modeling process are the relationships that were found between a few of the more significant expense accounts and the resultant model variables. As expected, high correlations were developed between full-time and part-time operator pay and the number of vehicle-hours in each division. The longer an operator is assigned to a vehicle, the greater his pay. Also expected were the high correlations between fuel, lubricant, and tire costs of a division and the number of miles in each division. As a vehicle accumulates greater mileage, the costs associated with fuel, lubricant, and tires also increase. An unexpected result, however, was the relationship found between mechanic pay and the number of bus pullouts. Traditionally, mechanic pay has been associated with the number of miles in a division (or system). Nevertheless, at SCRTD, mechanic pay was found to have a higher correlation with the number of buses required for peak service (bus pullouts). Each of the three ATU mechanic expense categories (previous list) consistently correlated better with the number of divisional bus pullouts than with divisional mileage.

The apparent explanation of the greater proportion of mechanic time spent in preparation of each day's peak fleet on a bus-by-bus basis than on an accumulated mileage basis includes a number of peak-related issues. Most prominent is that daily vehicle assignments that have frequent bus pullouts are generally peak period (tripper) assignments that incur heavy passenger loads and, therefore, higher maintenance expenses due to their associated brake, transmission, and general "running gear" failures. In addition, assignments that have numerous pullouts tend to require the replacement of parts needed for each start-up (i.e., batteries, starters, and their associated electrical systems) more often than other assignments. Preventive maintenance expenditures based on accumulated vehicle-miles were thought to have a relatively small role in explaining daily mechanic expenses.

MODEL CALIBRATION

Thus far in the discussion of the modeling design, two important issues have not been addressed: (a) all remaining (nondivisional) operating expenses and (b) the significance of the nonvariable (constant) dollar values in Equations 1-4. With respect to the constant dollar values, the slopes of the lines in Equations 1-3 were "forced through the origin" to eliminate the constants so that the aggregate model would be more effective in estimating line-by-line costs. (Note the significance, SIG T, of each model constant.) It was assumed that if no service was provided at the line level, zero expenses would be incurred. With respect to the remaining nondivisional operating expenses, a method was developed to proportionally calibrate each variable's coefficient such that the resultant model was capable of estimating total (as opposed to divisional) FY 1982-1983 district operating expenses. The calibrated model is represented by the following equation:

FY 1982-1983 SCRTD (system) operating costs =
$28.35 (total vehicle-hours) +
$1.12 (revenue-miles) +
$104.22 (bus pullouts) (5)

DIFFERENTIATION BETWEEN LOCAL AND EXPRESS SERVICE OPERATING COSTS

The second step in the modeling process was to develop a procedure capable of differentiating SCRTD's operating costs by type of service. Because previous studies had indicated that the variations between local and express unit costs were significant, separate models sensitive to these variations were thought to be useful in enhancing the overall modeling process. The objective was to split the system model (Equation 5) into two distinct models, one capable of estimating local service operating costs and one capable of estimating express service operating costs.

A divisional cost centers approach, identical to the approach previously discussed, was used to identify the variations in local and express unit costs. However, to produce two distinct models that, when used in tandem, could also accurately estimate total system costs, individual cost center analyses were regenerated from local and express (as opposed to system) service and expense statistics. At the divisional level, local and express mile, hour, and peak-related service statistics were developed from actual measurements of SCRTD services. Mile, hour, and peak-related service statistics associated with the high-speed freeway increments of express lines were regarded as express service; all other services were regarded as local SCRTD service.

The associated operating expenses, which were not available by service type, were proportionally allocated between local and express miles, hours, and so forth, on the basis of the relationships previously developed in the "system" Pearson Correlation Matrix. Operating expenses associated with the mileage variable of a division with 80 percent local service and 20 percent express service, for example, were allocated 80 and 20 percent, respectively. Because the percentage of local service ranged among the 12 divisions from 99.9 to 40.3 percent in hours of service and from 99.8 to 11.6 percent in miles of service, models with correlation coefficients and levels of significance similar to Equations 1-3 were produced. The resultant local and express models, which, in effect, are a weighted "split" of the FY 1982-1983 system cost model (Equation 5), are

FY 1982-1983 local service operating costs =
$28.35 (total vehicle-hours) +
$1.14 (revenue-miles) +
$104.08 (bus pullouts) (6)

FY 1982-1983 express service operating costs =
$31.00 (total vehicle-hours) +
$0.99 (revenue-miles) +
$134.57 (bus pullouts) (7)

As can be seen from a comparison of the system cost model (Equation 5) and the local cost model (Equation 6), the dominance of SCRTD local service throughout the system precludes any meaningful changes within the local model unit costs. All three of the coefficients in each equation are virtually the same. However, a comparison of the express model (Equation 7) and the system model (Equation 5) reveals that express service operating costs at SCRTD do indeed differ from the system average operating costs. More important, they vary in a manner that was not explained in the system cost centers approach. Express service hourly unit costs exceed the system average by 9 percent, express mileage unit costs fall below the system average by 12 percent, and express pullout unit costs exceed the system average by nearly 30 percent. In general, the variation between the express and the system average hourly unit costs can be attributed to the current operator work agreement that penalizes short (i.e., express) assignments, whereas the discrepancy between the express and the system average mileage unit costs can be attributed to the increased speed (i.e., efficiency) of the express assignments. The difference between the express and the system average pullout unit costs merely reinforces the finding that proportionally greater mechanic expenses can be associated with assignments that start up or pull out more times per day than does the average vehicle assignment.

DIFFERENTIATION BETWEEN PEAK AND OFF-PEAK OPERATING COSTS

The final step in the modeling design was to integrate the operator work rule stipulations that further explain variations in the estimates of line-by-line operating costs. Specifically, this involved an attempt to differentiate total weekday expenses between the peak and off-peak periods of service. Although the local and express models, as developed in the previous section, will, to some extent, address the issue of different time of day costs through the use of the bus pullout variable, the models will not account for the cost differences normally associated with the peak and off-peak time periods in which driver wages represent the largest single expenditure.

Because transit is a highly labor-intensive industry, stipulations in labor contracts, which limit the level of part-time drivers as well as the number of split shifts, have increased the costs of providing service. Because the size of an agency's operator labor force is scaled to the level of peak demand, many of these restrictions can be attributed to the peak period. A common consequence of the labor agreement penalties is that an agency's labor force must be maintained intact throughout much of the day, whether or not there is sufficient off-peak demand to warrant such employment levels. The problem is compounded by the nature of daily commuting patterns in which peak loads occur during a 2- or 3-hr time span in the morning and evening, necessitating full-scale operations over a 12-hr stretch of time. Although many of these excess wage expenditures occur during off-peak periods, a legitimate argument can be made for attributing a portion of them to the peak periods.

In addition to the union-related influences, other factors should be considered when assessing the true labor costs incurred during the peak period. For example, labor "efficiency" tends to be relatively low under peak operations because considerable time is spent in nonrevenue service traveling to additional bus runs. In general, the proportion of out-of-service to in-service pay hours is higher in the peak than in the off-peak period due to these deadheading activities.

To attribute a larger proportion of total hour costs to peak operations, a procedure was developed by Cherwony and Mundle (1) to adjust the vehicle-hour coefficient in the system cost models upward for the peak period and downward for the off-peak period, because the weighted average vehicle-hour variable underestimates the costs of peak service and exaggerates those of off-peak. Ideally, a cost model that employs operator pay-hours in lieu of vehicle-hours is desired. However, the scarcity of adequate operator pay-hour data has historically led to the use of the vehicle-hour variable as a surrogate measure.

The approach developed by Cherwony and Mundle ties together vehicle-hour and operator pay-hour data into a time-apportioned index of operating costs. The most salient feature of their approach is that the system vehicle-hour coefficient is modified for the peak and off-peak periods on the basis of two factors: an index of relative peak and off-peak period operator productivity and an index of relative amounts of peak and off-peak period service. The operator labor productivity index adjusts the vehicle-hour unit cost coefficient by comparing the ratio of operator pay-hours to vehicle-hours in the peak versus the off-peak. The service index simply compares the number of vehicle-hours in the peak with those in the off-peak. Although the operator labor productivity index functions as a measure of the penalizing features of the operator labor agreement, the service index measures the relative amount of service offered in each peak and off-peak period. The equations developed by Cherwony and Mundle to adjust the vehicle-hour coefficients are

$$VH_p = \{[n(1 + s)]/(1 + ns)\} VH$$

and

$$VH_o = [(1 + s)/(1 + ns)] VH$$

where

VH_p = peak vehicle-hour coefficient,
VH_o = off-peak vehicle-hour coefficient,

VH = total vehicle-hour coefficient,
n = relative operator labor productivity (i.e., the ratio of peak pay-hour/vehicle-hour to off-peak pay-hour/vehicle-hour), and
s = relative service index (ratio of peak to off-peak vehicle-hours of service).

Integration of the Cherwony and Mundle approach into the local and express operating models produced four distinct SCRTD cost models: two for estimating line-by-line peak period expenses (local and express) and two for estimating line-by-line off-peak period expenses (local and express). In addition, because the variations in the ratio of operator pay-hours to vehicle-hours differ significantly between weekdays and weekends (due to the differences in the peak-to-base vehicle ratios between weekdays and weekends), two system average weekend models were also developed to estimate the operating costs of local and express weekend service. No attempt was made to differentiate between peak and off-peak weekend operating costs because of the relatively "flat" demand for weekend service. The final model formats (FY 1982-1983) developed as a result of the entire modeling design are

Local $TC_p = \$30.34(THR_p) + \$1.14(RM_p) + \$104.08(PO)(APB/TB)$
Local $TC_o = \$27.16(THR_o) + \$1.14(RM_o) + \$104.08(PO)(BB/TB)$
Local $TC_w = \$28.35(THR_w) + \$1.14(RM_w) + \$104.08(PO_w)$
Express $TC_p = \$33.17(THR_p) + \$0.99(RM_p) + \$134.57(PO)(APB/TB)$
Express $TC_o = \$29.70(THR_o) + \$0.99(RM_o) + \$134.57(PO)(BB/TB)$
Express $TC_w = \$31.00(THR_w) + \$0.99(RM_w) + \$134.57(PO_w)$

where

TC_p = total cost of peak period weekday service, where peak period is defined as the sum of the a.m. peak (6:00 a.m. to 8:59 a.m.) plus the p.m. peak (3:00 p.m. to 5:59 p.m.),
TC_o = total cost of off-peak period weekday service, where off-peak period is defined as all weekday service minus the peak period service (see TC_p),
TC_w = total cost of weekend (24 hr) service (Saturday, Sunday, or holiday service),
THR_p = total peak period weekday vehicle-hours,
THR_o = total off-peak period weekday vehicle-hours,
THR_w = total weekend vehicle-hours,
RM_p = peak period weekday revenue-miles,
RM_o = off-peak period weekday revenue-miles,
RM_w = total weekend revenue-miles,
PO = number of weekday bus pullouts,
PO_w = number of weekend bus pullouts,
APB = average peak period buses (a.m. peak buses plus p.m. peak buses divided by 2),
BB = total base period buses (9:00 a.m. to 2:59 p.m.), and
TB = APB + BB.

As these equations indicate, the cost per hour of weekday peak period service (local or express) is marginally higher than the cost per hour of weekday off-peak period service. The cost per hour of weekend service is, essentially, the weighted average of the weekday peak and off-peak hourly unit costs. For all models, no attempt was made to differentiate between the peak and off-peak unit costs of the revenue-mile and pullout variables, nor was any attempt made to differentiate between the weekday and weekend unit costs of the revenue-mile and pullout variables. Nevertheless, so that a distinction could be made between the number of peak and off-peak bus pullouts at the line level, an index was developed to adjust the pullout variables of the peak and off-peak models on the basis of the relative number of peak and base period buses (see final model formats).

Throughout the modeling process the concept of having the "sum of the parts equal the whole" was maintained. Estimates of a line's peak period operating costs, therefore, must be added to the off-peak period operating costs to derive total daily operating costs. To estimate total system operating expenses, the system operating cost model (Equation 5) can be used or, through a series of line-by-line calculations, each line's peak period, off-peak period, and weekend operating costs can be added together to produce the same result.

SUMMARY

The final models were tested by comparing the daily peak and off-peak models with three traditional models currently in use throughout SCRTD. The models used for comparison were the 1984 Scatchard model, the 1984 Stopher (UTPS) model, and the 1980 Gephart model. The equations of each model, which have been calibrated to SCRTD's FY 1983-1984 operating budget, are

1984 Scatchard model

$TC = \$25.42(THR) + \$1.74(TMI)$

1984 Stopher (UTPS) model

$TC = \$44.00(RH) + \$0.57(RM)(PVR)$

1980 Gephart model

$TC = \$40.98(RH) + \$173.37(BPO)$

1984 Peak/off-peak models

Local $TC_p = \$30.27(THR_p) + \$1.14(RM_p)\ \$107.30(PO)(APB/TB)$
Local $TC_o = \$27.10(THR_o) + \$1.14(RM_o) + \$107.30(PO)(BB/TB)$
Local $TC_w = \$28.29(THR_w) + \$1.14(RM_w) + \$107.30(PO_w)$
Express $TC_p = \$33.09(THR_p) + \$0.99(RM_p) + \$138.73(PO)(APB/TB)$
Express $TC_o = \$29.63(THR_o) + \$0.99(RM_o) + \$138.73(PO)(BB/TB)$
Express $TC_w = \$30.93(THR_w) + \$0.99(RM_w) + \$138.73(PO_w)$

where

TC = total daily operating cost,
THR = total vehicle-hours,
TMI = total vehicle-miles,
RH = revenue vehicle-hours,
RM = revenue vehicle-miles,
PVR = a.m. peak-to-base vehicle ratio, and
BPO = number of bus pullouts.

TC_p, TC_o, TC_w, THR_p, THR_o, THR_w, RM_p, RM_o, RM_w, PO, PO_w, APB, BB, and TB are as previously defined.

Because the service variables required as input to the peak and off-peak models were not readily available for every line in the system, three relatively small but distinctly different lines were used for the comparative analysis. The 495 line, which provides peak period express service between downtown Los Angeles and Diamond Bar, was chosen because it typifies a type of service that is generally thought to have relatively high unit operating costs. The 495 line is a park-and-ride service that runs from 5:12 a.m. to 8:54 a.m. and from 3:20 p.m. to 7:05 p.m. It does not have base period service (i.e., between 9:00 a.m. and 3:00 p.m.). The 602 line, on the other hand, was chosen because of its unique daily schedule that requires more buses in service during the off-peak period than during either of the peak periods. Unit cost estimates associated with the 602 line were thought to be less than average because of its nearly equal (and efficient) spread of service throughout the day. The 602 line is the (local) downtown Los Angeles minibus shuttle. The third line selected was the 262 line, which travels between South Gate and San Marino. The 262 line typifies one of the district's "average" lines in terms of the relative amounts of service scheduled during the peak and off-peak time periods. Unit cost estimates associated with the 262 line were thought to closely approximate SCRTD's average unit operating costs. The service variables required to compare each of the three test lines are given in Table 3. The results of the model comparisons are given in Table 4.

TABLE 3 Daily Operating Statistics for Lines 262, 495, and 602 (FY 1983-1984)

	Line 262	Line 495	Line 602
Bus requirements (a.m., base, p.m.)	5, 4, 6	10, 0, 10	7, 12, 9
Total vehicle-hours	79.6	49.8	98.3
Total peak period vehicle-hours	32.0	41.5	37.8
Total off-peak period vehicle-hours	47.6	8.3	60.5
Total revenue-hours	76.8	35.5	93.5
Total vehicle-miles	985	1,441	757
Total peak period revenue-miles	472	705	300
Total off-peak period revenue-miles	415	288	393
Total revenue-miles	887	993	693

In general, the statistics given in Table 4 suggest that, to some extent, all of the models consistently address line-by-line variations in unit operating costs. Each model, for example, indicates that the highest unit cost of the three test lines is indeed produced by line 495, the lowest unit cost by line 602, and the "median" unit cost by line 262. Given the nature of the service scheduled for each line (i.e., that line 495 provides peak period service only and that line 602 provides relatively little peak period service), the results are logical as well as consistent. Comparisons of the magnitude of each model's results, nevertheless, indicate that significant differences exist among the model designs.

Of the three models developed from system average expenses (i.e., the 1984 Scatchard model, the 1984 Stopher model, and the 1980 Gephart model), the model that explains the least variation in line cost estimation is the 1984 Stopher model. The Stopher model estimates a unit cost difference of only 22 percent between the highest cost line (line 495) and the lowest cost line (line 602). The 1980 Gephart model and the 1984 Scatchard model, on the other hand, estimate a unit cost differential of nearly 100 percent between the same two lines. Apparently, the Stopher model's overall purpose--as an input parameter to the UTPS modeling efforts of SCRTD--has, in effect, constrained the modeling design. Comparisons of the 1980 Gephart model and the 1984 Scatchard model indicate that, although both models track closely together, the 1980 Gephart model tends to associate somewhat higher operating expenses with lines that operate relatively more peak service than base service. The inclusion of a peak-related service variable (bus pullouts) in the 1980 Gephart model appears to account for the difference.

The results of the 1984 peak and off-peak models indicate an even greater disparity in operating cost estimates. From the unit cost estimates given in Table 4, the difference in peak versus off-peak period unit costs between the 495 line and the 602 line is 201 percent. Although the peak period cost model estimated a peak hour unit cost (for line 495) that was 18 percent greater than the highest average daily cost estimate of the other models, the off-peak period cost model estimated an off-peak period unit cost (for line 602) nearly equal to the lowest average daily cost estimate of the other models. As indicated by these results, the peak and off-peak models tend to address the marginal variations in SCRTD's services to a greater extent than do the traditional unit cost models that are based on system average expenditures.

Further, comparisons of the 1984 peak and offpeak models indicate that not only does line 495 produce the highest unit (hourly) operating cost of the three test lines, it also has the largest difference between peak and off-peak unit costs. The peak period unit cost for line 495 is 83 percent greater than the off-peak period unit cost. The peak-to-off-peak unit cost differentials for lines 495, 262, and 602 are 83, 39, and 13 percent, respectively (Table 4). Because the amount of variation between the peak and off-peak unit costs is a function of a line's peak-to-base operational efficiency, each line's peak-to-off-peak unit cost differential can be used as an indicator of potential passenger loading efficiency. Assuming fares are equal on a per passenger basis, the peak-to-off-peak unit cost differential indicates the percentage of peak period passengers required above the number of off-peak period passengers to offset the higher peak period operating costs. On an hourly unit cost basis, this would indicate that for line 495, 83 percent more

TABLE 4 Comparison of SCRTD Operating Cost Models for FY 1983-1984 ($)

	1984 Scatchard	1984 Stopher	1980 Gephart	1984 Peak/ Off-Peak
Line 262				
Total daily cost	3,737.00	4,011.00	4,361.00	4,020.00
Total daily cost/vehicle-hour	46.95	50.39	54.78	
Total peak cost/vehicle-hour				60.67
Total off-peak cost/vehicle-hour				43.68
Line 495				
Total daily cost	3,773.00	2,694.00	4,922.00	5,376.00
Total daily cost/vehicle-hour	75.76	54.10	98.84	
Total peak cost/vehicle-hour				116.77
Total off-peak cost/vehicle-hour				63.98
Line 602				
Total daily cost	3,816.00	4,344.00	4,525.00	4,002.00
Total daily cost/vehicle-hour	38.82	44.20	46.03	
Total peak cost/vehicle-hour				43.86
Total off-peak cost/vehicle-hour				38.76

passengers would be required to travel during the peak than off-peak period to offset the peak period operating costs. For lines 262 and 602, respectively, approximately 39 and 13 percent more passengers would be required to travel in the peak than the off-peak periods.

Clearly, a cost centers modeling approach, based on an understanding of the variations between local and express services as well as peak and off-peak operator pay-hours, has increased SCRTD's capability to estimate marginal line-by-line operating costs. Operating costs associated with different times of day, different types of service, and different days of operation can be identified. Given that even greater variations in divisional expenses are known to exist, sensitivity analyses by type of expense account can also be performed. Cost-effectiveness sensitivity analyses by bus type, for example, can be developed if differences in fuel, tire, and other expenses can be quantified. Although the development of six distinct models has increased the difficulty of the cost estimation process, the increases in accuracy appear to justify the disaggregate modeling design. Although significant modifications of SCRTD's labor agreements or service types, or both will influence the degree of accuracy of the peak and off-peak models, minor modifications can be absorbed in periodic calibrations of each model to the SCRTD operating budget.

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Abridgment

Transit Routing and Scheduling Strategies for Heavy Demand Corridors

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ABSTRACT

Efficient routing and scheduling strategies for heavy-demand corridors are described. Examples are given. Four strategies pertain to local service: short-turning, restricted zonal service, semirestricted zonal service, and limited-stop zonal service. Zoning of express services and deadheading of both local and express service are also discussed. Advantages and disadvantages of the strategies, and conditions favoring their adoption, are discussed.

Transit service in radial corridors can often take advantage of a high level and concentration of demand by employing routing and scheduling strategies that are more efficient than the conventional local route. For the purposes of this paper, a corridor is the narrow area served by a single local route or by a set of routes operating on the same street, and a "heavy-demand corridor" is one in which peak passenger volume is roughly eight or more busloads per hour. Although service in such corridors will rarely be identified through service standards as substandard, it is nevertheless often possible to increase its productivity significantly through the use of routing and scheduling strategies tailored to the markets. Because of the large amount of service offered in these corridors, improved productivity here can lead to substantial operating cost reductions. Several of these strategies are described and their advantages and disadvantages are discussed. Proposed and actual examples of their applications are presented. A fuller description of these strategies is found in Furth et al. (1). Procedures for analysis and design are documented elsewhere (2-6).

ZONAL EXPRESS SERVICE

By separating the long-distance, central business district (CBD)-oriented market from the remainder of the transit market, the former can be more efficiently served with express service. Express routes are faster because they make fewer stops and can use high-speed roads for the express portion. If they can charge higher fares, they are all the more cost-effective. However, lower design load factors required on some express routes can lower their productivity.

If the demand for express service is at least six or eight busloads per hour (i.e., large enough to support at least two routes), express service can often be made more efficient by splitting the express service area into zones and serving each zone with its own express route. There are three advantages to zoning: (a) the routes serving the inner zones do not travel the full length of the corridor, (b) each route's service area is more concentrated so that each trip requires fewer stops to fill a bus, and (c) the outer zone routes can sometimes use high-speed roads or take advantage of signal progression as they travel express over the inner zones. The disadvantage of this strategy is that wait times will increase because the demand, and hence frequency of service, will be only a fraction of that of an unzoned express route serving the same market.

SHORT-TURNING

The short-turn strategy consists of a system of two (or more) service patterns along the same street in which the shorter pattern is entirely overlapped by the longer. The shorter pattern is commonly referred to as a "short-turn" or "turn-back" variation of the full-length pattern. No boarding or alighting restrictions are imposed on any sections of the routes. This strategy is suitable for corridors in which demand tapers off in the outer segments. Operating cost is reduced because short-turn trips are substituted for full-length trips. Because of the lowered frequency of full-length trips, wait time increases for passengers whose trips are not served by the short-turn pattern. Service level does not change appreciably for those whose trips are served by the short-turn pattern. This latter group is called the "choice market" because they can use either the short-turn or the full-length pattern depending on which bus comes first.

The existence of a large choice market necessitates schedule coordination between the service patterns to ensure that each trip of a given pattern has a (more or less) constant number of choice passengers waiting for it, or loads will be unbalanced. Efficient schedule coordination is most easily attained if each pattern has the same service frequency so that they alternate within the overlapped segment of the corridor (the portion served by both patterns). The offset between the patterns determines how large a share of the choice market each pattern gets. Because the full-length pattern has a captive market of its own and uses larger vehicles, short-turn trips should lead the full-length trips by a small interval so that most of the choice market uses the short-turn pattern. For example, full-length trips might pass a checkpoint in the overlapped segment at 10, 20, 30 min after the hour and so forth, and short-turn trips might pass that point at 8, 18, 28 min after the hour and so forth.

RESTRICTED ZONAL SERVICE

A major determinant of which strategy will be most efficient for local service is the degree of downtown orientation in the local transit market, measured by the ratio of the corridor's peak volume to its uptown boardings (uptown alightings for the outbound direction in the p.m. peak), called the PV/UB (PV/UA) ratio. Uptown boarding (alighting) is defined as the volume of passengers boarding before (alighting after) the peak volume point. A small PV/UB ratio implies a lot of passenger turnover before the peak volume point and thus favors a strategy such as short-turning that freely allows for passenger replacement. However, when the PV/UB ratio is near 1, few passengers alight before the peak volume point, so allowance for turnover is not as important.

For restricted zonal service, as for the zonal express strategy, the corridor is divided into two or more zones with a particular route designed to serve each zone. Inbound buses on a restricted zonal route begin at the outer boundary (farthest outlying stop) of their service zone, operate locally within the zone, and then remain on the local street as they continue toward downtown. Unlike zonal express service, the buses may stop at any stop on the trip inbound to allow passengers to alight. Similarly, outbound buses will stop at any stop to allow boarding only (no alighting) between the downtown and their service zone; they then operate locally within their service zone. This arrangement is called a local service strategy because it still makes it possible to travel directly between any pair of bus stops in the corridor.

Restricted zonal service, like zonal express service, lengthens wait times throughout the corridor because all passengers must wait for the one route that serves their origin-destination pair. However, speeds increase for outer segment travelers because their buses are able to skip many inner-segment stops. In long, high-demand corridors, the reduction in travel time can sometimes offset the longer wait times for outer-segment travelers.

Like the short-turn strategy, the restricted zonal strategy reduces the number of trips operating in the outer segments of the corridor, thus reducing vehicle requirements. Higher speeds on the longer routes can further reduce vehicle-hours needed. However, some of these advantages are offset by the effect this strategy has on the turnover of seats. For example, once an inbound bus leaves its service zone, no one may board to replace alighting passengers. (The mirror-image behavior occurs on outbound buses.) The peak load of a restricted zonal route will therefore occur at or before the inner boundary of its service zone. Thus, the load on the bus as it enters the downtown will be less than the load it carried leaving its service zone because of the alighting that occurs as the bus operates in the restricted mode. Therefore this strategy is best suited to corridors with a high PV/UB ratio.

Restricted zonal service is used by the Massachusetts Bay Transit Authority (MBTA) along Massachusetts Avenue between Arlington Heights and Harvard Square in suburban Boston. The shorter route, Route 77A, operates locally between the North Cambridge terminal and Harvard Square. The longer route, Route 77.4, acts as a local route between Arlington Heights and North Cambridge and then goes into restricted operation between the North Cambridge terminal and Harvard Square. During the morning peak, Route 77A, which uses trolleybuses, makes 12 trips per hour with a cycle time of 40 min, requiring eight trolleybuses. Route 77.4, using diesel buses, makes 20 trips per hour with a cycle time of 75 min, requiring 25 buses. In comparison, a full-length local route serving the entire corridor would have a cycle time of about 80 min and would have to make 30 trips per hour. (The frequency of this single route is slightly lower than the combined frequencies of Routes 77A and 77.4 because it would allow free turnover in the inner zone.) Thus, a single local route would require about 40 buses, 21 percent more vehicles than the restricted zonal system now in place. Passengers also benefit from the restricted zonal configuration. Average wait time in the corridor is only 1 min longer under the zonal service than it would be with conventional local service (2.2 min versus 1.2 min), and in-vehicle time is about 5 min less under the zonal service for passengers originating before the North Cambridge terminal and unchanged for those originating after North Cambridge.

SEMIRESTRICTED ZONAL SERVICE

Inbound, semirestricted zonal service operates in a zone configuration like restricted service but differs in that it permits vehicles, if they stop outside their service zone to let someone alight, to let waiting passengers board. Thus, this strategy overcomes the inefficiency of the restricted zonal strategy by allowing for alighting passengers to be replaced. However, unfortunately, the strategy will not work in the outbound direction. The mirror image of the inbound policy is that outbound, if a passenger destined for an inner zone stop boarded an outer zone bus, he would be allowed to alight at his stop only if the bus happens to stop there to pick up a passenger waiting to board. With this kind of uncertainty, nobody traveling within the inner zone could be expected to use an outer zone pattern.

The level of service impacts of this strategy are between those of the short-turn and the restricted zonal strategy. This strategy is particularly attractive in moderate length corridors with a PV/UB ratio between 0.75 and 0.95. However, transit systems that have applied this strategy report that passengers will often complain because a bus that stopped to pick them up yesterday passed them by today. Such pressure has, in some cases, led to the discontinuation of the strategy. Another difficulty is that in the outbound direction, a different strategy, such as short-turning or restricted zonal service, must be used. A strong public information effort may be required to make this strategy successful.

LIMITED-STOP ZONAL SERVICE

This strategy is well suited to long corridors and does not require a high PV/UB ratio. Like zonal routes in other strategies, a limited-stop pattern has a service zone in which passengers may freely board and alight at any stop. However, outside the service zone, buses stop only at designated stops generally spaced 0.50 to 1 mile apart (except in the CBD, where every stop is usually designated). At these stops, passengers may both board and alight. The innermost route or pattern in a limited-stop zonal configuration is simply a local pattern (i.e., it has no limited-stop segment). If there is a lot of local traffic in the corridor, it is possible to have a local route parallel the limited-stop route the entire length of the corridor.

Like the short-turn strategy, this strategy generates a choice market of passengers who can use either the limited stop pattern or the local pattern, whichever comes first. Many of these passengers will walk greater distances to be able to use the limited-stop pattern. Efficient service design requires (inbound) that use of the limited-stop pattern by choice passengers from the inner segment be limited as closely as possible to just replacing alighting outer segment travelers (the mirror image applies outbound). To accomplish this objective, several measures can be taken. In the outbound direction, most of the boarding usually occurs in and near the CBD, where limited-stop and local patterns all travel at the same speed. Thus, schedules can be coordinated as in the short-turn pattern to optimally share the choice market. In the inbound direction, schedule coordination can affect the division of the choice market to some extent, but its effect is limited because the buses operating limited stop will overtake the local buses, so that a constant offset cannot be maintained. Another feasible, though undesirable, way to efficiently split the choice market in the inbound direction is to simply use crowding as a deterrent within the inner segment. Finally, charging a higher fare on the limited-stop pattern, increasing the spacing of designated stops, and making only some CBD stops designated stops are all measures that will decrease the limited-stop pattern's share of the choice market, if that is needed.

An application of the limited-stop strategy is found in the Wilshire Boulevard corridor of Los Angeles, where Southern California Rapid Transit District (SCRTD) Route 308 operates local from Santa Monica to Beverly Hills and limited stop from there to downtown Los Angeles. Between Beverly Hills and downtown, the corridor is served by several local routes in a quasi-short-turn system. Compared to a simple short-turn system for the entire corridor, the popular limited-stop configuration reduces one-way travel time from end to end by 12 min, benefiting both passenger and operator.

DEADHEADING

It is common practice for express routes to deadhead in the reverse direction of travel. It is also possible for a local route to deadhead all of its trips in the reverse direction, as long as reverse direction service can be provided by another route. For example, in a two-zone system, the inner zone route could deadhead all of its trips, leaving the full-length route to provide local reverse direction service (provided the reverse direction demand is low

TABLE 1 Advantages and Disadvantages of Local Service Operating Strategies

	Short-Turn	Restricted Zonal	Semirestricted Zonal	Limited-Stop Zonal
Need for schedule coordination and strict adherence	Vital	None	None	May be valuable in a.m.; valuable or vital in p.m.
Reliance on overtaking	None	Strong	Moderate	Strong
Wait time impact[a]	Up by 90% in outer segment, by 20% in inner segment	Up by 90% throughout	Up by 90% in outer segment, by 20% in inner segment	Up by 90% in outer segment, by 20% in inner segment
In-vehicle time reduction	None	Considerable	Moderate	Considerable
Walk-distance impact	None	None	None	Up by 0.2 mile for some outer segment passengers
Difficulty in public comprehension	Little	Moderate	Considerable	Moderate
Most favorable conditions for vehicle savings				
PV/UB ratio (%)	40-90	90-100	80-99	Any
Corridor length	Short	Long	Any	Long
Ambient speed on transit route	Slow	Fast	Fast	Fast

[a]Average impact to peak direction travelers in typical application.

enough). To avoid angering waiting passengers, many systems make it a practice to deadhead vehicles on streets that have no bus service.

Another deadheading option is to have only a fraction of the runs on a route return in service while the remainder deadhead. This strategy, called "alternating deadheading," is studied in Furth (6). The simplest alternating deadheading schedule is to have every other bus deadhead. In an application on an available freeway, alternating deadheading saved 4 of 29 buses on a busy route.

COMPARISON OF LOCAL SERVICE STRATEGIES

Table 1 gives a summary of the four major strategies for local service. Included are operational and public information problems, level of service impacts, and the conditions that most favor efficient operation of each strategy.

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Maintenance and Operating Costs of Small Buses

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ABSTRACT

Maintenance and operating cost data are provided for small buses. These data were obtained by analyzing the maintenance and fuel use records of 187 small buses from 16 transit properties located in different parts of the country. Specific cost data are provided for four types of small bus: vans and modified vans, body on van chassis, body on truck chassis, and purpose built. Both the labor hours and the materials cost are calculated on a per mile basis. The effects of climate and duty cycle on maintenance cost are evaluated. The procedure used in collecting the data and the characteristics of the data bases developed to store and analyze the data are described.

One of the important decisions facing small urban area and rural transit decision makers, who are interested in establishing new transit systems, is whether to invest scarce public funds in lower-capital-cost, more-efficient, less-durable transit vehicles or higher-capital-cost, less-energy-efficient, more-durable ones. Although previous research has provided reliable life-cycle cost and fuel use estimates for taxi vehicles and full-size standard transit vehicles, little information is available for vanpool vehicles, medium-size transit vehicles, or nonstandard, full-size transit vehicles (such as body-on-chassis-type school buses converted for transit use). If vehicle purchase decisions are to be soundly based, life-cycle cost comparisons and energy use information for those types of vehicles are essential.

Toward this end Arthur D. Little, Inc., undertook a project entitled "Small Transit Buses: A Manual for Improved Purchasing, Use and Maintenance" under the sponsorship of UMTA. This project was conducted through the National Cooperative Transit Research and Development Program. The general objective of this research was to develop a workbook-style manual that can be used by local transit operators and to identify key recommendations that might feasibly be applied by transit operators, local governments, states, and UMTA to substantially improve procurement, appropriate use, and maintenance for small transit buses. Furthermore, the manual was to assist individuals in the cost-effective procurement, maintenance, and operation of buses in a wide range of local, institutional, service, and operating environments. The manual will be available shortly.

The most important portion of this research project, the part dealing with what the costs of maintaining an operating small buses are and how these costs were obtained, is described. This work required collecting data through visits to a number of transit properties, developing data bases, and analyzing the data to obtain the required information.

DATA COLLECTION APPROACH

A review of the literature indicated that the prevalent method of estimating life-cycle maintenance costs is as follows:

- List the principal vehicle components (e.g., engine, transmission);
- Estimate the number of miles between repair or replacement of each component;
- Estimate the cost to repair or replace each component;
- For each component, divide the expected life mileage of the bus by the number of miles between repair or replacement and multiply by the cost of the component; and
- Add costs associated with each component.

This approach is particularly useful for comparing components made by different manufacturers and for scheduling preventive maintenance or inspections. However, it does not guarantee that the total cost to maintain the bus will be measured, because a large part of bus maintenance costs involves small repairs, adjustments, and inspections. Also, a study of component life requires a data collection period at least as long as each component's life.

The approach used for this project has been to attempt to measure total maintenance costs accurately and to make the results applicable to a wide range of bus types and operating conditions. This was done in three steps:

- Develop a test plan that includes appropriate combinations of bus types and operating conditions;
- Request the participation of transit properties that fulfill the requirements of the test plan; and
- Visit the properties and record, in detail, all work performed on specific buses during a period of approximately 6 months.

These steps resulted in data bases containing a complete maintenance history "snapshot" covering 6 months for each bus studied. The 6-month period amounted to about 10,000 miles per bus. This is certainly less than the mileage required to determine the life of most bus components. However, it was assumed that by studying several buses in similar operating conditions and at different odometer mileages the average maintenance costs under given conditions could be estimated. In retrospect, this assumption has held up reasonably well and the statistical confidence of the results can be improved by simply adding more 6-month "snapshots" to the data base.

The data collection plan began with a broad definition of the many areas of cost (cost elements) associated with operation and maintenance, such as brake repair and engine tuneups. A list of the cost elements, which an attempt was made to quantify, follows:

- Body work,
- Wheels,
- Brakes,
- Axles,
- Suspension system,
- Steering,
- Interior,
- Air conditioning,
- Special equipment (wheelchair lifts),
- Fare collection,
- Voice communication,
- Fuel,
- Chassis,
- Bumpers,
- Windows and wipers,
- Doors,
- Engine,
- Fuel system,
- Electrical system,
- Exhaust,
- Engine cooling system,
- Driveline,
- Tires, and
- Oil.

Each cost element was then examined to determine the principal factors (independent variables) that can affect it. Some of the variables examined are bus type, duty cycle, odometer mileage, and climate.

Then, on the advice of consultants familiar with the U.S. transit industry, 27 properties were selected that, together, fulfilled the requirements of the data collection plan. Letters describing the project and requesting their participation were then mailed to the properties. Subsequently a telephone call was made to each property to confirm their willingness to support this research and to establish a schedule for on-site visits.

In preparation for visits to the properties, two data collection forms were developed, one for characterizing details of each bus and its operating environment and one for recording the maintenance performed on each bus. The bus characteristics data collection form was seven pages long and included space for entering engineering data as well as subjective comments from interviews with personnel at the transit properties. The maintenance reporting form included space for the following items:

- Bus identification number;
- Time period covered;
- Odometer mileage range covered;
- Fuel consumed during period; and
- Information on all maintenance activities, including (a) odometer reading, (b) job description, (c) labor hours spent, (d) parts costs, and (e) total job cost.

With the data forms in hand, investigators spent 1 day at each of the 27 selected properties. The properties surveyed are given in Table 1.

Two principal sources of information used during the site visits were staff interviews and historical work orders. Maintenance staff members were interviewed for details of vehicle characteristics, duty cycle descriptors, and maintenance experience. Records of daily work orders were reviewed and, usually, photocopied as the source for maintenance labor hours and parts costs. As might be expected, there was a wide variation in the forms of the available

TABLE 1 Properties Surveyed for Small Bus Maintenance and Cost Data

Property	Location
Included in Analysis	
Care-A-Van	Fort Collins, Colo.
Transfort	Fort Collins, Colo.
SEMTA, Macomb	Detroit, Mich.
MTA	Flint, Mich.
CY-Ride	Ames, Iowa
The Bus	Greeley, Colo.
STS	Saginaw, Mich.
GET	Bakersfield, Calif.
JTS	Jackson, Mich.
RTA	Cleveland, Ohio
CCCTA	Contra Costa, Calif.
TRT	Norfolk, Va.
SEMTA, Port Huron	Detroit, Mich.
Pierce Transit	Tacoma, Wash.
Intercity Transit	Olympia, Wash.
OCTD	Orange County, Calif.
Not Included in Analysis	
Public Service	New Orleans, La.
SEMTA, Taylor	Detroit, Mich.
Bay Metro	Bay City, Mich.
SCAT	El Paso, Tex.
TARC	Louisville, Ky.
Metro Transit	Kalamazoo, Mich.
SEMTA, Pontiac	Detroit, Mich.
RTA	Sumter, S.C.
SST	Steamboat Springs, Colo.
The Ride	Ann Arbor, Mich.
Road Runner	Lowell, Mass.

data, from extensive computer files to handwritten notes in a spiral binder. All forms were useful and as much data as possible was gleaned from each source. However, not all types of data were readily available at each location. Maintenance record-keeping policies fell into the following four broad categories:

- Computer files containing coded descriptions of work done plus parts costs and labor hours;
- Individual handwritten work orders describing work done, labor time, and parts replaced (and parts costs);
- Summaries of parts costs and labor time, with little detail of work done; and
- Incomplete records of work done, perhaps with no indication of odometer mileage.

The most common practice, by far, was the use of individual work orders. These were usually found, ordered chronologically, near the shop area. Because the time period of study was only the previous 6 months, all pertinent work orders were readily available. The work orders collected are the basis of billing and, often, maintenance scheduling at the garages and seemed to be well kept. This gives confidence in the completeness and accuracy of the data.

To prepare for the analysis, record-keeping procedures were established and two computer data bases were developed. The primary purpose of record keeping was to assure that all primary data were collected completely, reviewed for quality control, and available for analysis.

DATA REDUCTION

From the volume of information collected at each property, several key parameters were selected for tabulation and entry into two computer data bases, the Vehicle Characteristics Data Base (BUS) and the Maintenance Events Data Base (MAINT). BUS contains specifics of the vehicle design, the environment in which the vehicle operates, and the service it performs. MAINT is linked to BUS by a unique bus ID number and contains the details of the maintenance and operations events related to that specific bus. The information in MAINT is set up with codes to describe each event, such as replace some gallons of diesel fuel or repair the shocks on the front end, and with the concurrent cost information, such as number of gallons (with cost per gallon to be added later) or labor hours plus materials costs.

The data file BUS contains the following elements of information:

- Bus ID number,
- Authority ID number,
- Climate,
- Bus type,
- Bus make and model,
- Year built,
- Gross vehicle weight rating (GVWR),
- Seating capacity,
- Wheelchair provisions,
- Fuel type,
- Brake type,
- Average speed en route,
- Stops per mile,
- Average peak passenger load,
- Duty cycle,
- Acquisition cost,
- Resale value,
- Maintenance records--beginning mileage,
- Maintenance records--ending mileage, and
- Comments.

The data file MAINT contains the following elements of information:

- Bus ID number;
- Origin of maintenance (e.g., scheduled or driver report);
- Maintenance action (repair, replace, or inspect);
- Major system ID (e.g., electrical or front end);
- Part ID (e.g., disc pads or muffler);
- Labor hours;
- Split, actual, not applicable, or estimated (SANE) cost index for labor;
- Materials cost;
- SANE index for materials cost;
- Contracted cost;
- SANE index for contracted cost;
- Total cost, nonstandard;
- SANE index for total cost;
- Unit quantity; and
- Unit cost.

More than 200 separate codes were used to encode the maintenance data. For this analysis, the codes were combined into seven bus systems:

- Brake and suspension,
- Engine and driveline,
- Electrical,
- Body and interior,
- Wheelchair,
- Auxiliary equipment, and
- Unspecified.

Each work event was coded as repair, replacement, or inspection, when the distinction could be made. Records of fuel use were also contained in the MAINT data base.

The SANE index for labor, referred to previously, made it possible to account for the variability in the source of maintenance labor hours and costs. Split record ("S") is used when the total labor hours are obviously divided over two or more events. For instance, if it is given that 3 hours were spent changing spark plugs and fixing a flat tire, the 3 hours would be split between two records in MAINT and the code "S" applied to the labor hours. Again, this allows for rapid coding and an opportunity for later quality control. Actual ("A") is used when the information is accurate and complete, as in "1 hour spent replacing a speedometer cable." Not applicable ("N") is used in circumstances where labor is not charged, as during daily refueling. Estimated ("E") is used when no specific details are available and engineering judgment is required. For instance, if a maintenance event was found that involved the replacement of a speedometer cable with no associated labor charge, an "E" was entered next to a blank labor hour field, which was later filled with an estimate of the time required.

These data bases were appropriate for rapid coding of the basic elements of the data collected. They provided the basis for quality control and were sufficient for the primary regression analyses.

Data were accumulated from 27 transit properties representing 316 buses. However, not all properties could provide complete details of maintenance labor and parts costs. This necessitated dropping some buses from further analysis. Analysis was actually performed on 187 buses from 16 authorities (Table 1) encompassing about 2.37 million bus-miles and 1,200 bus-months of operation, including more than 5,000 separate maintenance events.

In preparation for statistical data analysis, the definitions of the independent parameters were reviewed and put in final form. The key independent parameters are described in the following sections.

Bus Type

The fleet of small transit buses was divided into four categories:

1. Van--A standard, light-duty automotive vehicle with no extensive body modifications beyond an after-market raised roof or the addition of a wheelchair lift.
2. Body on van chassis--A light-duty van chassis with a full passenger body; for example, a Collins Omnibus body on a Dodge B-300 chassis.
3. Body on truck chassis--A complete bus body built onto a truck chassis supplied by a major vehicle and engine manufacturer; for example, a Superior Transliner body on a GMC chassis.
4. Purpose built--A bus built onto a chassis or frame specifically designed for that purpose and built by the bus builder; for example, a TMC Citycruiser.

Climate

Three climatological parameters were used to quantify a "climate rating" for the general location of each authority:

- Annual inches of snow,
- Annual degree-days, and
- Annual days of precipitation.

Each parameter represents an average of many years of data at each location. The data were obtained from National Oceanic and Atmospheric Administration reports. One consideration is that this rating is not tailored to the specific time range of the maintenance data collected, although it does represent the general year-round climate the buses have been exposed to. Also, data for all individual cities are not available so data from the nearest major city were selected.

Table 2 gives a summary of the elements that make up the climate rating code for each location. The codes appear to accurately represent the climatological differences between the various locations and should be sufficient for investigating the broad effects of climate on maintenance costs. Three ratings codes were used. Examples of each are given in Table 2.

TABLE 2 Summary of Climate Rating Code

Climate	Characteristics
Mild (Code 1)	On average, less than 20 in. of snow and less than 4,000 degree-days[a] per year (e.g., Bakersfield, Calif. and Norfolk, Va.).
Moderate (Code 2)	On average, more than 4,000 degree-days and less than 100 days of precipitation per year (e.g., Tacoma, Wash. and Fort Collins, Colo.).
Severe (Code 3)	On average, more than 20 in. of snow, more than 4,000 degree-days, and more than 100 days of precipitation per year (e.g., Flint, Mich. and Ames, Iowa).

Note: Climate data can be obtained from the National Oceanic and Atmospheric Administration reports.

[a]"Degree days" is determined as the sum of (65°F-average temperature during the day) for each day that the average temperature is less than 65°F.

Duty Cycle

Several measures were available from which to synthesize a duty cycle code. These included

- Average speed while moving;
- Typical number of passenger stops per mile;
- Average peak passenger load, to be compared with seating capacity;
- Maximum route speed; and
- Service descriptors (e.g., demand-response, elderly and handicapped, school tripper, shuttle, fixed route).

These measures were examined and found to be highly correlated; that is, as one measure changed, most of the others also changed in a predictable fashion. The most fundamental descriptor of duty cycle is the typical number of passenger stops per mile. This appears to readily separate the basic service areas. High numbers of stops per mile occur in city or urban areas, medium numbers of stops per mile indicate a low-density city or perhaps a suburban area, and low numbers of stops per mile indicate longer distance runs, as in rural areas. Higher vehicle speeds tend to accompany lower stops per mile. The wear that a bus must withstand is directly related to the amount of stop-and-go action it encounters--especially as evidenced by brake and front-end work. As an example of its application, this duty cycle descriptor allows a distinction between the maintenance costs for a high-mileage bus that has "worked in the city" to one that has had "an easier life." Table 3 gives definitions of various duty cycles.

TABLE 3 Summary of Duty Cycle Rating Code Characteristics

Duty Cycle	Characteristics
Mild (Code 1)	On average, less than or equal to 1 stop per mile (e.g., a rural elderly and handicapped route).
Moderate (Code 2)	On average, more than 1 but fewer than 3 stops per mile (e.g., a demand-response city route).
Severe (Code 3)	On average, more than or equal to 3 stops per mile (e.g., a fixed city route).

TABLE 4 Total Maintenance Mileage and Number of Buses in the Data Bases

	Bus Type							
	Vans		Body on Van Chassis		Body on Truck Chassis		Purpose Built	
Duty Cycle	Maintenance Miles	No. of Buses	Maintenance Miles	No. of Buses	Maintenance Miles	No. of Buses	Maintenance Miles	No. of Buses
Light	11,700	4	395,700	36	57,000	6	0	0
Medium	73,000	6	316,800	21	193,400	19	0	0
Heavy	83,500	8	20,700	3	12,300	1	1,203,000	83

Average Mileage

This is the midpoint of the mileage range of each bus covered in the survey or, in general terms, the mileage of each bus at the time of the survey. This became a principal descriptor of maintenance costs, following the hypothesis that buses cost more to maintain as they age.

As described next, various statistical techniques were applied to generate meaningful maintenance and operating cost data on small buses.

SUMMARY OF RESULTS

The data bases contain the maintenance events and costs for about 2.37 million miles of bus operation. The data given in Table 4 indicate how these maintenance miles are distributed over the four bus types and three duty cycles. The number of buses in each combination is also shown. Although an attempt was made to survey buses with a wide range of operating conditions, the distribution on Table 4 seems to indicate the way bus types and duty cycles are usually combined. All of the purpose-built buses are used in heavy stop-and-go service. The body-on-van-chassis buses are used principally in light and medium service and the heavier body-on-truck-chassis buses are used principally in medium-duty service. Vans, perhaps because of their flexibility, appear in all duty cycles.

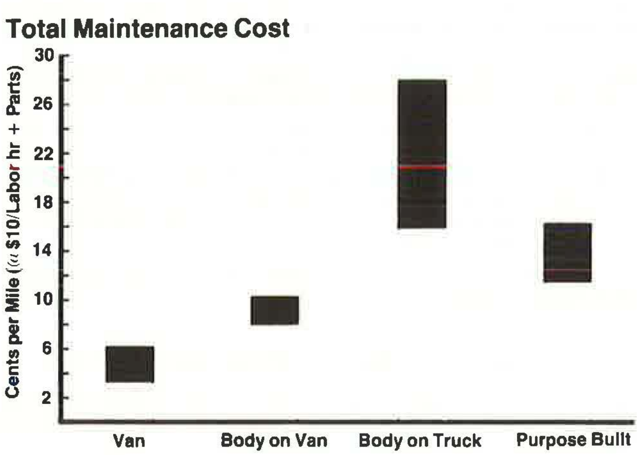
These data bases can be used to obtain many different types of useful information. For the purpose of developing a manual on small buses, they were analyzed in several different ways as described hereafter.

Figure 1 shows the 95 percent confidence ranges of the total maintenance costs of the four types of small buses, which were obtained assuming a labor rate of $10 per hour. As can be seen, the maintenance cost for a body-on-truck-chassis bus may lie between 16 and 28 cents per mile, whereas that for vans may lie between 3.4 and 6.2 cents per mile. A substantial portion of the variability is explained by variations in climate, duty cycle, and cumulative mileage, which are given in Tables 5 and 6.

Table 5 gives estimated maintenance requirements for each type of small bus. In this table, the requirements are expressed in terms of labor hours and materials cost. From this table, it is easy to obtain maintenance cost per mile estimates given the bus type, climate severity, duty cycle characteristics, and local labor rate in dollars per hour. It can be seen from the table that maintenance requirements are generally strongly dependent on climate, duty cycle, and bus type. In developing the costs in Table 5 from the regression equations, the trends in cost have been smoothed out in those cases in which the equations provided results counter to engineering judgment and past knowledge of maintenance costs.

The labor hours and materials cost for body-on-van-chassis buses is shown independent of climate severity. This is not because climate severity is not considered an important variable for this bus type but because sufficient data were not available to determine a statistically valid relationship. Similar comments apply to the materials cost for purpose-built buses.

Using the data bases, the effects of bus odometer mileage on the maintenance requirements can also be determined (Table 6). To incorporate mileage effects, simply multiply the labor hours and materials



95% Confidence Range	Van	Body on Van	Body on Truck	Purpose Built
	3.4	8.1	16.0	11.6
	6.2	10.3	28.0	16.3

FIGURE 1 Data scatter in total cost per mile for different bus types.

TABLE 5 Small Bus Maintenance Requirements

Climate	Duty Cycle	Van or Modified Van	Body on Van Chassis	Body on Truck Chassis	Purpose Built
Labor Hours per 100 Miles					
Mild	Mild	0.17	0.46	0.61	0.29
	Moderate	0.22	0.57	0.77	0.38
	Severe	0.27	0.71	0.96	0.50
Moderate	Mild	0.22	0.46	0.79	0.31
	Moderate	0.28	0.57	0.99	0.41
	Severe	0.35	0.71	1.23	0.54
Severe	Mild	0.30	0.46	1.08	0.33
	Moderate	0.38	0.57	1.36	0.44
	Severe	0.48	0.71	1.69	0.58
Materials Cost per Mile (1983 cents)					
Mild	Mild	1.2	4.3	5.9	2.6
	Moderate	1.3	4.7	6.5	3.9
	Severe	1.4	5.2	7.1	6.0
Moderate	Mild	1.2	4.3	6.1	2.6
	Moderate	1.4	4.7	6.8	3.9
	Severe	1.5	5.2	7.5	6.0
Severe	Mild	1.6	4.3	8.1	2.6
	Moderate	1.8	4.7	8.9	3.9
	Severe	2.0	5.2	9.8	6.0

TABLE 6 Mileage Factors

Mileage at Start of the Year	Mileage Factor for Labor Hour: Van or Modified Van	Body on Van Chassis	Body on Truck Chassis	Purpose Built	Mileage Factor for Materials Cost: Van or Modified Van	Body on Van Chassis	Body on Truck Chassis	Purpose Built
0-10,000	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
10,000-20,000	1.00	1.05	1.05	1.01	1	1.1	1.01	1.01
20,000-30,000	1.00	1.11	1.10	1.02	1	1.2	1.03	1.02
30,000-40,000	1.00	1.16	1.14	1.03	1	1.3	1.04	1.03
40,000-50,000	1.00	1.22	1.19	1.04	1	1.4	1.05	1.04
50,000-60,000	1.00	1.27	1.24	1.05	1	1.5	1.06	1.05
60,000-70,000	1.00	1.33	1.29	1.06	1	1.6	1.08	1.06
70,000-80,000	1.00	1.38	1.34	1.07	1	1.7	1.09	1.07
80,000-90,000	N/A[a]	1.44	1.38	1.08	1	1.8	1.1	1.08
90,000-100,000[b]	N/A[a]	1.49	1.43	1.09	1	1.9	1.12	1.09

[a] All vans in the survey had fewer than 80,000 odometer miles.
[b] Above 100,000 miles, use the following formulas: Mileage factor for labor hours = 1 + (n/100) x (mileage/10,000) and mileage factor for materials cost = 1 + (m/100) x (mileage/10,000) where n is 0, 5.5, 4.8, and 1 for van or modified van, body on van chassis, body on truck chassis, and purpose built, respectively, and m is 0, 10, 1.3, and 1 for van or modified van, body on van chassis, body on truck chassis, and purpose built, respectively.

cost obtained from Table 5 by appropriate mileage factors given in Table 6.

The data collected included the quantity of fuel consumed by each bus during the period studied. This allows an estimation of miles per gallon (MPG) for each bus type. The average values are given in Table 7.

TABLE 7 Average MPG of Different Types of Small Buses

Bus Type	Fuel Type	Average MPG	Standard Deviation, MPG
Van	Gasoline	8.9	6.3
Body on van	Gasoline	6.5	1.7
Body on truck	Gasoline	5.1	1.8
Purpose built	Diesel	6.1	2.8
Purpose built	Gasoline	3.6	0.0

In addition to these general results, the data base can be used to obtain more detailed information on maintenance cost. An example is given in Table 8. In this table, the maintenance cost is given in terms of cents per mile, assuming a labor rate of $10 per hour. As can be seen, a body-on-truck small bus is more expensive to maintain than the other types, and vans are the least expensive. Also, maintenance of brakes and suspension and engine and driveline dominate the overall maintenance requirements.

The maintenance cost results presented in these tables are statistical averages of data that, in

TABLE 8 Total Maintenance Cost per Mile by Bus Type and System (cents per mile)

System	Van	Body on Van	Body on Truck	Purpose Built
Unspecified	1.12	1.03	2.44	2.58
Brakes and suspension	1.24	3.53	6.15	4.00
Engine and driveline	1.03	2.34	7.59	2.65
Electrical	0.44	1.07	2.19	1.51
Body and interior	0.42	0.54	0.82	1.74
Wheelchair	0.32	0.39	1.15	0.55
Auxiliary equipment	0.15	0.34	1.76	0.91
Total	4.72	9.24	22.10	13.94

Note: Cost per mile is calculated as: sum of parts cost + labor @ $10 hr)/Sum of maintenance miles.

fact, have a significant amount of scatter. The reasons for the scatter are

- The maintenance survey period, about 4 to 8 months, is not always long enough to capture many of the major maintenance events for every bus.
- One bus may have entered a period of intensive renovation and consequently had a low mileage during that period of time. Another bus, in similar conditions, may have accumulated higher mileage, because little major maintenance work was performed.
- The make and model of the bus can significantly affect maintenance costs. Proper specification and quality of design, manufacture, and assembly are obviously important but could not be adequately addressed in this study.

The data in Figure 1 suggest that the following approximate 95 percent confidence bands be applied to the mean values of total maintenance cost per mile derived from Tables 5 and 6: ±35 percent for vans, ±10 percent for body-on-van-chassis, ±30 percent for body-on-truck-chassis, and ±20 percent for purpose built.

It is believed that the data presented will prove valuable in making decisions about the purchase, maintenance, and operation of small buses. However, it is recommended that any quantitative analysis performed using these data be tempered with the user's own experience or that of others in the transit industry.

CONCLUSIONS AND RECOMMENDATIONS

Maintenance and operating cost data for small buses have been provided. In addition, the process of gathering the data and the characteristics of the data bases developed to analyze these data have been discussed. Specific data provided in this paper are

- Small bus maintenance cost per mile in terms of labor hours and materials costs for different bus types, climate severity, and duty cycle characteristics;
- Small bus fuel use;
- Effects of odometer mileage on maintenance cost per mile; and
- Maintenance cost per mile for different systems for each bus type.

In addition, the potential for using the data base for developing maintenance and operating cost data that are specific to a particular application has been demonstrated.

It is recommended that this effort be continued because the usefulness of the data bases will decline over time unless they are periodically modified to

- Add information on new types of small transit buses entering the market and
- Update information on maintenance and operating costs of buses already included in the data bases.

Also, a similar project should be undertaken to investigate reliability of small buses, which is a major factor affecting the quality of service, the cost of maintenance, and the spare bus capacity required to meet service objectives. Therefore, the users of small buses will benefit from a study in which the maintenance records of a large number of small buses are examined to evaluate their reliability. The end result of such a study will be estimates of reliability of various bus types, expressed in terms of time-to-failure and time-to-repair statistics for different components.

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Revitalizing Express Bus Services in a Suburban Community: A Public-Private Partnership

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ABSTRACT

In response to rapidly deteriorating privately owned and operated express bus service, Prince William County, Virginia, developed a program designed to stabilize and improve services. The program, conceived by a citizens advisory committee and initiated with state and local funding, uses a public-private partnership whereby the local government purchases and remanufactures suburban coaches and then leases the coaches to a private operator. Lease fees are nominal, and the private operator is contractually obligated to the local government to provide all necessary coach maintenance. Thus the local government in effect provides a capital subsidy to a private operator and helps provide reliable public transportation without becoming the actual provider. The local government reviews routes and schedules and assists in marketing but does not defray operating costs. To date, the county has remanufactured and leased 10 suburban coaches to a local private operator. This has resulted in the availability of more reliable, more comfortable, and safer express bus service for county commuters. Express bus patronage is increasing, and the county hopes to remanufacture and lease an additional 10 coaches. The program appears to be successful and incorporates several strategies that may be of interest to suburban jurisdictions considering initiatives in express bus operations.

Prince William County, Virginia, is a rapidly developing suburban jurisdiction in the Washington, D.C., metropolitan area with a 1980 population of 144,700. Two Interstate highways, I-95 and I-66, provide access to key employment centers in Washington as well as to the Pentagon, Crystal City, Rosslyn, and Tysons Corner. Although most daily work trips from Prince William County are made by single-occupant vehicles, other modes have assumed greater importance in recent years. Throughout the 1970s a private operator provided express bus services from the residential eastern part of the county. However, in the late 1970s and early 1980s, deteriorating rolling stock, under capitalization, mediocre management, and severe winter weather contributed to unreliable and uncomfortable service. County residents were presented with the alternative of participating in ridesharing arrangements that were sponsored by a local government ridesharing matching service. Because carpools and vanpools are permitted access to the I-95 high-occupancy-vehicle (HOV) lanes, it is not surprising that many commuters began to rideshare instead of using the express bus.

This contributed to a further decline in patronage, so in an effort to stabilize and improve express bus service, a Prince William County citizen advisory committee, the Mass Transportation Committee (MTC) began to examine the problem. The MTC, created on August 31, 1973, by the Prince William Board of County Supervisors (PWBOCS), is comprised of up to 15 county residents appointed by the county supervisors. To encourage coordination with other committees, the by-laws specify that one member be from the County Planning Commission, one from the Highway Safety Committee, and that there be an ex officio supervisor from the county board. Typically, this supervisor is also the county's representative at the Transportation Planning Board, which is the metropolitan planning organization for the region. The MTC's responsibilities include

- Making recommendations to the Board of County Supervisors on the subject of mass transportation, which can be taken to include "commuter transit, bus service, rail service, mini-bus service, metro service, dial-a-bus service, carpools, and other public or private modes of transit; and shall include consideration of vehicles, transfer points, stops, routes, fees, regulations, applicable laws, stations, ramps, exclusive bus lanes, parking for users of mass transit services; and shall also include federal and state programs and grants for mass transportation; and other matters related to the above" (by-laws of the MTC);
- Promoting the development of viable mass transportation services in the county;
- Cooperating and working with public and private sectors throughout the county and region to improve levels of mass transportation services in the county;
- Serving as a clearinghouse for ideas and suggestions for improving mass transportation services in the county, and acting as the county's point of contact with local, state, and federal agencies on matters related to mass transportation; and
- Studying ways in which mass transportation services may be improved.

In the past, the MTC helped to develop the transit element of the county's comprehensive plan and to promote ridesharing. The MTC with state and local funding has helped to establish an interest free "start-up" loan for vanpool operators, and a ridesharing coordinator position in the County Planning Office was established as a result of MTC efforts. Moreover, several MTC officials were instrumental in the development of the Virginia vanpool association. The vanpool association, a private organization, now provides information on financing, forming, operating, maintaining, and ride-matching for members. With these activities, the county has achieved an extraordinarily high rate of ridesharing. In fact, Prince William County in 1980 had the highest rate of ridesharing in the Washington, D.C., area: 37 percent.

In June 1981 the MTC began its most ambitious project to date. The project was suggested by a member who was aware of state funding available and who had the idea of obtaining 20 remanufactured buses. These buses would be owned by the county but leased to one or more private operators in an effort to stabilize service. Project MOVE was initiated to help "Make Our Vehicles Efficient." A subcommittee of three individuals was assigned to develop a proposal for the Board of County Supervisors. The subcommittee was composed of a lawyer, a highway safety engineer, and a regional transportation commission official. One subcommittee member addressed legal questions that would be raised with the county attorney. The other subcommittee members talked to manufacturers and transit authorities to obtain estimates of costs and to learn about the availability of buses and the scope of remanufacturing that would be desirable. The scope of the project as initially proposed called for an estimated 20 vehicles, 40 ft in length with a seating capacity of 53 passengers at an investment of $70,000 per vehicle. This unit investment of $70,000 was expected to provide an extended economically useful life of 6 to 8 years of service. Several public transit agencies including Detroit, New Orleans, Philadelphia, Chicago, Washington Metropolitan Area Transit Authority, and New Jersey Transit had recently embarked on coach remanufacturing and this estimate was consistent with their costs.

Thus, the MTC subcommittee determined that there was a need to maintain an inventory of high-occupancy coaches to make the most efficient use of highway investments. This capability is even more critical if highway funding shortfalls delay the extension of high-occupancy-vehicle (HOV) lanes on I-95.

The subcommittee report was endorsed by the full MTC, which then recommended that the Prince William County Board of Supervisors initiate an application of $1.4 million in Capital Assistance to Mass Transit under the provisions of Item 640.D of the 1981-1982 Biennial Budget of the Commonwealth of Virginia. The vehicles were expected to provide an extended economically useful life of 6 to 8 years of service. As noted previously, these vehicles would be leased under competitive bidding procedures to a private transit operator for exclusive use in commuter service between the county and employment centers in metropolitan Washington. As originally conceived, operating lease conditions were not to cover routes or fares, nor provide county financing for operation. Lease conditions would require maintenance of equipment, appropriate insurance, and reimbursement of all county expenses for administration of the project. It was hoped that the successful bidder would provide the funds for the 5 percent local match required to obtain state aid for mass transportation.

To summarize, the rationale behind this project was based on the need to provide reliable, comfortable, and flexible service; to address the deteriorating condition of the existing rolling stock of the financially ailing private company; and to help relieve congestion on major routes such as I-95.

The proposal was endorsed by the full MTC in November 1981 and, after lobbying of the Board of County Supervisors, the project was presented in December 1981 and the board approved the program concept and directed county staff to prepare the appropriate documentation for state officials.

Accordingly, a grant application was drafted, and in early 1982 the Prince William Board of County Supervisors approved, by a narrow margin, the formal submission of a $1.4 million grant application to the Virginia Department of Highways and Transportation (VDH&T). The initial grant application generated several conferences between state and local transportation staff. One issue, the source of the local match, was of concern to state officials. The citizens committee had hoped that the private operator would provide the required local 5 percent match. However, in order to provide funds, state officials needed a local match from the public sector.

In effect, Prince William County, a fiscally conservative local government, would be required to provide approximately $70,000 in local funds.

These staff conferences set the stage for a work session with the Prince William Board of County Supervisors (PWBOCS), at which time state procedures and guidelines were communicated to local elected officials. This work session was instrumental in explaining to local decision makers the fiscal, operational, and policy implications of pursuing the grant application. It is important to note here that these discussions with state public transportation officials were typified by candid and constructive exchanges, which contributed to the establishment of a positive working relationship between state and local staff.

In late spring 1982 the PWBOCS reaffirmed its desire to seek state funding for the program and subsequently directed county staff to pursue the grant application. Thus state officials, in June 1982, were evaluating a $1.4 million grant application to be funded under the Experimental Aid for Public Transportation program. Pursuant to the program's funding formula, if the grant were approved, the state would reimburse the county for up to 95 percent of total program costs, and the county would be responsible for the remaining 5 percent.

The review process culminated in a recommendation from VDH&T staff that the Virginia Highway and Transportation Commission approve the grant application. Consequently, in August 1982, the commission approved $1.4 million in funding for the Prince William County Commuter Bus Program.

APPROACH

Shortly after the grant award and execution of the necessary state-local agreements, staff began work on the two key program elements: vehicle procurement and selection of one or more private operators.

Vehicle Procurement

Because many of the program tasks, particularly those involving coach specifications and preventive maintenance programs, required knowledge or skills unavailable at the local staff level, a decision was made to seek consultant assistance. Consultant participation was structured such that local staff were actually doing much of the "legwork": forming contacts with individuals in the remanufacturing industry and with key staff of public transit authorities that were already involved in coach remanufacturing either through in-house programs or by private contractor. At the beginning the consultant's role was mainly to provide a technical check on the products developed by local staff. This was intended to allow the staff to develop as much technical expertise as possible. For example, the consultants provided resources and guidance in developing remanufacturing specifications and reviewed the final product, but the actual specifications were developed at the local level so that they were tailored to local needs. More extensive consultant assistance was employed during the actual remanufacturing process. This on-line inspection was important to ensure contractor compliance with the county's specifications and to ensure quality control.

A significant decision about vehicle procurement was made at this stage. A turnkey approach was adopted whereby the remanufacturer would be required to locate and purchase vehicles in addition to remanufacturing. This approach eliminated several firms that were unwilling to locate vehicles. Also at this time staff were beginning to focus on the type of coach necessary for operations. Although over-the-road, three-axle coaches were attractive, it was thought that a suburban configuration with overhead reading lights, all forward-facing seats, and under locker loaders, was most appropriate.

At this stage county staff began to develop remanufacturing specifications. Drawing from documents supplied by other transit authorities and discussions with industry representatives, the county in conjunction with its consultants began the task of developing comprehensive specifications that would later be incorporated in a bid document. Because a basic objective of the program was to provide safe, reliable, and comfortable public transportation, rigorous specifications were drafted. The major coach components specified for remanufacturing were (a) power module, including engine, transmission, and accessories; (b) steering system, including universal-joint assemblies and drag link assemblies; (c) heating, ventilating, and air conditioning system; (d) suspension, axles, and differential; (e) brakes, wheels, and wheel bearings; (f) fuel tank and line; (g) exhaust system; (h) electrical system; (i) structure (underframing) including bulkheads; and (j) exterior surface and interior, including seats, rubber floor covering, and paint.

These vehicle remanufacturing specifications were incorporated into a bid document that was issued in the late spring of 1983. Three responses were received: two from remanufacturers in the northeast and one from a firm in the midwest. One bid was immediately declared nonresponsive because it clearly failed to respond to the program goals and was not accompanied by the required bid bond. Of the two remaining bids, one was certified as responsive, but it was feared that the unit cost, in excess of $100,000 per coach, would provide far fewer coaches than needed. The remaining bid also exceeded budget but not as significantly. However, the bid proposed remanufacturing General Motors Corporation (GMC) transit diesel hydraulic (TDH) vehicles, which are a basic transit configuration. The issue of whether to accept a TDH took several weeks to resolve, and, after a meeting of state and local officials and the consultants, it was decided that the county would exercise its option of not awarding a bid.

At this point the county was faced with a private operator that was barely solvent and a delay of several months before the project could be rebid. Consequently, the MTC held a special meeting that was attended by approximately 100 concerned commuters. Although the meeting was often heated, it was valuable in providing citizens with accurate information on the program's timetable.

The remanufacturing specifications were soon rebid using a more flexible procedure: competitive sealed proposals. This approach allowed for limited negotiation and evaluation of factors other than unit cost, such as quality of work and delivery schedule, and resulted in selection of a midwest remanufacturer at a significantly lower unit cost of $73,000. (The complete remanufacturing specifications are given in the appendix.)

Shortly after the contract between the county and the remanufacturing firm was executed, a preproduction meeting of the remanufacturer, county staff, and the consultant management and inspection team was held at the bus remanufacturing facility. Refinement of the specifications and a production schedule were discussed. The contractor and the online inspector had to agree on the staging of the remanufacturing process, the interpretation of rebuilding in application to specific components, the testing procedures to be followed, tolerances permitted, and instrumentation used to conduct the tests. Because more than one inspector would be assigned to the project at different periods, it was essential to adopt basic uniform inspection procedures in order to avert any production delays that could result from contrasting styles or methods used by subsequent inspectors.

A production schedule was presented by the remanufacturer that showed a project completion date of 3.5 months. The consultant questioned the feasibility of the schedule, indicating that it was overly ambitious and without contingency considerations. Despite the reservations of the inspector, the remanufacturer was confident that the targeted completion date was within the capabilities of the firm's production crews.

Production on the county project began in the final week of January 1984, and delivery of the first bus was anticipated in mid-February. A request for a 2-week extension of the delivery date was submitted by the firm to compensate for severe inclement weather that had delayed supplier shipments. The first vehicle was not received by the county until the final week in March. It was later learned that many of delays were due to financial constraints affecting the firm. As of this writing, the county has taken delivery of 10 of the 20 buses slated for remanufacture.

As each bus was received by the county, a postdelivery inspection was performed by a team consisting of the inspector, the operator's maintenance personnel, and county staff. All defects were recorded and reported to the firm's quality control staff. Also, the county's on-site inspector was alerted to specific problems discovered after delivery. This created an effective feedback loop, so similar problems could be avoided on remaining coaches. When the postdelivery inspection had been completed, the acceptance of the coach was certified and county officials released payment of the coach.

Operator Selection

The process of selecting a private passenger transportation carrier to operate the remanufactured coaches was undertaken by the county in tandem with the advertisement of the second bus remanufacture request for proposals (RFP). It was decided that citizen involvement would continue through this phase of the project.

Operator RFP

A Citizens Coordinating Committee (CCC) was appointed by the Board of County Supervisors to serve as the steering committee in the solicitation and selection of a commuter bus operator. A draft RFP was developed by the planning staff and distributed to CCC members for review and comment. The RFP package was designed for the solicitation of carriers that had sufficient administrative, maintenance, and operational experience in the bus service industry. Background information about corporate status, personnel organization; certification by the Interstate Commerce Commission and the Virginia State Corporation Commission; and a submission of the financial condition of the company were required of each firm offering a proposal. Details regarding the bidders' operating capabilities in the following areas were also requested in the RFP document:

- Existing facilities and bus fleet size and composition,
- Maintenance capabilities,
- Existing services provided by the operator,
- Services proposed for Prince William County,
- Lease fee proposal, and
- Experience of firm and existing contractual obligations.

A weighted evaluation system that indicated how the offeror's proposal would be judged was included in the RFP. The criterion of greatest value was the operator's ability to provide safe over-the-road operations. This criterion accounted for 65 percent of the total rating scheme and included the operator's competence in maintaining the motor coaches as well as his effectiveness in providing for an adequate driver training and safety program. The bidder's financial capabilities and service (route and schedule) proposal, which formed the remaining items of the evaluation criteria, assumed weighted values of 20 percent and 15 percent, respectively.

The operator RFP was advertised for bid in October 1983 with 1 month allowed for receipt of proposals from prospective bidders. On the closing date, November 9, the County Purchasing Office had received two proposals from interested firms. (A total of 35 RFP documents had been sent to firms requesting an RFP package.) Along with the RFP, a sample lease agreement, also developed by the staff, was included in the proposal mailout.

Proposal Evaluations and Operator Selection

The Citizens Coordinating Committee members, who monitored development of the RFP document and operator lease agreement, received copies of both proposals and were asked by the staff to assess the merits of each individually. It was agreed at that point that the committee would invite each operator to make a verbal presentation at the next CCC meeting. Both bidders consented to meet with the committee and present their submission.

In early December the CCC convened subsequent to the presentations by the operators and voted unanimously to select Washington Motor Coach Inc. (WMC), a company that was currently providing commuter bus service in the county, as the operator for the bus lease program. The CCC recommendation of WMC as the program operator was submitted to and approved by the Board of County Supervisors on January 17, 1984. The Virginia Department of Highways and Transportation, after a thorough review of the proposals, concurred with the selection and authorized county execution of the service-lease agreement with WMC.

Lease Agreement

The drafting of a lease document, which would primarily govern the use of the buses as well as institute scheduled vehicle maintenance controls and service reporting requirements, was undertaken by the planning staff before the operator RFP solicitation. A number of vehicle lease arrangements between public transit properties and contracting parties (both public and private) were examined for their applicability to the lease program envisioned by county officials. The lease contract that appeared closest in character to the county's effort was the agreement that existed between New Jersey Transit and various individual private operators that supplied commuter services with vehicles rented from that state's Public Transit Organization. Many of the terms and conditions were, in effect, adapted for use in the county's contract.

The lease agreement, through the terms set forth in it, was designed to achieve the following goals:

- Assure that the equipment is used for program-specific purposes,

- Assure that the public investment in the equipment is protected, and
- Promote the efficient use of the equipment.

The conditions highlighted next were included in the lease in order to accomplish these program goals:

Use of Vehicle

The motor coaches are restricted to commuter transportation service. All other uses, with the exception of special purchase of service or emergency transportation authorized by the county, are restricted. State guidelines prohibit the use of the coaches for charter service.

Maintenance and Repairs

The operator is responsible for maintenance and repair of the buses. A scheduled routine preventive maintenance program is incorporated as part of the lease. A maintenance reporting system required of the operator enables the county to monitor operator performance.

Insurance

The operator is required to carry an insurance policy that includes minimum liability coverage of $10 million. The county reserves the right to approve the insurance carrier or the policy in whole or in part. The operator agrees to hold the county harmless from all loss or damage.

Service Coverage and Reporting Requirements

The operator and the county agree to joint approval of all route and schedule development in the county.

The operator is responsible for keeping service and financial records of the company's performance. A summary of these data is reported to the county's Bus Operations Review Subcommittee (BORS).

The draft lease agreement was reviewed by the CCC, the County Finance and Purchasing Offices, the County Insurance Broker, the County Attorney's Office, and the VDH&T. A final lease was completed in January 1984 and executed in April before the delivery of the first bus from the remanufacturer.

OPERATIONS AND SERVICE MONITORING

April 5, 1984, marked the initial day of service with the first county-leased coach. The vehicle was planned for rotation among the 12 service runs on the operator's three routes until more remanufactured buses were delivered to the county. This would permit the widest exposure to the system's riders. Passenger reaction to the coach was extremely favorable.

Data Reporting

The monitoring of bus operations focused on three areas of reporting: service information, level of maintenance, and financial records review. Each of these items is a reporting requirement in the lease agreement. Data-specific reports are detailed as follows:

- Service reporting includes daily ridership figures, daily driver manifest, daily rider check (random), documentation of passenger complaints, and accident reports.
- Maintenance reporting includes daily bus driver vehicle safety report, fuel and oil consumption report, mechanic work orders, preventive maintenance service schedules, vehicle road call report, and a monthly unit maintenance expense summary.
- Financial reporting includes a quarterly company balance sheet and income and expense reports. These statements are prepared by the operator's accountant and are not publicly disclosed but are reviewed by the county's Bus Operations Review Subcommittee.

Because WMC is a small concern, much of these data had not been recorded before the execution of the lease. Bus maintenance files had not been kept for any of the units because of the limited administrative staff. Service documentation had been limited to ridership figures and revenue totals. The reporting requirements of the lease necessitated expanding the administrative staff from two to three persons, two of whom also drive the buses.

Company Organization

A breakdown of WMC personnel should emphasize that each of its 25 employees including the president of the firm can be classified as a driver; however, a more accurate division of labor, which reflects the actual duties and responsibilities of the work force, is given in the following table:

Category	Status	No. of Employees
Administrative, clerical		3
Drivers	9 full time 7 part time	16
Mechanics and vehicle service personnel	4 full time 2 part time	6
Total employees		25

Operating with nonunion personnel, the owner of WMC is able to contain labor expenses sufficiently to allow for committing the majority of the company's resources to commuter bus service. The ability to continue operating with a large part-time contingent in the labor force is critical in local commuter bus service, which does not provide the larger profit margins of charter service. Nearly one-half of the drivers who are part-time employees are actually full-time workers in the Washington metropolitan area. They receive a $7.00 fee for each one-way trip driven. As worker-drivers, their responsibilities entail driving a morning scheduled run, parking the bus, and returning in the afternoon from their full-time position to make a scheduled evening run. Full-time driving staff receive $13.00 for each one-way commuter run made.

Full-time drivers will generally have additional duties that can include bus maintenance, record keeping, dispatching, and interim charter and contract driving. Several of the worker-drivers are employed by the federal government and occasionally are required to go on out-of-town work-related assignments. This has created driver scheduling problems for the operator who is unable to obtain immediate back-up assistance on short notice. Nevertheless, the decision of the company to use worker-drivers bears significantly on WMC's ability to keep labor costs at approximately 38 percent of the firm's total expenditures.

Routes and Schedules

WMC currently operates service on three base routes in the county. Seventeen daily commuter runs are provided on the three routes. The majority of commuter bus stops are concentrated along major arterial roads. Five formal commuter lots and numerous informal lots are the major staging areas for passenger boarding and alighting. All commuter destinations are limited to the major employment cores in Northern Virginia and Washington, D.C.

Initially, it was agreed to in the lease that the county and the operator would jointly approve all revisions or modifications of commuter routes and schedules. To date, the operator has had the independence of developing these changes without a great deal of input from the county other than submitting them for review to a bus operations committee. It has been observed, however, that many of the decisions regarding routes and schedules made by WMC hinge more on operator experience than on the use of accepted route planning and scheduling techniques. If the system is to sustain an orderly route expansion and as the scheduling system requires greater sophistication in its planning, it may be necessary for the county to assume a larger role in this aspect of service development by supplying the necessary expertise.

Fares

Passenger fares for the commuter bus service vary from a daily round-trip ticket range of $7.00 to $9.00 to the weekly 10-ride discount pass range of $20.00 to $23.00. The operator is somewhat limited in establishing his fare structure by the fares charged by vanpool and carpool operators. The ridesharing network in the county is well organized and the fares set by the bus operator must be competitive to avoid a loss of ridership. Thus the need to include fare controls in the lease agreement was determined to be an unnecessary regulation.

According to the latest financial data provided by the operator, commuter fare revenues comprised more than 95 percent of the total income earned by WMC in 1984.

Ridership

Table 1 gives WMC's ridership since the operator formally assumed the provision of commuter bus service in September 1983. As noted earlier, the county bus lease program began in April 1984.

TABLE 1 Washington Motor Coach Commuter Service Passenger Trip Summaries

	Average Daily Trips 1984[a]	Average Daily Trips 1983	Monthly Total Trips 1984	Monthly Total Trips 1983	Year-to-Date Trips 1984
January	744		15,640		15,640
February	731		14,635		30,275
March	767		16,885		47,160
April	800		16,811		63,971
May	822		18,101		82,072
June	844		17,726		99,798
July	857		17,998		117,796
August	908		20,888		136,684
September	1,102	665	19,552	9,988	158,236
October	1,053	716	23,168	14,332	181,404
November		802		15,245	
December		757		12,883	

[a]Average daily passenger trips are based on the service days for each month.

This is not the place to speculate on the reasons why the increase in ridership has occurred. An effort to measure passenger satisfaction with the service is planned in the near future and may provide the county and the operator with some insight into the specific reasons for the increased usage of bus service by county commuters.

Passengers per vehicle trip at the present time reflect a systemwide average of approximately 29 riders (October 1983) or roughly 60 percent of vehicle capacity. This average has remained fairly constant throughout the operator's history of service despite the enhancement in the level of service during that time (total daily commuter runs have risen from 24 daily one-way vehicle trips to 36 one-way vehicle trips since September 1983). What is somewhat surprising is that the bus operator has maintained the 60 percent seat occupancy with a minimal effort to market the service and attract new passengers during expansion.

Marketing

The operator is essentially responsible for promoting and advertising the service; however, the county has assisted WMC in distributing route and schedule information through its COMMUTERIDE program. COMMUTERIDE is a combined effort by the county ridesharing and commuter bus programs to assist residents of Prince William County in seeking alternative means of commuting to their places of employment. Acting as a broker for commuter services, the COMMUTERIDE office will supply ride-matching services for carpool and vanpool requests and also will provide commuter bus schedule information. Because pooling services are a directly competing mode, WMC is not overly comfortable with the idea of the dual promotion; however, the county is committed to the combined approach because it provides the commuter with a wider range of alternatives for the journey to work. To date, both the ridesharing and commuter bus programs have sustained patronage growth.

The operator has chosen not to advertise the bus service to any great extent; instead WMC has largely relied on the county and word of mouth to communicate the availability of service. Approximately one-tenth of 1 percent of the total company expenditures have gone toward the purchase of advertisement. The county through its Commuter Bus Administrative budget has committed funds on a limited basis, which may be used to match WMC revenues for the purchase of advertising for the bus service. This incentive to advertise commuter bus transportation has not affected WMC's decision to refrain from developing a marketing program for its service.

Bus Maintenance Program

At the time that a proposal was submitted by WMC for the operation of the county buses, the company was having all of its major repairs and corrective maintenance performed by a private firm located about 40 miles south of the county. This was of some concern to the operator selection committee because of the number of non-revenue-miles that would be accumulated by the buses. Before the execution of the lease agreement WMC was able to secure occupancy at the bus storage and maintenance facility that was vacated by a previous operator. The facility is centrally located in the highly populated eastern section of the county.

With the physical capabilities to perform all forms of maintenance, the owner of WMC began to employ both full- and part-time mechanics. Consequently, the problem of accrual of non-revenue-miles has been eliminated.

The operator's maintenance facility consists of four maintenance bays (two with pits) and one bus wash lane. Maintenance employees are specialists in engine and transmission servicing (including rebuild projects), air conditioning, body work and painting, and electrical troubleshooting. Part-time specialists perform many of the maintenance tasks during the evening hours.

The preventive maintenance (PM) program was implemented shortly after the execution of the lease. PM inspections are scheduled at 5,000-mile intervals or at least once each month, whichever occurs first. Driver manifest sheets are used to track upcoming PM. The filing system responsibilities are assigned to a driver with the company. An analysis of the efficiency and effectiveness of the operator's maintenance program has not been undertaken as of this time.

Service Profitability

The operator's financial reports indicate that, between April and August 1984, the company maintained an even balance between expenditures and revenues while significantly reducing its outstanding debt. As mentioned previously, the vast majority of income (95 percent) is received from commuter operations. Before April 1984, however, the operator had accrued earlier losses that can to a great extent be attributed to the in-house bus revitalization program that the WMC undertook to increase the fleet rolling stock. Many of these coaches are in marginal "revitalized" condition and probably will be sold or retired when the additional 10 county coaches are available for lease.

Although the Commuter Bus Program does not involve the support of an operating subsidy through public funding, the bus lease program is definitely a form of capital assistance to the operator. If calculated over the expected 6-year life of each coach and assuming an average passenger occupancy rate of 60 percent as a constant, the subsidy per trip is approximately $0.79 per passenger. Annualized in dollars for a 20-bus fleet at the same passenger occupancy rate, the subsidy would equal $231,889.00 or about 36 percent of the total projected revenue. How these estimates relate to the firm's costs is more difficult to determine because the operator will probably incur additional expenditures through program growth (e.g., implementation of an employee fringe benefits program). At current levels of spending, however, the operator is in a position to realize a profit, and this assessment is supported by WMC's most recent monthly income and expenditure statement.

SUMMARY, OBSERVATIONS, AND RECOMMENDATIONS

It is thought possible to present recommendations in three areas: program and policy development, vehicle procurement, and operations.

Program and Policy Development

• Citizen involvement, if properly structured, can provide expertise to assist in the development of innovative public transportation programs and is often critical in persuading decision makers to pursue experimental programs.

• Adequate institutional support is necessary to initiate a program in a timely fashion. Prince William County was not able to bring to bear the resources of an established transit entity. Specifically, the lack of purchasing and fiscal staff with transit experience was a continuing weakness. County legal staff, however, very quickly got "up to speed" and provided positive support. In lieu of project engineers, the county had to rely on the expertise of private consultants. Consultant participation created weaknesses in project management.

• Continued progress reports, in this case to the MTC, ensure continued citizen participation in the program.

Vehicle Procurement

• Continued evaluation is needed to compare the long-term benefits of remanufacturing buses versus purchasing new buses. The procurement of remanufactured coaches may be an appropriate approach if passenger demand and funding constraints preclude the purchase of new coaches. The county was able to purchase remanufactured coaches at about half the cost of new coaches. Typically, remanufacturing is a fleet replacement technique and not used for program start-up. Although it is preferable to begin a program with new coaches, the Prince William County approach appears to be cost-effective.

• The level of remanufacturing is the key determinant of unit cost. Coach restoration ranges from low-cost, cosmetic work (seats, paint, glass) to rebuilding of major components (power train) to complete remanufacturing (including structural work). Prince William County desired a comprehensive, thorough remanufacturing, and contractors' bids were priced accordingly.

• The method of procurement also influences cost. Use of a competitive sealed proposal approach allows flexibility and limited negotiation of specifications and price. Prince William County was able to execute a remanufacturing contract within budget using this method.

• Geographic proximity of the remanufacturer emerged as a more significant factor than originally anticipated. Travel to the midwest from Northern Virginia was expensive and time consuming. Using a firm within 1 hour flying time would have allowed for more effective project management.

• The number of on-line inspectors should be carefully limited. The county's consultant used an excessive number of production line inspectors; this led to problems with the consistent application of standards.

Operations

• Although the authors are not able to pinpoint the exact factors that have contributed to the increase in commuter bus ridership at this time, it can be assumed that it is a result of some service improvement and may indicate a longer term reverse trend toward the use of commuter bus service by residents of the county.

• The development of bus routes and schedules has largely been performed by the operator with the county reviewing the service proposals. The responsibility for this aspect of service development may require reevaluation by the county if the program is to sustain an orderly and systematic growth.

• In the county RFP for the solicitation of operators, it was required that a prospective operator ensure that the necessary facilities be secured for operating and maintaining the vehicles (ideally to be located in the county to avoid accumulating substantial deadhead mileage). It should be noted that such facilities (storage and maintenance) are often limited in their availability and it is recommended that potential sites be investigated before the solicitation of operators to ensure that the offerors can in fact locate such a facility. Notification in the RFP of county involvement in the site location could have generated a greater response by interested operators.

• To date, the operator has chosen not to commit moneys to marketing the program to any great degree, even with limited county matching funds available to do so. Because the county desires to achieve maximum vehicle use by its commuting residents and in light of the value of the capital subsidy, the operator may be requested to place greater emphasis on promoting the service.

• The program at this time does appear to have the potential for profit accrual by the operator. It is premature to estimate to what extent profits can be realized. Much will depend on the operator's ability to manage his resources if and when new growth occurs.

• The roles of the operator and the county are still being defined and will evolve further as the experiment matures. Unless circumstances dictate otherwise, the goal of the program will be to maintain the bus service as a function of the private operator.

• Much attention is being focused on the public-private partnership that has been used to meet the need for improved express bus service in the county. The success or failure of the program will largely be dependent on the balance achieved between the partners. The carrier has demonstrated his ability to control those operating costs (particularly labor costs) generally found to be much greater in the public sector or in a unionized environment. Some of the cost containment is necessary as a matter of survival. On the other hand, the public sector must ensure that the prospects for continued efficient private bus operations are buoyed by assisting the program when it is essential to do so, or suffer the consequences of an inferior or inadequate service.

CONCLUSION

To date, the county has remanufactured and leased 10 suburban coaches to a local private operator. This has resulted in the availability of more reliable and comfortable and safer express bus service for county commuters. Express bus patronage is increasing, and the county hopes to remanufacture and lease an additional 10 coaches.

This paper in some respects is a preliminary evaluation of the Prince William County Commuter Bus program. However, because the program appears to be successful and incorporates several approaches that may be of interest to suburban jurisdictions considering involvement in express bus operations, the authors are disseminating information in a timely fashion in the hope that other local and state transportation agencies may find it useful.

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APPENDIX: PRINCE WILLIAM COUNTY REMANUFACTURING SPECIFICATIONS FOR SUBURBAN COACHES

Power Module: Engine, Transmission, and Cooling System (accessories)

Engine

Remove, disassemble, inspect, and remanufacture 8V-71 engine and fluid fan drive to Detroit Diesel Allison (DDA) specifications, using original equipment manufacturer (OEM) parts; 6V-71 engines are not acceptable. Remanufacturing is to be performed by an authorized DDA contractor, in accordance with current DDA specifications. All seals, hoses, gaskets, and filter elements are to be replaced with new parts. The remanufactured engine is to be tested using a dynamometer; no engine will be considered remanufactured until dynamometer test results indicate the engine meets or exceeds specifications outlined by the engine manufacturer and that it will perform properly under service conditions. A copy of the dynamometer test result is to be submitted to the county or the county's authorized representative.

The following engine rebuild tasks are to be performed in accordance with current DDA specifications and procedures:

1. Cylinder block. Clean and degrease; scale and flush; pressure test. Measure and repair all irregularities; no welding or pinning allowed on cooling system.
2. Crankshaft. Clean, inspect, and magnaflux. Crankshaft journals and crank pins shall be precision chrome-plated to standard diameter.
3. Piston, liners, and connecting rods. Pistons and liners will all be replaced with new DDA kits. Connecting rods are to be reconditioned.
4. Oil pump. Oil pumps are to be completely reconditioned.
5. Camshafts. Clean, inspect, and magnaflux camshaft. Precision grinding may be used to maximum DDA allowable specification. All new bushings, bearings, seals, and thrust washers are to be used.
6. Gear train and idler gear. Timing idler and drive gears will be replaced with new DDA parts, including new bearings and thrust washers.
7. Flywheel. Flywheels are to be cleaned, inspected, and replaced when necessary.
8. Cylinder heads. Cylinder heads shall be cleaned, degreased, scaled and flushed, and magnafluxed. No welding or pinning repair is acceptable. All valves, guides, springs, keepers, followers, rollers, locks, and injector tubes to be replaced with new DDA parts, as necessary, and rebuilt.
9. Flywheel vibration damper. To be rebuilt with new DDA parts to current DDA specifications.
10. Injectors. All injectors are to be replaced with rebuilt C55 units.

11. Fan and drive. Shall be completely reconditioned, including crankshaft dampers.

12. Blowers. To be completely reconditioned, including new bearings, gaskets and seals, and new blower drive shaft.

13. Fuel pump. To be completely rebuilt.

14. Governor and cover. To be completely rebuilt, including new bushings, bearings, and seals.

15. Water pump. To be completely reconditioned, including new gaskets, bearings, seals, and impeller.

16. Thermostats. All thermostats to be replaced with new.

17. Oil cooler core. To be flushed, cleaned, and tested. Any faulty elements are to be replaced with new assemblies.

18. Oil relief and regulator valves. Shall be replaced with new assemblies.

Accessories, such as engine mounts and cradle, are to be replaced with remanufactured parts. Engines are to be painted DDA green. All oil hoses are to be replaced by new Strato-Flex Teflon No. 246 hoses. All engines are to be protected against low oil pressure and high water temperature by the installation of a Motor Guard Engine Shut Down System. The engine shut down system should have provisions for restarting the engine and moving the vehicle off the road.

Transmission

Disassemble, inspect, and remanufacture manual transmission to DDA specifications; all parts that are removed are to be replaced with OEM parts. Remanufacturing is to be performed by an authorized DDA contractor or by the contractor. Remanufacturing by the contractor is acceptable, subject to review and approval by the county. The remanufactured transmission is to be run in on a dynamometer; no transmission will be considered remanufactured until dynamometer test results indicate that the transmission meets or exceeds specifications as outlined by the transmission manufacturer and that it will perform properly under service conditions. All filters and filter assemblies, seals, gaskets, bearings, and bushings are to be replaced with new parts. New shift governors are to be installed. Vehicles must be able to attain a top speed of 60 to 65 mph with the engine properly governed.

The following components are to be replaced or repaired as necessary (optional transmission specification):

- Filter assembly,
- U-joint assembly,
- Transmission housing,
- Control valve,
- Converter housing cover,
- Converter housing,
- Direct and hydraulic clutch,
- Shifter fork and shift gears, and
- Bevel drive gears.

Cooling System and Radiator

The radiator is to be disassembled, cleaned, inspected, repaired as necessary, rebuilt, and pressure tested. As needed repairs will not remove over 10 percent of radiating capacity, new OEM cores are to be installed. All connecting hoses are to be replaced with new silicone hoses Strato-Flex Silicon No. 4214, new gaskets and two (2) new clamps at the end of each connection. Radiator tanks and fittings are to be case iron or brass. New thermostats and transmission water lines are to be installed.

Air Systems

The air systems are to be purged of all foreign material, dirt, water, and so forth. The air compressor is to be a remanufactured B-1 TuFlo 700 size with ball bearing crankshaft. The air compressor governors shall be relocated on the left-hand hanger support and shall be preset for 135 psi.

Oil-Cooled Generator

Remove, disassemble, clean, inspect, and rebuild to Delco-Remy specifications. Test each unit under full load after rebuilding and provide the county with written certification of satisfactory performance.

Steering System

Provide new OEM steering U-joint assemblies, new drag link end assemblies, and new drag link tube assemblies. New hoses and fittings are to be provided throughout the steering system.

The steering column, overaxle steering box, and propeller shaft are to be rebuilt using new seals and bearings. All parts, including steering knuckles, are to be magnafluxed and inspected, and any components appearing defective will be replaced with new OEM parts.

Heating, Ventilating, and Air Conditioning

The heating, ventilation, and air conditioning systems are to be remanufactured to restore original performance levels. All lines are to be inspected and restored as required.

Heating and Ventilating

The heating system is to be entirely rebuilt, with rebuilt heating cores, rebuilt heater blower motors, rebuilt defroster motors, core and housing, rebuilt heater compartment doors, and reconditioned valves. New filters, seals, and hoses are to be provided as part of the heating system rebuild. The circulation pump and motor are to be restored and relocated to the engine compartment.

Recondition heater/defroster core as follows:

- Thoroughly clean by submerging in hot radiator cleaning solution.
- Repair as needed; repairs will not remove over 10 percent of radiating service.
- Straighten inlet and outlet pipes.
- Reassemble and test at 15 to 18 psi.
- Straighten pins and paint black.
- Install with new silicone hoses.
- Recondition water modulating valve; circulating pump and motor will be restored and relocated to the engine compartment.
- Recondition ventilation blower motors, installing new blower motor relays.
- Recondition ventilation heater cores, install new hoses, clamps, and sealing compound.
- Clean and recondition heater compartment doors.

Air Conditioning

The air conditioning system is to be entirely rebuilt, using new brackets, filters, hoses, fittings, expansion valves, and seals. A new air conditioning compressor, the TRANE Model CROG-1500-2A, or equivalent, is to be installed in conformance with the original equipment shown on the line ticket for each coach. New clutch and driver shafts are to be installed. All wiring and piping is to be properly aligned and supported to prevent vibration, chafing, and crimping.

The following components are to be restored or replaced with new OEM parts. The exact nature of the restoration will depend on whether the system is hydraulic or electrical.

- Remanufactured condenser pump (hydraulic system) or
- New AC condenser alternator driver assembly and new alternator (electrical system) and
- Remanufactured condenser motor (hydraulic system) or
- New AC condenser fan drive motor assembly (electrical system).

Front and Rear Axles and Suspension Including Steering: Differential

Where appropriate, components of the steering are to be magnafluxed and inspected, and any components appearing defective are to be replaced with new OEM parts.

Front Axle and Suspension

- Install new steering knuckle kingpins, bushings, kingpin bearings, tie rod assemblies, and front axle bumpers.
- Replace, with new parts, radius rod bushings, lateral rod bushings, upper radius rod bracket, leveling valves and linkages, bellows, piston, shock absorber assemblies, clamps, and bellows support assemblies.

Rear Axle and Suspension

- Install new gaskets, seals, and axle bumper assemblies; install new rear axle housing, as necessary.
- Replace, with new parts, radius rod bushings, lateral rod bushings, upper radius rod bracket, leveling valves and linkages, bellows, piston, shock absorber assemblies, clamps, and bellows support assemblies.
- Axle shafts are to be removed, cleaned, and inspected. Damaged or twisted axle shafts are to be replaced with new axle shafts.

Differential and Carrier Assembly

Inspect and repair as necessary differential and carrier assembly. Differential is to be remanufactured as necessary so that it meets or exceeds the original manufacturer's specifications.

Brakes, Wheels, Bearings, and Tires

Brakes

Front and rear brakes are to be returned to standard. This includes new brake drums, linings, shoes, camshafts, slack adjusters, anchor pins, bushings, seals, brakeshoe return springs, and brake chamber assemblies. Front and rear hubs are to be inspected and replaced, if necessary. In addition, the following components of the brake system are to be replaced with new OEM parts:

- Brake application valve,
- Brake relay valve,
- U-bolts,
- Teflon hose assemblies with stainless steel braiding, and
- Valves (such as check valves and quick release valves).

The parking brake is to be returned to standard. This includes a new drum, linings, shoe, anchor pins, bushings, seals, brake return springs, slack adjuster level, link pins, and parking brake control parts (as required).

American Brake Block (ABB) 80 mixture or equivalent is required. The air tanks are to be inspected and repaired as necessary.

Wheels and Bearings

All wheels are to be inspected for deformation and out of roundness and worn or elongated bolt holes, and are to be replaced as necessary. All wheel studs are to be replaced. All cup and cones, inner and outer, are to be replaced with new parts. All wipers, seals, and gaskets are to be replaced by new parts. Wheel bearings and races are to be replaced with new parts.

Tires

Bidders should assume bias, over-the-road, 14-ply rating tires will be used. All tires and rims should be standard throughout the vehicles proposed.

Fuel System

The fuel tank and all lines are to be flushed and cleaned. All fuel lines are to be inspected for crimping, chafing, or other damage and replaced as necessary. The fuel tank is to be inspected and repaired as necessary. New pins on fuel filters and strainers are to be installed throughout the fuel system.

Exhaust System

All exhaust system components are to be replaced with new OEM parts. This includes new mufflers; new tailpipes and exhaust pipes; and new gaskets, clamps, and grommets. Left-hand and right-hand manifolds are to be inspected and replaced if necessary.

Electrical System

The electrical system will be completely inspected and tested to OEM specifications, including, but not limited to, the following:

- Visual inspection,
- Continuity test,
- Ohmmeter test, and
- Other tests as necessary.

Any defects found by the contractor or county inspector involving the main wiring looms and harnesses will require replacement (or repair) with new wiring looms and harnesses that meet or exceed original capacity. All subwiring looms and harnesses will be replaced in accordance with OEM specifications and standards.

For new electrical circuits, wiring diagrams are to be submitted to the county or its authorized representative for approval. Wire is to be of the original size or larger. Insulation is to be cross-link polyethylene and color coded so that the circuit of each wire can be readily determined at any point along the wire.

All wiring is to be properly grouped and installed so as to permit ease of replacement. Wiring is not to be run through metal or other parts of the structure, except where unavoidable; at such points rubber bushings are to be provided.

All electrical switches, relays, circuit breakers, solenoids, dash gauges, lenses, and bulbs are to be replaced with new parts. Lamp assemblies, sealed beam assemblies, cables are to be replaced with new OEM parts. Amphenol connectors are to be inspected and replaced as necessary.

The starter, alternator, and voltage regulator are to be remanufactured so that they meet or exceed the original manufacturer's specifications.

Batteries are to be replaced with new batteries that conform to OEM specifications. The existing battery cable is to be replaced with new 4/0 size battery cable, and the battery tray is to be replaced with a new tray constructed of steel and coated with corrosion resistant material.

All internal lighting power packs are to be converted to individual ballast operation.

Structure

Underframing

Lift vehicle and remove all mechanical and electrical components, clean thoroughly and sandblast all underframing so as to expose the metal for complete inspection.

All engine bulkheads will be replaced using new steel bulkheads, new engine mounting brackets, new angles, new reinforcement plates, new closure panels, new support assemblies, new beams, and new longitudinal plates.

All remaining defects or excessive wear and tear found in the underframing/structure due to corrosion, fatigue, age, or abnormal use will be replaced completely in order to restore underframing/structure to meet OEM and county standards. The decision to replace all bulkheads other than the engine bulkhead will be based on the following conditions:

- If more than 15 percent of each bulkhead is in need of repair, it will be removed and replaced with a new bulkhead.
- If less than 15 percent of the bulkhead is defective, it may be repaired as necessary.

Replacement will be determined by the county inspector and the contractor's quality control department. All new replacement bulkheads must be of steel composition.

Floor

All floor covering will be removed to expose plywood. Contractor and county inspector will make a complete inspection of the condition of the plywood and the contractor will replace those sections that are deteriorated or do not meet OEM standards.

New black rubber flooring will be installed over plywood covering the rear reinforcing plate. The floor will be bolted down; if this is not possible, it must be screwed down with self-tapping screws.

Roof, Upper and Lower Posts

The posts, carlines, stiffeners, strainers, reinforcements, and panels are to be inspected and replaced with new parts as necessary.

Body Interior and Exterior, Doors, Seats, and Paint

The body interior, exterior structure, windows, doors, seats, and related items are to be completely restored in accordance with the following sections:

Body Interior

The interior is to be completely restored, with new moldings. All front stepwells will be replaced. All wheelhousings that are determined to be substandard by the contractor or the county inspector will be replaced as necessary. New rubber floor covering (aisle, toe board, and underseats) and platform plate, ribbed rubber stepwell treads, and window glazing will be installed. Additional interior items are to be replaced as necessary, including, but not limited to, the following components:

- Interior panels;
- Crown panels;
- Windows: side, intermediate, drivers (windows are to be operable);
- Brake and accelerator pedals;
- Air ducts;
- Grab rails;
- Trim molding;
- Window channels and seals; and
- Destination signs, channel filler, rubber harness.

The driver's compartment is to be inspected and restored with new speedometers, pedal treads, and switches.

Body Exterior

The exterior of the body is to be completely restored, using new lenses, mirrors, wiper system (blades, arms, and motor), bezels, bumpers (Firestone Help bumpers), grilles, and reflectors. Transmission doors, radiator doors, rear end closure doors, and all other access doors are to be replaced as necessary with reconditioned parts. The following items are to be inspected and replaced as necessary:

- Towing brackets,
- Fluted panels,
- Skirt panels, and
- Roof panels.

Doors

Single front door vehicles are required. Doors and door mechanisms are to be inspected and restored as necessary using new bearings, bushings, rollers, pins, seals, retainers, and shims. Door glass is to be replaced as necessary.

Seats

Reclining or semireclining, high-back, cushioned seats are to be installed. All passenger seats must be forward facing. Seats are to be reupholstered, and seat assemblies including frames, reclining mechanisms, and adjustable headrests and footrests if so equipped are to be inspected and replaced with new parts or repaired. Additional seating specifications such as color arrangement, manner of attachment, and accessories will be specified by the county at a later date. Overhead package racks and individual reading lights are required. Vinyl/cloth box seats with supported expanded vinyl 4502 to the yard with Fifth Quality 4916 fabric for the cloth are required. Armrests and headrests should be vinyl.

Paint, Trim, Striping, and Undercoating

The bus interior and exterior are to be painted according to the graphics scheme specified by Prince William County.

Striping and decals are to be installed according to the graphics scheme specified by Prince William County.

Detailed painting and graphic specifications will be provided by the county at a later date. However, the bidder should submit the cost of a standard three color paint scheme. Exterior and interior paint is to be Dulux paint (Alkyd enamel) or an approved equivalent.

The bus understructure is to be undercoated with Tectyl 165G or an approved equivalent.

Life-Cycle Costing in the Transit Industry

ALLEN R. COOK, T. H. MAZE, UTPAL DUTTA, and MARK GLANDON

ABSTRACT

Life-cycle costing is an economic evaluation scheme that accounts for capital, operating, and maintenance costs during the usable life of transit vehicles. Cost containment is a major concern of transit agencies, and life-cycle costing has the potential to facilitate significant decreases in transit agency budgets as well as to enhance future budget planning and cost forecasting. However, a 1983 General Accounting Office (GAO) survey of 186 transit agencies found that most agencies lacked experience with and understanding of the procedures. The GAO concluded that most agencies lacked adequate technical information and adequately trained staff. In this paper an independent analysis of the original GAO data is reported. The analysis found that many agencies still keep largely manual operating and maintenance records. Some do not collect this information by individual bus. Seven prerequisites to good life-cycle costing procurement are presented.

Present practices in life-cycle cost procurement in the American bus transit industry are reviewed. The role of life-cycle costing is discussed first. There follows an analysis of the types of maintenance information collected by transit agencies and their experiences with life-cycle costing as reported in a 1983 General Accounting Office survey of 186 transit bus fleet operators in the United States. The paper concludes with a review of seven prerequisites for good life-cycle cost procurement.

LIFE-CYCLE COST PROCUREMENT

Background

Life-cycle costing is an economic evaluation scheme that accounts for capital, operating, and maintenance costs during the usable life of an investment. In theory, it is both a common-sense approach to equipment procurement and a well-established evaluation procedure in engineering economics. Most private equipment investment and replacement decisions instinctively incorporate at least a recognition, if not a formal accounting, of life-cycle costing.

In practice, at least in the public sector, life-cycle costing has been promoted as an innovative alternative to equipment procurement based on minimum initial capital cost, the "lowest bid" (1). In the federal government life-cycle costing has been used for military procurement by the Department of Defense since the 1960s (1). It is also used by the General Services Administration for the purchase of such standardized items as typewriters and office supplies.

UMTA, in response to congressional dictates, first required life-cycle costing for the purchase of transit vehicles in 1982 (Federal Register, Vol. 47, No. 33, Feb. 18, 1982, pp. 7361-7364), and later, in 1983, UMTA made it optional. A 1983 General Accounting Office (GAO) report (2) castigated UMTA for not documenting the cost-effectiveness of life-cycle costing, although it conceded that UMTA previously had expressed similar reservations to Congress.

Both UMTA and GAO agreed that most transit agencies lacked the technical information, resources, and staff expertise to adequately undertake a life-cycle procurement program. The GAO report noted that for many transit agencies the program was costly to implement and occasionally delayed vehicle procurement. However, because the federal government funds most of the capital investment, it is in the best interests of all concerned, including the taxpayer, that this investment be protected through adequate procurement and maintenance management systems. Life-cycle costing can facilitate both programs.

Cost Factors in Transit Bus Operations

Bus operating and maintenance expenses are significant elements in transit agency budgets. A 1983 UMTA report estimated transit bus operating and maintenance costs as follows, on the basis of 1981 Section 15 reports (3):

Cost Category	Percentage of Total
Operator labor (wages, benefits)	46
Vehicle maintenance	
Labor	15
Materials and supplies	6
Fuel and lubricants	10
Other	23
Total	100

Those costs directly associated with the operation of transit vehicles, fuel and maintenance, were 31 percent of the total, and this amounted to an annual national expenditure of more than $1.3 billion in 1981.

Individual public transit agencies report figures similar to these national statistics. In FY 1983 these costs amounted to about 34 percent of the total operating expenses for the Central Oklahoma Transportation and Parking Authority in Oklahoma City. Jones (4) cited fiscal year cost projections from 1981 to 1985 for Tri-Met in Portland, Oregon, of which about 27 percent was for maintenance and fuel costs. Peskin (5) projected that bus vehicle maintenance costs (including fuel) for Houston's Metropolitan Transit Authority would be 45.8 percent of total operating costs in 2000.

Inadequacy of Common Bus Costing Models

Conventional bus costing models, typically developed with other objectives in mind, are generally unable to extract these factors. Both Cherwony et al. (6) and Kemp et al. (7) have reviewed the state of the art in bus costing models. Most of these models appear to be based on average costs per vehicle-mile or vehicle-hour and are intended for use in making service provision decisions about things like route and headway changes.

Such models assume that a bus is a bus and they do not address different bus models or alternative maintenance policies. Kemp et al. (7,p.29) complain that present models are inadequate even for level of service decisions:

> Much of the information in the bus costing literature is not directly relevant to practical problems of this nature. Many studies have suffered from a lack of attention to the reasons for wanting cost information and to the relation between the information and the decisions being made.

The same argument could be made for their utility in life-cycle costing analysis. Ortner (8) reviewed eight urban transit operating cost models and found that all were unreliable in forecasting future operating costs.

Cherwony et al. noted in 1982 that more recent research in bus costing has emphasized labor costs because transit is a labor-intensive industry: "Not surprisingly, the latest research places a common focus on examining the major cost element of transit service: drivers' wages" (6,p.59). They conclude: "With greater emphasis on cost containment and resource allocation in the future, planners will need to understand the factors that influence bus operating costs" (6,pp.59-60). Kemp et al. (7,p.29) contend that future bus costing procedures must be more responsive to what they call "innovation":

> By comparison with service changes that use only procedures and types of resources already in use, innovation involves some new feature in the way output is produced. For instance, transit management might be asking whether new types of buses can be substituted for old, whether cheaper sources of labor might be used, whether a new way of organizing services might be beneficial, and so on. Bus operators face make or buy decisions; for example, they must decide whether to contract for maintenance work or provide it in-house.

One example of a more responsive costing framework is suggested by Peskin (5) and used to project the costs of significant transit alternatives (e.g., bus-only options, options that include light rail service) to the year 2000 for the Metropolitan Transit Authority in Houston. Costs are allocated in this model to administrative units (e.g., maintenance and operations) and labor categories, hence making it possible to extract the cost implications of different vehicle technologies and management strategies. It is interesting to contrast Peskin's application of the term "cost allocation" with Cherwony et al. (6) who "allocate" costs to aggregate measures of transit service, such as vehicle-miles and number of peak service vehicles. Another example is provided by Jones (4) who describes a costing methodology used by Tri-Met to forecast revenues and costs 5 years in advance. This methodology is also based on labor, administrative, operational, and maintenance components.

Applications of Life-Cycle Costing

Seldon (1) described six primary uses for life-cycle costing, which have been adapted to the transit industry:

Long-Range Planning and Budgeting

As Seldon notes, gathering the data needed to do life-cycle analysis forces an agency to clarify and identify the operational and maintenance cost elements of a transit organization. This should facilitate the projection of agency budgets over a long period of time, as demonstrated by Jones (4) and Peskin (5).

Comparison of Competing Programs

Life-cycle costing can provide some of the information needed for broader policy making, such as proposals to implement light rail services as an alternative to expanded bus service. Other examples include decisions to purchase different types of buses (e.g., vans, articulated buses, minibuses) or proposals to purchase used or remanufactured buses.

Comparison of Maintenance Strategies

There are alternatives in maintenance management that are best analyzed in the long range, in keeping with the life-cycle costing approach. These include analysis of the levels of maintenance to be performed as a function of equipment life and policies with regard to the use of in-house maintenance expertise instead of contracting for some maintenance work from outsiders.

Decisions About Replacement of Aging Equipment

There is a variety of strategies for determining when to replace aging vehicles [Rueda and Miller (9) compare six of the more popular models] and most would benefit from the information needed for life-cycle costing. Life-cycle costing would enable transit agencies to more effectively implement and monitor a particular procurement strategy.

Control over an Ongoing Program

The effective management of any program requires adequate information on what aspects of the organization contribute to costs. Life-cycle costing implies the development of a data base that should facilitate the ongoing monitoring of organizational performance. In the 1980s this is of particular significance to transit agencies that are experiencing soaring operating deficits at a time of diminished financial resources. Cost containment is a primary objective of contemporary transit service provision.

Selection Among Competing Contractors

Finally, life-cycle costing, in principle, is the rational economic approach to evaluating alternative bids for equipment, including transit buses. Seldon in 1979 anticipated the questions that UMTA and GAO were grappling with 5 years later: Can explicit performance requirements be written? Are enough historical data available? Is the additional time required for life-cycle costing acceptable? Do both the buyer and the seller have the management resources to carry out the analysis?

Example Application

Figure 1 shows one potential product of a life-cycle costing information base. The average capital, operating, and maintenance costs per mile over the lifetimes of 120 automobiles owned by the Oklahoma Department of Transportation were modeled and graphed in the figure for a range of hypothetical original purchase prices. The operating and maintenance costs per mile were modeled as a function of mileage. Differences in the operating characteristics of automobile models were factored out using dummy variables. The hypothetical purchase prices ($6,000 to $16,000) were divided by the mileages and added to the average operating and maintenance costs.

Note that the average cost minimums of all six curves are at approximately the same mileage, about 71,000 to 78,000 miles, which is a range of 9 percent of the mean mileage. Total average costs per mile at the minimums vary from $0.21 to $0.33 per mile, a range of 44 percent of the mean value, and the assumed purchase prices vary from $6,000 to $16,000, a range of 91 percent of the mean value. Note that the large variations in purchase price have a relatively small impact on the total average cost and an insignificant impact on the optimal replacement mileages. This example demonstrates that the original capital cost of a vehicle is not as important as the operating and maintenance costs incurred over time.

Such information is useful for long-range planning and budgeting and for decisions about vehicle replacement, two of Seldon's applications for life-cycle costing. Because unexpected problems can occur with vehicles, this information is equally useful for the annual planning of vehicle replacement. The costs associated with retaining vehicles that have incurred unexpectedly large operating and maintenance expenses can be compared with those of new replacements each budget year, regardless of the remaining useful lives of the older vehicles. Furthermore, this information can be used to support transit agency contentions that some information supplied by manufacturers is inaccurate or that certain components or bus models should be avoided. The only real assurance that transit agencies have that data supplied by manufacturers are accurate is confirmation from actual operating experience.

Summary

Cost containment is a major concern of the transit industry in the 1980s. Present bus costing models tend to be unresponsive to some of the larger issues confronting transit agencies, notably significant and rising operating and maintenance costs. The federal government is halfheartedly encouraging the transit industry to engage in life-cycle costing procurement in hopes that it can help transit agencies save money and get a better grasp of the cost drivers in transit operations. In the past, life-cycle costing has been promoted as a strategy that can respond to these issues and concerns.

TRANSIT INDUSTRY EXPERIENCE WITH LIFE-CYCLE COSTING

Background

In 1983 the GAO undertook a survey of 186 transit operators with motor bus fleets to support their report, "Cost Effectiveness of Life-Cycle Process in Buying Transit Vehicles Questionable" (2). The GAO used this information to support their contentions that transit operators lacked sufficient guidelines and information to adequately do the job. The questionnaire responses presented in this paper were obtained from independent statistical analysis of the GAO questionnaire results and represent information not reported in the GAO report.

The GAO data were used to determine the extent of computerization of maintenance records by transit agencies, the types of maintenance data collected, and the difficulties agency personnel have encountered in doing life-cycle costing. This information helped in the formulation of the seven prerequisites to life-cycle costing that conclude the paper.

The respondents represented approximately 53.8 percent of the estimated 346 transit systems eli-

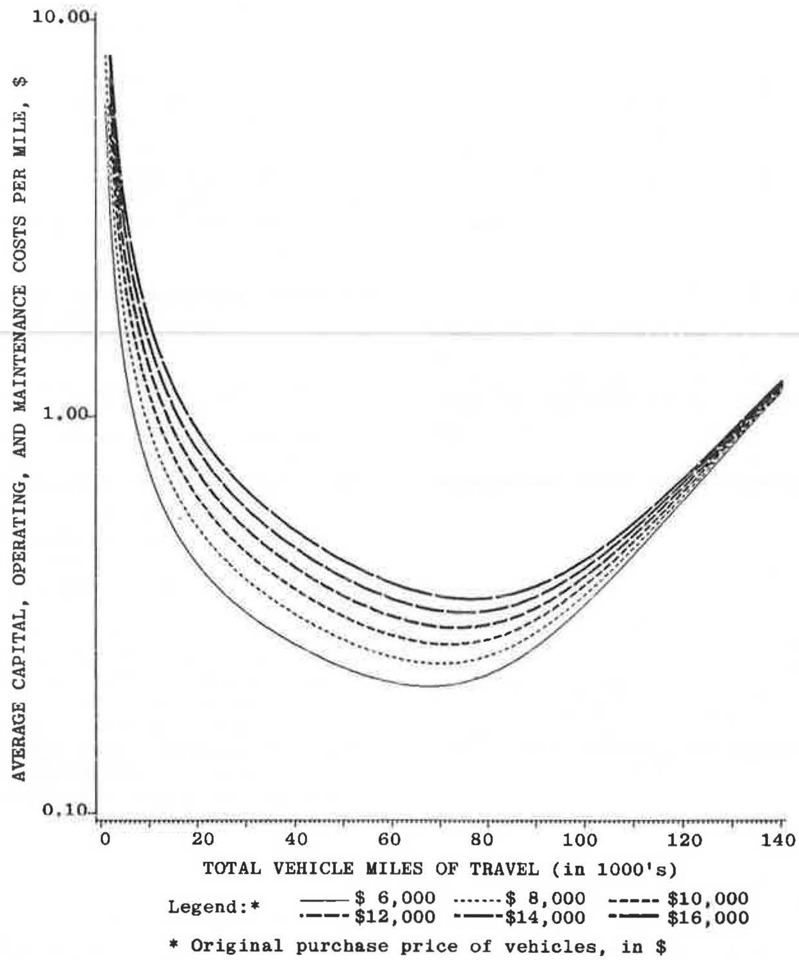

FIGURE 1 Example life-cycle costing analysis.

gible to receive federal financial assistance to purchase buses and included most of the largest bus fleet operators. For purposes of statistical analysis the transit systems were grouped into four fleet size ranges: less than 25, 25 to 99, 100 to 999, and 1,000 or more vehicles. The majority of these bus fleet operators, regardless of fleet size, have buses made by more than one manufacturer. In most fleets the average fleet age tends to be 7 to 9 years.

Use of Computer-Based Operating and Maintenance Records

The 186 transit agency respondents were asked if their operating and maintenance cost and frequency of occurrence records were kept manually or on a computer. Surprisingly, four systems (2.2 percent of the total) indicated that they kept no cost records at all, and 19 systems (10.2 percent) kept no frequency of occurrence records. There was no particular correlation of lack of record keeping and size of the motor bus fleet, although all operators with more than 1,000 buses kept records.

Tables 1 and 2 give the type of record-keeping system, by size of bus fleet, for cost and frequency of occurrence records, respectively. In both tables a statistically significant interaction between the variables is present; the larger the bus fleet is the more likely it is that records are computerized. However, in this age of rapidly advancing computer technology, it is somewhat startling to note that 77 operators (42.3 percent) kept manual cost records only in 1983 and 91 (54.5 percent) kept only manual frequency of occurrence records.

Only about one-fourth of the sampled transit agencies have gone largely to computerized record-keeping systems. Only four operators (2.2 percent of the total 186) reported fully computerized cost records, and only six (3.2 percent) had fully computerized frequency of occurrence records.

Vehicle Classifications in Record Keeping

The GAO asked if the respondents kept their operating and maintenance records by individual bus, bus model, total fleet, or some combination thereof. Agencies that at least aggregate their records by bus model can use their own past experience in the life-cycle costing procurement process; those that keep individual bus records are in an even better position do so. Furthermore, the latter operators can relate operating and maintenance histories and costs to the operating environment and service characteristics experienced by each bus.

The majority of bus operators who kept records did so by individual bus. GAO requested the record type for the following factors: fuel, tires, engine oil, brakes, transmission, engine, air conditioning, preventive maintenance, and chassis. Responses were virtually identical for all factors except tires, which typically are leased from manufacturers or

TABLE 1 How Bus Operating and Maintenance Cost Records Are Kept

Record Type	Size of Motor Bus Fleet: Less than 25	25 to 99	100 to 999	More than 1,000	Total
Only manual records	35 (59.3%)	23 (38.3%)	16 (32.0%)	3 (23.1%)	77 (42.3%)
Mostly manual but some computerized	15 (25.4%)	22 (36.7%)	15 (30.0%)	6 (46.1%)	58 (31.9%)
Mostly or all computerized	9 (15.3%)	15 (25.0%)	19 (38.0%)	4 (30.8%)	47 (25.8%)
Total	59 (100.0%)	60 (100.0%)	50 (100.0%)	13 (100.0%)	182 (100.0%)

Chi-square = 14.305. d. f. = 6. prob. = 0.0264, significant

TABLE 2 How Bus Operating and Maintenance Frequency of Occurrence Records Are Kept

Record Type	Size of Motor Bus Fleet: Less than 25	25 to 99	100 to 999	More than 1,000	Total
Only manual records	38 (71.7%)	28 (53.9%)	22 (44.9%)	3 (23.1%)	91 (54.5%)
Mostly manual but some computerized	9 (17.0%)	14 (26.9%)	11 (22.5%)	7 (53.8%)	41 (24.5%)
Mostly or all computerized	6 (11.3%)	10 (19.2%)	16 (32.6%)	3 (23.1%)	35 (21.0%)
Total	53 (100.0%)	52 (100.0%)	49 (100.0%)	13 (100.0%)	167 (100.0%)

Chi-square = 17.703, d. f. = 6, prob. 0.0070, highly significant

distributors. The transmission records reported hereafter are representative of the remaining operating and maintenance factors.

The data given in Table 3 indicate a highly significant interaction between vehicle classification and size of the bus fleet; the larger the fleet the less likely agencies were to keep transmission cost records by individual bus. Overall, 68.9 percent of those operators that kept transmission records (115 operators) did so by individual bus. Fifty-two operators (31.1 percent) kept transmission cost records by total fleet or bus model only; 47 of the 52 kept their records by total fleet only. Smaller operators were more likely to keep individual bus records; only half of the nation's largest transit fleet operators bother to collect the information for each bus.

The same patterns did not prevail with frequency of occurrence records; transit agencies were much more likely to keep these records by individual bus. Furthermore, there were no significant interactions by size of the bus fleet, as indicated by the data given in Table 4 for transmission records. These responses should not be a surprise because frequency of occurrence records are most relevant for the analysis of vehicle and parts histories, whereas cost records are developed primarily for accounting purposes.

Eighty-nine percent of the operators (145) kept transmission frequency of occurrence records by individual bus. Relatively few operators aggregated this information for the whole fleet, and 15 (8.1 percent) kept fleet transmission records only.

Difficulties with Life-Cycle Costing Procurement

On the basis of their questionnaire survey and additional discussions with transit agencies, the GAO identified 43 agencies with past or present experience in life-cycle cost procurement (2). The GAO concluded that many of these operators had experienced higher costs and delays in bus procurement because of life-cycle costing. The lack of standard-

TABLE 3 Vehicle Classification for Cost Records Kept of Transmissions

Vehicle Classification	Size of Motor Bus Fleet: Less than 25	25 to 99	100 to 999	More than 1,000	Total
By total fleet or by bus model only	15 (28.8%)	10 (17.5%)	21 (45.7%)	6 (50.0%)	52 (31.1%)
Individual bus	37 (71.2%)	47 (82.5%)	25 (54.3%)	6 (50.0%)	115 (68.9%)
Total	52 (100.0%)	57 (100.0%)	46 (100.0%)	12 (100.0%)	167 (100.0%)

Chi-square = 11.55, d. f. = 3, prob. = 0.0091, highly significant

TABLE 4 Vehicle Classification for Frequency of Occurrence Records Kept of Transmissions

Vehicle Classification	Size of Motor Bus Fleet: Less than 25	25 to 99	100 to 999	More than 1,000	Total
By total fleet or by bus model only	6 (11.5%)	4 (8.0%)	8 (16.7%)	0 (0.0%)	18 (11.0%)
Individual bus	46 (88.5%)	46 (92.0%)	40 (83.3%)	13 (100.0%)	145 (89.0%)
Total	52 (100.0%)	50 (100.0%)	48 (100.0%)	13 (100.0%)	163 (100.0%)

Chi-square = 3.643, d. f. = 3, prob. = 0.3026, no significance

ized vehicle performance data hampered the agencies in preparing and evaluating their procurement requests and made it difficult for the GAO to assess the economic benefits of life-cycle costing procurement. The GAO noted that UMTA had not prescribed specific procurement guidelines and that there was inadequate information on bus operating and maintenance costs.

Finally, transit agencies typically reported that they lacked sufficient staff expertise to adequately evaluate life-cycle cost information. The GAO reported that 36 of the 43 transit systems had obtained outside technical and legal assistance, typically from UMTA, other transit systems, private consultants, and the American Public Transit Association.

Among 173 questionnaire respondents to the question, "How difficult will it be for your transit system to prepare a LCC procurement bid for motor buses given the cost data your transit system currently maintains?" more than 40 percent indicated that they would experience great or very great difficulty, or that it would be impossible. A tabulation of the responses is given in Table 5.

The size of the bus fleet made no difference in the reported degree of difficulty, but past experience in life-cycle costing did make a difference. The data in Table 6 indicate the statistically significant relationship between degree of difficulty and past experience. Interestingly, 22.4 percent of the experienced agencies still found the task to be of very great difficulty or impossible. Finally, there was no significant relationship at all between the availability of computerized records and the degree of difficulty.

With respect to frequency of occurrence records, the degree of difficulty responses were similar, although there was a significant interaction with bus fleet size, as the data given in Table 7 indicate. The smallest fleet operators tended to report greater difficulty than the larger operators. As with the cost records, it made no difference in difficulty whether records were kept manually or by computer.

Understanding of Life-Cycle Cost Procurement

The GAO asked operators how well their staff understood the current life-cycle costing requirement. Their responses are given in Tables 8 and 9. Only 35 of the respondents (18.8 percent) stated that they had a "great amount" of or a "thorough" understanding, and the interaction in Table 8 indicates that understanding increased with the size of the transit operation. Less than 10 percent of the operators of fleets of less than 25 buses had a great amount of or a thorough understanding. It is likely that larger agencies have more knowledgeable staff mem-

TABLE 5 Difficulty of Preparing a LCC Procurement Bid for Motor Buses on the Basis of Currently Maintained Cost Data

Degree of Difficulty	Number of Respondents	
Little or no	10	(5.8%)
Some	25	(14.4%)
Moderate	65	(37.6%)
Great	38	(22.0%)
Very great	28	(16.2%)
Impossible	7	(4.0%)
Total	173	(100.0%)

TABLE 6 Difficulty in Preparing a Life-Cycle Costing Procurement with Cost Data Based on Agency Experience

Degree of Difficulty	Transit System Has or is Making an LCC Procurement	Transit System Has Never Made an LCC Procurement	Total
Some, little, or none	18 (31.0%)	18 (15.1%)	36 (20.3%)
Moderate	15 (25.9%)	51 (42.9%)	66 (37.3%)
Great	12 (20.7%)	28 (23.5%)	40 (22.6%)
Very great or impossible	13 (22.4%)	22 (18.5%)	35 (19.8%)
Total	58 (100.0%)	119 (100.0%)	177 (100.0%)

Chi-square = 8.316, d. f. = 3, prob. = 0.0399, significant

TABLE 7 Difficulty in Preparing a Life-Cycle Costing Procurement Using Frequency of Occurrence Maintenance Records

	Size of Bus Fleet			
Degree of Difficulty	Less than 25	25 to 99	100 or more	Total
Some, little, or none	11 (19.0%)	12 (21.4%)	21 (33.9%)	44 (25.0%)
Moderate	14 (24.1%)	26 (46.3%)	17 (27.4%)	57 (32.4%)
Great	18 (31.0%)	9 (16.1%)	14 (22.6%)	41 (23.3%)
Very great or impossible	15 (25.9%)	9 (16.1%)	10 (16.1%)	34 (19.3%)
Total	58 (100.0%)	56 (100.0%)	62 (100.0%)	176 (100.0%)

Chi-square = 12.859, d. f. = 6, prob. 0.0453, significant

TABLE 8 How Well Transit System Staff Understand Life-Cycle Costing

Degree of Understanding	Size of Motor Bus Fleet: Less than 25	25 to 99	100 or more	Total
Limited	29 (47.5%)	19 (31.2%)	9 (14.1%)	57 (30.7%)
Some	11 (18.0%)	16 (26.2%)	10 (15.6%)	37 (19.9%)
Moderate amount	15 (24.6%)	17 (27.9%)	25 (39.1%)	57 (30.7%)
Great amount or thorough	6 (9.8%)	9 (14.8%)	20 (31.2%)	35 (18.8%)
Total	61 (100.0%)	61 (100.0%)	64 (100.0%)	186 (100.0%)

Chi-square = 42.124, d. f. = 6, prob. 0.0005, highly significant

TABLE 9 How Well Do Transit System Staff Understand Life-Cycle Costing Based on Agency Experience?

Degree of Understanding	Transit System Has or is Making an LCC Procurement	Transit System Has Never Made an LCC Procurement	Total
Limited	5 (8.5%)	49 (40.2%)	54 (29.8%)
Some	8 (13.6%)	28 (23.0%)	36 (19.9%)
Moderate	23 (39.0%)	33 (27.0%)	56 (30.9%)
Great	10 (17.0%)	9 (7.4%)	19 (10.5%)
Thorough	13 (22.0%)	3 (2.5%)	16 (8.8%)
Total	59 (100.0%)	122 (100.0%)	181 (100.0%)

Chi-square = 37.689, d. f. = 4, prob. = 0.0000001, highly significant

bers or have a greater ability to make use of outside consultants.

Not surprisingly, experience with life-cycle costing made a difference in the degree of understanding, as indicated by the extremely highly significant interaction shown in Table 9. However, it is evident in both Tables 8 and 9 that all too many transit agencies were experiencing problems with life-cycle costing. Even among the experienced agencies, more than 20 percent of the respondents had only "limited" or "some" understanding of the process (Table 9).

Transit Agency Support for Life-Cycle Costing

Respondents were asked if they favored or opposed life-cycle cost procurement requirements for motor buses. Fifty-seven percent of those who answered the question were neutral or favored them to some degree. Responses were about the same regardless of the size of the bus fleet and past experience with the procedures, although proportionately fewer experienced respondents were neutral on the subject. In terms of degree of difficulty, those who favored life-cycle costing tended to have, or expected to have, less difficulty with the requirements, although the interaction was not statistically significant.

Summary

Significant numbers of transit operators still kept manual or mostly manual operating and maintenance records in 1983, making it less convenient for them to do life-cycle costing analyses. Large fleet operators, were even less likely to have computerized records. Furthermore, many agencies did not keep such records by individual bus. Finally, many operators, even some of those with experience, have difficulty with the life-cycle costing procedures. The existence of computerized maintenance records did not appear to help transit agencies in easing their difficulties with the procedures. The GAO found that transit agencies lacked guidelines and many of them lacked adequate staff expertise to do the job satisfactorily. It was concluded that this has led to added expense and delays in bus procurement with no guarantees that the buses so obtained will cost less over their operating lives.

PREREQUISITES TO LIFE-CYCLE COSTING

Kain et al. (10,p.2) noted:

> The success of life cycle costing in the procurement of buses depends upon several factors. First, the property must have the ability to identify, measure, and evaluate the factors affecting its current operating and maintenance costs. Second, the bus manufacturers must demonstrate the ability to identify, quantify, and support their estimates of the cost impact which bus design changes will have on a property's operating and maintenance costs. Third, harmonious working relationships between the manufacturers and the properties must exist.

The GAO study (2) concluded that none of these factors were particularly present in the American transit industry today.

The following prerequisites to successful life-cycle cost procurement therefore appear to be in order on the basis of the comments of the GAO and the questionnaire responses summarized previously.

1. Standard and uniform guidelines for life-cycle costing procurement are necessary both to facilitate the task for the operator and to encourage manufacturers to provide appropriate information. This would promote transit agency understanding and either enable their own staff to do the work or facilitate the use of outside expertise.

2. Transit operators need adequate records to support the procedures and monitor the results when buses have been procured. In addition, comprehensive cost and frequency of occurrence records would enable the efficient management of transit operations, a worthy objective in its own right. Such records should be computerized to facilitate statistical and economic analysis with mathematical models appropriate to the available data. For example, meaningful cost and frequency of repair predictions can be accomplished with a relatively small number of cases (e.g., 10 to 20 buses), but the analysis is best done on a computer.

3. Transit agencies should integrate their operating and maintenance records with both long-range and annual budget and operations planning. As noted earlier, Seldon described a variety of applications for life-cycle costing information in planning.

4. Cost and frequency of occurrence records should be collected for individual buses. A southwestern transit agency maintenance manager, responsible for a fleet of 100 buses, told the authors that 100 buses was about the limit of his ability to be personally familiar with each vehicle's maintenance history without the help of a good record-keeping system. With computer-based records, summaries can easily be provided for bus fleet and model totals.

Transit agencies typically expect bus manufacturers to provide frequency of occurrence information for the major maintenance tasks and components in a bus. For example, Table 10 gives the cost drivers used in the bus procurement process by the Central Oklahoma Transportation and Parking Authority (COTPA). The major cost drivers, as interpreted by COTPA, are fuel and oil consumption, tires, preventive maintenance, brake relining, engine repair, transmission repair, and air conditioning repair. The associated costs are itemized for each bid received. Other aspects of comparative evaluation included performance criteria (service support, compliance with specifications, and delivery dates) and component standardization, and these aspects are included in the bid evaluations by means of a rating scheme.

Although the information on these major cost drivers is obtained from the manufacturer, it can be helpful to the transit agency to have its own tabulations. Conscientious transit operators, including COTPA, are alert to and commonly specify specific types and brands of components (e.g., air conditioning units or engines) in their bid specifications because of past maintenance experiences, either within the agency or reported by other agencies. Maintaining a data base of frequency of occurrence statistics for the transit agency's own fleet can only facilitate the procurement process. It gives the agency a basis for assessing the validity of manufacturer claims or justifying the specification of specific components. It also enables the agency to account for local climatic and bus duty cycle conditions.

Cost and frequency of occurrence maintenance records are useful for planning and annual budget analysis as well as life-cycle procurement. It is probably not feasible to account for every component of a bus in life-cycle costing because too much information could defeat the objectives of life-cycle cost procurement. The analysis of these other components (e.g., body parts, door components, passenger seats), however, can aid in monitoring the performance of the maintenance shop. Particularly troublesome components (e.g., body components that corrode) could be identified and thus included in future bus procurement specifications.

5. The time value of money should be considered in life-cycle cost procurement, mainly because of the long time period involved (12 years typical bus life) and the magnitude of fuel and maintenance costs that are incurred over time. This was demonstrated earlier in the example shown in Figure 1. The GAO noted that few transit operators included the present worth of future expenditures. Uncertainties about such things as future fuel prices and maintenance expenses are best accounted for by the thoughtful and conservative use of economic principles.

6. None of this is easy to implement without adequate staff expertise and the availability of training courses and guidelines. Tables 6 and 7 indicate that good records alone are not enough. Management information systems and a capable supporting staff should be recognized as fundamental components of transit agency administration.

7. Top-level management support is needed because life-cycle costing departs from traditional procurement practices and requires more staff time to prepare and evaluate. Management must be willing to provide the staff and training resources needed to satisfy prerequisite six.

TABLE 10 Life-Cycle Cost Procurement Information Required from Manufacturers by Central Oklahoma Transportation and Parking Authority

COST FACTOR	INFORMATION REQUIRED [a]
FUEL CONSUMPTION	Fuel economy in miles per gallon based on specified fuel economy test operations.
OIL CONSUMPTION	Consumption (excluding oil changes) in miles per quart
TIRES	Number of tires (brand specified by COTPA) required for 500,000 miles of anticipated bus use
BRAKE RELINING (front and rear)	Parts and labor for life of bus, including expected interval in miles between replacements and overhauls
PREVENTIVE MAINTENANCE	
Oil change & filter	Parts and labor, expected intervals
Engine air filter	Parts and labor, expected intervals
Engine Tune-up	Parts and labor, expected intervals
Transmission	Parts and labor, expected intervals
Air conditioning	Parts and labor, expected intervals
Chassis lubrication	Parts and labor, expected intervals
Differential	Parts and labor, expected intervals
Brake adjustment	Parts and labor, expected intervals
ENGINE REPLACEMENT AND OVERHAUL	Parts and labor, expected intervals
TRANSMISSION REPLACEMENT AND OVERHAUL	Parts and labor, expected intervals
AIR CONDITIONING COMPRESSOR REPLACEMENT AND OVERHAUL	Parts and labor, expected intervals

[a] The manufacturer is required to tabulate all of the above costs and maintenance performance intervals and provide total maintenance costs for the life of the bus using labor, fuel, and oil costs supplied by COTPA as well as miscellaneous maintenance practices information.

CONCLUSIONS

Life-cycle cost procurement is a rational economic approach to the selection of transit vehicles. The data base needed to support the process has a variety of other uses in maintenance planning and operational management.

At present most transit agencies lack the information needed to facilitate life-cycle costing, and even experienced agencies have difficulty with it. The development of computer-based operating and maintenance records, coupled with adequately trained support staff, is among the prerequisites to successful implementation of life-cycle costing. Because vehicle operating and maintenance costs are significant elements of transit budgets, both annually and over the long term, life-cycle costing has the potential to generate significant savings to agencies and to lead the way to improved transit cost forecasting methodologies. It will do so only if transit agencies collect the proper data and then make good use of it.

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Use of Cooperatives for Alternative Rural Passenger Transportation: Report on a New York Study

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ABSTRACT

The New York State Department of Agriculture and Markets conducted a study to examine the feasibility of using the cooperative concept to provide rural passenger transportation. On the basis of interviews with transportation providers in two study counties and an analysis of transportation in each county, three transportation alternatives using the cooperative approach were developed. The first alternative provides for a cooperative composed of public and private human service agency transportation providers and the users of that transportation service. The study details the activities such a cooperative may progressively undertake, beginning with a simple clearinghouse function and moving toward a cooperative that would assume all transportation responsibilities for its members. The second cooperative concept relies on a service club or civic organization to provide rural passenger transportation. Composed of service club members, human service agencies, and community residents needing transportation, the cooperative would depend on volunteers to maintain a transportation network for rural residents. A third alternative incorporates rural postal carriers in either the human service agency cooperative or the service club cooperative. Rural postal delivery routes extend into virtually all isolated rural areas and are a ready-made transportation system that can augment existing passenger transportation services at a low cost. By providing an array of flexible organizational options to supplement existing transportation resources at a low cost the cooperative approach can offer transportation alternatives, which are subject to local control and responsive to local conditions, to rural areas.

The need for effective rural passenger transportation gained national attention only recently. Beginning with rural Poverty Program transportation projects in the late 1960s, interest in rural passenger transportation had developed by 1973 into the Section 147 Rural Highway Public Transportation Demonstration Program. As the first national program to explicitly recognize rural transportation needs, it was designed to test a variety of transportation methods to fit highly variable rural transportation needs. By 1978 the Section 18 Program, the Formula Grant Program for Areas other than Urbanized, became the first full-scale federal program providing assistance for transportation in rural areas (1,2).

As part of its continuing interest in developing alternative approaches to providing rural passenger transportation, the Office of Service and Methods Demonstration of UMTA funded a study in cooperation with the U.S. Department of Agriculture Office of Transportation to examine the feasibility of using cooperatives for rural passenger transportation. The New York State Department of Agriculture and Markets had previously conducted studies to determine the potential for using cooperatives to provide freight transportation service in areas where rail service has been abandoned, and those studies had indicated that cooperatives can provide a viable mechanism for retaining vital transportation service for rural and agricultural industries (3-5).

STUDY OBJECTIVE

The overall study objective is to evaluate the potential for using the cooperative concept to provide rural passenger transportation. The study was to examine the feasibility of

- Using vehicles for a combination of freight and passenger service,
- Using new or existing cooperative organizations to provide passenger transportation, and
- Determining the feasibility of coordinating the use of existing private or public vehicles and resources.

A constraint on implementing any program that might result from the study is that no new federal funds would be available. However, use of local, state, or private funding could be considered.

RURAL PASSENGER TRANSPORTATION IN NEW YORK

National statistics indicate that 15 percent of rural households do not own a car, 57 percent of the rural poor do not own a car, and 52 percent of households with a car own one car only, leaving the family without transportation when the car is used for work (6). Data for New York reflect the national pattern.

A 1981 report by the New York State Legislative Commission on critical transportation choices (7,8) indicated that nearly half the state's rural counties lacked local public transportation. On the average, 40.4 percent of the population in rural counties living in urban places of more than 2,500 population had no access to public transportation. The lack of such local transportation is particularly troublesome for the rural elderly because 39 percent of elderly households have no access to a car and 77 percent of single elderly females have no available automobile.

Although the report indicated that 93 percent of rural places are served by an intercity bus system, examination of bus schedules reveals many inconveniences for the traveler who often must stay overnight in order to conduct necessary activities. Other than intercity and local transportation authorities and systems, rural transportation need in New York has largely been defined at the county level by social services agencies that attempt to meet specialized client needs on an as-needed basis.

No reliable estimates of the total amount of funds expended for social service agency transportation exist. However, a 1973 study of special transit services for human service agencies estimated the cost at between $80 and $100 million annually. A 1981 Office for the Aging study estimated an annual expenditure of more than $800,000 for transportation in 30 rural counties. The Institute for Public Transportation (9) found more than 110 programs in the state providing transportation services for a variety of specified clients.

The statistics indicate that New York is allocating substantial public funds to provide specialized transportation services for rural residents not currently served by the existing transportation system. Yet lack of sufficient funding means the agencies can only provide transportation services for mandated programs, leaving many other eligible rural residents without access to transportation and, hence, needed services. Further, the continued inability of rural residents not eligible for social service agency programs to obtain necessary transportation for employment, medical care, and shopping merits a fresh examination of new mechanisms to restructure more traditional transportation services.

SUMMARY DEFINITION OF A COOPERATIVE

Cooperatives have long been part of rural American life, providing agricultural producers with a mechanism for marketing products, obtaining production inputs, and supplying the various services necessary to operate a highly capitalized agriculture. Cooperatives have also played an important role in rural electrification.

Although the cooperative concept can be defined in various ways (10,11), the following definition [Savage and Volkin cited in Cooperative Principles and Legal Foundations (10,p.2)] describes in some detail what a cooperative consists of:

> A cooperative is a voluntary contractual organization of persons having a mutual ownership interest in providing themselves a needed service(s) on a non-profit basis. It is usually organized as a legal entity to accomplish an economic objective through joint participation of its members. . . . the investment and operation risks, benefits gained, or losses incurred are shared equitably by its members in proportion to their use of the cooperative's services. A cooperative is democratically controlled by its members on the basis of their status as member users and not as investors in the capital structure of the cooperative.

In New York, the Cooperative Corporations Law, Section 3(c), defines a cooperative as "A corporation organized . . . for the cooperative rendering of mutual help and service to its members." The law authorizes the formation of general cooperatives, membership cooperatives, and agricultural cooperatives (12).

There is no general federal incorporation statute for cooperatives, so a cooperative wishing to incorporate must do so under an appropriate state law. Along with a general incorporation statute, all states have a "cooperative" statute under which a cooperative may incorporate (10,p.14;13). In evaluating the feasibility of using cooperatives in rural transportation, it is first necessary to review applicable state statutes because several state laws may limit cooperative functions.

Cooperatives were mostly confined to agricultural producer organizations and rural electrification associations until the passage of the Economic Act and the Appalachian Regional Development Act of 1965. Cooperatives now include "buying clubs . . . consumer stores, craft, credit, fishing, forestry, health, housing, legal services, memorial, migrant labor, mutual insurance, sewer, water" (14), and a wide range of other activities. Cooperatives are being looked to in rural areas as an economic development tool for medium to low resource producers (15).

Yet, with the exception of the Green Eagle Program in North Carolina and the South Anne Arundel County Project in Maryland (16,p.80), the cooperative concept has had limited application in rural passenger transportation. However, in a period of diminishing overall federal support and of deregulation of various transportation modes, a fresh assessment of the potential use of cooperatives may encourage the development of innovative mechanisms for delivering passenger transportation services.

APPLICATION OF THE CONCEPT

The cooperative, long used in rural America to meet rural needs, is especially well adapted to meet rural passenger transportation needs. A cooperative structure, layered into existing transportation providers and users, has the potential to change the organization and distribution of transportation resources, thereby closing some of the gap between need and access. Several characteristics of the cooperative structure help improve the fit between rural passenger transportation need and existing resources.

Key to a cooperative organization is member-user ownership and operation in conjunction with the cooperative's primary function of providing service to its members. The result is a highly flexible local organization that is responsive to member needs. The members-users define the organizational structure, determine its objectives, set membership criteria, and control its operation.

Although a cooperative can be formed without regard for geographic boundaries, it is suggested that an appropriate organizational level for a rural transportation cooperative would be the county. Many organizations currently providing transportation are organized at the county level, including many human service organizations. Although many trips are intracounty in nature, much out-of-county travel is fairly well defined by commuting patterns, medical facilities, or shopping areas; these trips are being accommodated by county-level transportation providers.

Such a cooperative, by pulling together existing county-level transportation users and resources, could bring about certain efficiencies. For example, by coordinating the purchase of vehicle supplies such as fuel, tires, and parts, the cooperative could reduce costs through discount buying arrangements.

The cooperative structure can thus be a highly flexible organization responsive to local needs and conditions. Member owned and controlled, it can tailor its particular objectives and functions to member preferences. By streamlining certain transportation tasks, it can simplify the provision of transportation and create certain efficiencies in transportation delivery.

CRITERIA FOR COUNTY SELECTION

Early in the study process, it was determined that two representative areas would be selected for detailed analysis. Because the study was to develop a conceptual approach for use in rural areas nationally, the selection process required the use of criteria that could be applied in a variety of rural settings. From the beginning of the project, the study team coordinated its activities closely with the staff of the New York State Department of Transportation (NYSDOT), and relied on their expertise and knowledge of state and local transportation resources.

On the basis of administrative and demographic criteria, the county was chosen as the geographic unit for study. The county is a jurisdictional unit for which a range of data is collected, including the population census, economic information, and human services data. Many state agencies are organized on a county basis, as are many private organizations. The geographic area of a county is also likely to provide a mix of passenger needs that could form a viable base for a transportation cooperative.

Specific criteria used to select counties for study included

- A large rural population,
- A demonstrated need for passenger mobility,
- Centers of trade and commerce, and
- A current transportation network.

The county selection process took place in four stages. The first step involved elimination of strictly urban counties. In the second phase, counties ranking high on a transportation disadvantaged measure were selected for closer examination. (Ira Kaye, Rural Transportation Specialist, developed the transportation disadvantaged measure to derive an estimate of transportation needs. Using the 1980 Census of Population and Housing data, the measure included population older than 65, disabled and handicapped population, percentage in poverty, and those with no car or one car.) In the third step the Section 18 Service Plans provided by NYSDOT were used to determine availability of transportation resources. NYSDOT then reviewed the counties selected strictly on the basis of available transportation and lack of transportation resources and suggested appropriate study counties based on their first-hand experience with those counties.

STUDY COUNTIES

As a result of the previously discussed methodology, two rural counties were selected for study--Cortland and Otsego. Although these counties are similar in many respects, each exhibits a different pattern of transportation needs and a different use of available resources to meet those needs.

Cortland County

Cortland County, located in the south-central part of the state, has a population of 48,820. As measured by the transportation disadvantaged index, 21.4 percent of the population lacked adequate access to transportation. Eleven percent of its population is older than 65; 54 percent of households have no car or one car.

The largest population center is the city of Cortland, the county seat. Secondary centers, Homer and McGraw, are clustered close to Cortland, and Marathon is located in the south-central part of the county. Approximately half the county population is concentrated in the Cortland-Homer-McGraw area, with the remainder scattered throughout the county in villages of fewer than 2,500 population or in the open country.

Public transportation is provided by Greyhound along the north-south axis of Interstate 81, which passes through Cortland north to Syracuse and south to Binghamton. A second route connects Cortland with Ithaca. Taxi service is provided in Cortland by a taxi company with 10 vehicles and is largely limited to the Cortland area because of the high cost of providing service in the more distant areas.

Human service agencies providing transportation service include the J.M. Murray Center for the Handicapped, the Department of Social Services, the Retired Senior Citizen Volunteer Program, the Office for the Aging, the Community Action Program of Cortland County, and Head Start. Individuals who are not eligible for the programs administered by those agencies and who live off I-81 or Route 13 have no access to transportation if they do not have an automobile. Because the I-81 and Route 13 bus routes cover only the western edge of the county and travel west from Cortland, the major portion of the county east of I-81 has no access to public transportation.

Otsego County

Otsego County is located on the eastern edge of New York's southern tier, a mountainous and generally hilly terrain. The 1980 population was 59,075. The county's largest population center is Oneonta, located on the southeastern edge of the county, with the county seat located at Cooperstown, approximately 20 miles to the north of Oneonta. Several other populated areas, including Unadilla, Schenevus, Laurens, and Otego, are located along I-88, the southeastern boundary of the county. Richfield Springs is located in the north-central part of the county, and several less populated centers are scattered throughout the county.

Twenty-eight percent of the county population is transportation disadvantaged, with 14 percent of the population older than 65. Fifty-four percent of the households have zero or one car. Eighty-one percent of county residents work within the county, and 24 percent of those who work away from home use a carpool.

Public transportation is provided by three intercity bus companies. Adirondack Trailways serves towns along the central part of the county. Pine Hill Trailways serves Oneonta. Greyhound serves towns along I-88, the central part of the county, and several towns along the northeastern edge of the county. The eastern and western halves of the county are not served by the bus lines. Three taxi companies serve Oneonta, and two companies are located in Cooperstown. Because of deadhead costs associated with rural trips, taxi service is largely confined to Oneonta and Cooperstown.

The human service agencies providing transportation service include the Office for the Aging, the Department of Social Services, Opportunities for Otsego, the Community Action Program (CAP), and the Association for Retarded Children. Taxis and staff cars are used to transport clients on an as-needed basis.

STUDY PROCEDURE

After the selection of Cortland and Otsego counties was made, initial field trips were made to each of the counties to inform the county supervisor and the cooperative extension agent of the project. The county supervisors were invited to bring along either other county legislators or county staff. It was believed that it was necessary to inform the county supervisor as the leading county political officer to avert potential misunderstanding and to solicit suggestions about possible contacts or information sources, or both, that might have been overlooked during initial project analysis. The cooperative extension agent in a rural county is generally a person who has contacts with a wide variety of groups and individuals and can provide useful leads on contacts and information sources.

Following the initial meetings, project staff visited the major transportation providers in each county and, using a standard questionnaire, obtained information on eligible clientele; location of that clientele; number, condition, and use of vehicles; funding or program restrictions; and coordinating transportation services and insurance limitations. Respondents were also asked to comment on whether a cooperative transportation program might be acceptable and feasible.

The results of the surveys can be briefly summarized as follows:

- Transportation was provided through a combination of taxi companies, agency-owned vehicles, agency employees' cars, and volunteers.
- Clientele was concentrated in the more populated areas.
- Transportation was arranged for the most part on an ad hoc basis as needed, with many organizations counting only actual out-of-pocket expenditures (vehicle maintenance, contract payments, and so forth) for transportation but not including staff or director time spent scheduling or providing transportation.
- Each agency indicated that they were able to provide transportation only for mandated trips (i.e., Medicaid Foster Care visits) and that there were people unable to access their services because the agency lacked transportation resources.
- Each agency indicated a strong preference for giving up their transportation responsibilities and said they would favor an arrangement whereby they could refer clients to a transportation provider whom they could reimburse for services rendered.
- No funding restrictions on transportation coordination were found, although vehicles purchased with program funds were required to fill program needs first before agency vehicles could be used in a coordinated arrangement.
- Insurance presented no problem; each agency was able to secure adequate insurance, apparently at a sustainable cost.

THE COOPERATIVE AS COORDINATING MECHANISM

A major study mandate was the development of alternatives to rural passenger transportation that did not call for additional federal funds. That mandate led naturally to an interest in exploring the possibility of coordination. Although all agencies interviewed in the two counties indicated a strong interest in coordination, actual coordination activities were limited for the most part to purchase of service contracts, indicating that coordination needs to depend on more than interest and even a desire to coordinate (17). Another factor appeared to be the simple lack of funds and time available to understaffed agencies for planning and coordination of transportation. The agencies also appeared to be a bit unclear about the extent to which they could coordinate transportation across agencies: the application of the federal and state regulations appeared somewhat hazy at the county level on several issues surrounding client transportation.

Because the number of agencies providing transportation in each county is not high, coordination can be more easily accomplished than in a county with many transportation providers. The agencies had common clients; for example, CAP clients overlapped to some extent with Social Service clients, and the

Office of the Aging had overlap with Social Services as well as with certain CAP activities.

Each county also had a Human Services Council, an umbrella organization that met monthly to discuss problems common to all agencies and to develop appropriate responses to those problems. As a result, agencies are aware of their interdependence as well as of service failures and unmet needs that cut across agency boundaries.

The overlap of transportation services and agency clients and agency awareness of their interdependency creates an environment in which coordination can successfully occur. Use of the cooperative concept as a coordination mechanism can take place across a range of transportation activities and functions. Because coordination would involve only transportation and not programmatic activities requiring substantial policy decision-maker input, the probability of successful coordination may be quite high in the two counties.

Potential Applications

The following cooperative organizations progress from information exchange activities to a full-scale consolidation of agency transportation. It is believed that effective coordination requires time before the cooperating agencies are comfortable working together. Because the emphasis is on beginning with a low-key coordination effort, agencies will not be subjected to inordinate time and funding pressures to initiate a large-scale program. Each agency retains its control over its transportation resources.

Cooperative Clearinghouse

A first-level cooperative would engage in what could be termed clearinghouse activities. Each agency now has a list of clients who need transportation and the type of transportation they require. The cooperating agencies could pool client lists and assign an individual in each agency to be responsible for gathering information on client trips. Geographic "pools" could be formed to transport all clients from cooperating agencies to common destinations on specified days of the month.

Purchase of a microcomputer would greatly facilitate the organization, storage, and use of information now stored on 5 in. x 7 in. file cards. Compilation of transportation needs, along with client eligibility, would allow an individual to verify eligibility, check transportation requests from the same location, and schedule a trip with minimum effort. Software packages are being developed for rural passenger transportation. If no software program is available, local colleges and universities could be tapped to develop a package as a computer science course requirement or as a community service project.

Cooperative for Administrative Activities

One step beyond a clearinghouse is a cooperative that performs common transportation administrative activities. Bookkeeping, accounting, client transportation record-keeping requirements, purchase of service billings, and vehicle use records could be handled by a cooperative. Vehicle records could be kept by the cooperative and vehicle maintenance scheduled according to state or vehicle requirements. At this level of coordination, each agency retains full control over its vehicles and other transportation resources. Providers bill users for services rendered, but the administrative functions could be conducted cooperatively.

Cooperative Vehicle Maintenance and Repair

Each agency now bears individually full responsibility for vehicle maintenance and repair. A cooperative could keep records on all vehicles owned by its members and schedule the required maintenance when recommended. A parts inventory could be maintained, with a potential for a discount on volume purchases. A fleet rate could be negotiated for vehicle maintenance and repair. If local garages object to loss of business because individual agencies now go to one facility, a standard rate for repair by eligible garages could be established at the county level.

Cooperative Fleet Purchase

While retaining agency vehicle ownership, the cooperative could explore the potential for joint fleet purchase of vehicles when replacement vehicles are needed. The objective would be to move toward a standard vehicle that meets the majority of the needs of all agencies. Such a purchase strategy would be responsive to local transportation needs while maximizing purchasing power of individual agencies. Maintenance of a fleet of standardized vehicles would be more cost effective because discount parts purchase and fleet rates could be more easily attained than with a fleet of diverse, nonstandard vehicles.

Consolidated Agency Transportation Cooperative

The ultimate passenger transportation cooperative would be what is termed a consolidated system, an organization in which the cooperative owns and operates the vehicles for member agencies. At this level of coordination, the cooperative is fully responsible for performing all transportation functions for member agencies. It is important to note that, in a cooperative arrangement, the members jointly own the vehicles and other related transportation resources. Member agencies retain control over vehicle purchase, maintenance, repair, and deployment. They do not lose control; they delegate control as if to a transportation unit within their own agency.

In addition to cost efficiencies brought about by discount purchasing, fleet rates for maintenance and repair, and reduction of redundant routes, a cooperative may also be able to obtain lower insurance rates.

Interagency Coordination: Advantages and Difficulties

Before developing a cooperative structure to assume responsibility for certain transportation-related services, agencies would need to consider both the advantages and the difficulties associated with coordination. Advantages include

- Reduction of time spent by directors and staff of each agency in providing transportation service and
- Possible cost reduction brought about by joint vehicle maintenance, joint bookkeeping, and joint routing and scheduling.

Although coordination can bring about cost savings, there are several difficulties or barriers that may inhibit implementation:

- Agencies that own vehicles may be reluctant to lose control over their use;
- Differences in funding sources, funding cycles, accounting procedures, and reporting standards may complicate financial and billing procedures; and
- An immediate financial incentive, a strong mandate to coordinate by funding sources or an imminent loss of transportation funding, can highlight the need to coordinate transportation; lack of any immediate incentive or need encourages continuing the status quo.

SERVICE CLUB COOPERATIVE

The service club cooperative concept uses a civic organization or several such organizations to provide rural passenger transportation. (The service club cooperative concept is based on the work of Judith Kuba of the Transit Division of NYSDOT.) Civic organizations or service clubs such as Rotary, Lions, Kiwanis, or the Junior League are chartered to provide community service. Establishing a rural passenger cooperative could be done as a community service.

Membership

Membership in the service club cooperative would be open to any community residents interested in implementing a volunteer transportation system. Membership would consist of three classes: riders, volunteer drivers, and volunteers to perform certain administration and operation tasks. Individuals could concurrently hold membership in all three classes.

Membership fees for riding members could be contributed by the individual or a third party. Riding members could earn a reduction in their fees by volunteering to perform administration or operation tasks. Membership fees for volunteer drivers would be the lowest on the schedule because drivers would contribute time and the use of their personal vehicles.

Organization

In the state of New York, the cooperative could be organized as an organization separate from the service club under the provisions of the Not-For-Profit Corporation Law. The operation of the cooperative would need to be consistent with requirements specified in the New York State Business Corporations Law, the Transportation Corporation Law, and the Transportation Law. Articles of incorporation and by-laws would be submitted to the New York State Department of State for review and approval. The New York procedure is briefly outlined as an example of the categories of laws that may affect a service club transportation cooperative. Because each state has its own cooperative statute, interested organizations would need to review appropriate state statutes before moving to establish a passenger cooperative.

A primary advantage in setting up a separate not-for-profit corporation is that liability for the management and operation of the transportation system would be limited to the cooperative and would be independent of the sponsoring organization. The disadvantages include incurring legal costs to file a certificate of incorporation and develop by-laws for the cooperative and obtaining liability insurance coverage for the cooperative.

An alternate organizational structure would be for an already incorporated service organization to amend its articles of incorporation to include a statement of purpose to permit the operation of a volunteer transportation service. However, before making such an amendment, a civic organization needs to consider the liability implications for the organization because the organization may become liable for operating and managing the system.

The service club cooperative would be governed by a policy board elected by vote of the general membership with by-laws adopted by the general membership. It is suggested that committees be established from the general membership to

- Recruit members;
- Supervise driver selection and training;
- Manage finances;
- Coordinate volunteer operation activities including scheduling, dispatching, and routing; and
- Direct public relations and fund-raising activities.

Other committees could be established to divide cooperative management responsibilities and tasks in a different manner. However, each of the committees outlined would perform specific functions necessary to the operation of a cooperative that uses volunteers for drivers and other operating responsibilities. A clear outline of responsibilities is necessary to facilitate the effective operation of an organization that relies on volunteers.

Service Orientation

The cooperative would need to fill requests for transportation service in priority order because arranging a trip would depend on the availability of volunteer drivers. Ride requests for routine medical appointments (nonemergency), social services, employment, and grocery shopping should be given preference.

Transportation service would be limited to fee-paying riding members of the cooperative to ensure the safety of both the drivers and their passengers. Drivers would continue to be responsible for vehicle registration, licensing, and insurance, and the cooperative would purchase additional insurance to cover the excess liability a driver would assume in transporting riding members. The driver selection and training committee would arrange for all certified drivers to participate in a defensive driver training course, cardiopulmonary resuscitation classes, and other safety programs. These procedures would minimize risk factors commonly used by insurance carriers to determine insurance premium rates and thereby reduce insurance costs of the cooperative.

Advantages and Disadvantages

The concept of a cooperative building on a local organization established to provide a community service to set up a rural transportation network is especially attractive. That no federal operating or capital assistance is needed makes the concept even more appealing. However, the advantages and disadvantages need to be considered by localities interested in implementing the service club concept.

The advantages of the service club cooperative center primarily on cost savings resulting from the use of volunteers and joint community effort:

• Because of its dependence on volunteers the cooperative could provide rural transportation at reduced cost.

• Professionals who are members of the cooperative could denote their service to assist the cooperative. For example, an attorney could prepare the articles of incorporation, by-laws, and any other necessary legal work or an accountant could set up the bookkeeping and accounting procedures.

• It brings private and public organizations with a community service objective together to meet a recognized community need. Civic organization membership often includes local government, business, and agency officials; bringing the service club membership together with agencies needing transportation can draw the community together to develop strategies to meet other local needs.

The disadvantages of the service club cooperative rest on the difficulty of maintaining a sustained volunteer effort:

• Because most civic organization members have full-time employment, it may be difficult to assemble a sufficient number of volunteers to operate a transportation cooperative on a daily basis.

• Because primary liability coverage would remain with the volunteer driver, individuals may be reluctant to volunteer as drivers; claims for personal injury or negligence resulting from an accident would be filed first against the volunteer's insurance carrier.

POSTAL CONTRACT ROUTES AS COOPERATIVE VENTURES

The use of the rural postal contract route has been gaining attention in recent years as a possible transportation alternative in sparsely populated rural areas (18-20). Highway contract routes are contracted mail pickup and delivery routes serving rural post offices. The carriers deliver mail, generally twice a day, to outlying post offices from regional processing centers or larger post offices. The processing centers and larger post offices are located in populated areas that are also medical, shopping, and human service centers. If passenger service were added to the mail delivery routes, residents of more isolated areas could use an already established transportation system and could do so with little additional cost.

Although the practice is not common in the United States, postal buses are used for passenger transportation in England, Scotland, Switzerland, Germany, Austria, and Sweden. In Switzerland, Germany, Austria, and Sweden passenger service is confined to bulk mail delivery along major truck lines. In Britain and Scotland the postal bus is used in town or village mail delivery routes that connect to larger urban centers, a situation more closely matching rural transportation needs in the United States.

In the United States, few examples of the postal bus exist. California has two such operations; both offer passenger transportation as a secondary service. Both have remained limited in size: the Mount Lassen Motor Transit Company transported 1,204 passengers in 1980, and the Kernville Stage and Freight Lines averages two one-way trips per day six days a week.

As part of the study effort, project staff met with regional post office distribution center officials in Buffalo, New York. After they were briefed on study objectives and the selected counties, the postal officials indicated serious interest in pursuing coordination of postal service with passenger transportation. They saw no restrictions on a postal contract carrier also transporting passengers. The only requirement was that the mail be carried in a locked box or security compartment, a condition they did not perceive as prohibiting the transportation of passengers. They provided project staff with postal routes in Cortland and Otsego counties. The material detailed vehicle requirements, delivery and pick-up locations, routes, and schedules.

Review of the routes in both counties indicated that the postal service provides regular daily service to many of the more isolated rural communities. Although all the routes do not lead to county centers, they do link with larger centers where rural residents could receive medical care, shop, or link with transportation to county centers containing human service agencies. Because postal routes in the two study counties appeared to form feasible passenger transportation routes or links to such routes, cooperative structures using postal routes were developed as rural transportation alternatives.

A Cooperative Opportunity

The potential for increased service and cost savings accruing from the use of a coordinated postal-passenger transportation service would apply to either of the passenger transportation alternatives discussed previously. Each of the alternatives (i.e., the consolidated agency transportation cooperative or the community service cooperative) could include coordination of passenger service with postal routes.

The transportation cooperative would need to contact postal carriers currently operating in the area to determine whether joint operation was possible. Time schedules for each route would be matched with transportation needs of people living along those routes.

Another possibility is to use the layover time of the postal carrier to provide passenger transportation. Because many postal routes require service in the morning and afternoon only, the carrier would be available for service during the middle of the day. Human service agency clients and other eligible rural residents could be transported to service centers during this time.

After a passenger transportation cooperative becomes operational, it could bid on a postal contract. The cooperative would keep its vehicles productively employed and could generate more income than with passenger transportation alone.

Advantages and Disadvantages

The coordination of postal routes with passenger transportation has several advantages for rural passenger transportation:

• The postal route offers a ready-made transportation system to many isolated areas the residents of which have little or no access to transportation.

• Adding postal routes to existing agency transportation service would cost little to implement and could expand transportation available to rural residents.

• Postal carriers would be able to earn additional income with little extra cost.

• Drivers are preselected by the Postal Service and carry specified insurance coverage, thus eliminating the need for agencies to screen drivers.

• A postal-passenger transportation cooperative would be a local organization controlled by local agencies and residents.

There may also be several disadvantages associated with postal-passenger cooperatives:

• Not all postal routes may be usable for passenger transportation: they may not go to service centers of interest to rural residents.
• Postal routes are set and no route deviations are allowed to pick up individual passengers living a distance from the post office.

SUMMARY AND CONCLUSIONS

A study conducted by the New York State Department of Agriculture and Markets and funded by UMTA/SMD in conjunction with the U.S. Department of Agriculture Office of Transportation developed three cooperative alternatives to provide rural passenger transportation.

Each cooperative alternative relies on local resources, local interest, and local initiative. These cooperative approaches would thus be under local control and responsive to local conditions. Each approach, by combining available local resources in an innovative organizational structure, can provide additional low-cost transportation services to those community residents without access to transportation. Although each alternative requires substantial local input and dedication, each alternative also provides local communities the opportunity to enhance necessary transportation services without making significant financial outlays.

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Microcomputer Assistance for a Rural Transportation Operation: The Tennessee Experience

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ABSTRACT

As microcomputers become increasingly popular, rural transportation operators are anxious to know if microcomputers can improve their current bookkeeping and operational analysis techniques. Present methods used by most of these operations are typically manual or performed by a mainframe computer through time-sharing or consulting contractual arrangements. A few operations have experimented with minicomputers or microcomputers. Primary objectives of a recently conducted study were to investigate and evaluate commercially available data base management software, adapt the most suitable software to a current operation in middle Tennessee, and develop a systematic and rather self-explanatory package of software and accompanying instructions to simplify management analysis procedures and generation of reports. One of the most significant contributions of this research will be the transferability of study results. The transportation management program described has contributed to the development of a more generic version that can be used by a large number of other rural transportation operations across the country.

In this paper documentation is presented on how one large rural transportation operation in middle Tennessee recognized the potential assistance to be derived from microcomputers, resisted initial pressures to buy a system immediately, and through a federally funded research project was able to gain insights and purchase recommendations concerning their unique needs. The agency subsequently obtained a complete hardware and software system and is in the process of integrating this new technology into their operational scheme. Evaluations are continuing, but the impacts of this agency's conversion to microcomputer operations and many of the lessons learned from and results of this research project will be valuable to other rural transportation facilities.

Background

The Transportation Systems Center of the U.S. Department of Transportation initiated a funded research project in 1984 to investigate the roles microcomputers could play in the operations of rural transportation operations. There were three major reasons why this research was believed to be necessary:

1. Several rural transportation operations across the country were purchasing microcomputers and experimenting with software packages in an attempt to manage their transportation operations more efficiently;
2. The experiences, both successes and failures, gained from these efforts were not being nationally disseminated; and
3. Numerous other rural transportation operators were interested in obtaining tested and widely applicable data base management software that was available in the public domain.

Therefore, the innovative transportation pioneers experimenting with microcomputers had

1. Experienced problems with equipment,
2. Attempted to write their own programs in some instances with varying degrees of success, and
3. Often discovered after installation of a file management program that they really needed the increased flexibility and power of a data base management program.

After a search for a candidate agency among various rural transportation agencies, the Upper Cumberland Area Regional Transportation System (UCARTS) in Algood, Tennessee, was selected. This agency typically provides between 17,000 and 18,000 client trips per month with 38 vehicles serving a 14-county rural area. The 1,500 to 2,000 clients served during any month require services to many different destinations throughout middle Tennessee. In addition to the diversity of their operations, UCARTS was selected as the project research site because

1. A microcomputer system was desired (and was already being studied) to give the agency greater in-house management and reporting capabilities;
2. Existing operational data were already being compiled by a contractual arrangement with a mainframe computer company (i.e., the transition from large computer processing to a microcomputer should be easier because UCARTS was acquainted with computer data requirements and report capabilities); and
3. Experienced researchers knowledgeable about rural transportation, the specific UCARTS operation, and microcomputers were available nearby at Vanderbilt University.

The willingness to work together of researchers familiar with the UCARTS system and operators appreciative of research benefits that could be derived from their close regional proximity to one another was a definite consideration in the U.S. Department of Transportation selection of a final test site. It was believed that these factors would increase the likelihood of a successful research project.

Research Development

Two important objectives in developing the microcomputer transportation package were

1. A sufficient information dissemination and training period for personnel inexperienced with microcomputers, who would be the key daily operators and must fully understand the system; and
2. An easily understood, menu-driven, and commercially available data base management program from which various functional transportation modules could be created.

The researchers observed that the nonexistence of computer skills and experience and a general apprehension about computers by rural agency personnel appeared to be the norm. Because these premises were accepted and attempts to overcome them were made in a systematic manner, the likelihood of a rural transportation operation successfully converting from manual or contractual management operations to an in-house computerized operation was enhanced.

A training scheme to gradually familiarize agency personnel with the capabilities of a microcomputer proved to be successful. Cornerstones of the educational process were

1. Initial introduction of games, word processing, and simple basic programs to merely acquaint personnel with the power and fun of microcomputers;
2. Development of a list of simple cures for correcting those confusing situations frequently encountered by a neophyte operator; and
3. Designation of one key person who had total control and authority over the use of the microcomputer.

By starting the educational process gradually and using a variety of games and basic programs, the natural inherent fears of a person unfamiliar with and apprehensive about the microcomputer were overcome. Advancement to other more complex activities proceeded smoothly after the initial anxieties and natural inertia of resistance to change had been dispelled.

Compilation of a basic list of "what if" actions proved to be extremely helpful. This help list consisted of typical screen displays or error messages along with simple sequential descriptions, in laymen's terms, of the procedures necessary to remedy problems, or at least return the user to a recognizable restarting point. Anyone who has ever dealt with a computer of any type has experienced the frustration caused by the coldness of that inanimate collection of electronic gadgetry when it simply refused to respond to seemingly logical commands. By developing the trouble-shooting commands for agency personnel, researchers were able to minimize these anxieties and create a useful crutch or security blanket for the fledgling operator.

With regard to software development, the researchers sought to choose a good, adaptable data base manager that was widely used and readily available in the commercial marketplace. By studying the attributes of various data base managers before final selection was made, researchers hoped to more closely match program capabilities with system needs and minimize later frustrations when information from separate files could not be compatibly accessed. The selection of a popular data base management software package would increase transferability, availability, and training opportunities at other operations across the country. Researchers felt that these objectives were best satisfied by ASTON-TATE's dBASE II software. Although no single data base manager could perform every function exactly as analysts might have desired, the abilities and popularity of dBASE II appeared to most nearly satisfy the majority of the desired objectives. An IBM XT microcomputer was selected for this test project.

Careful study of UCARTS procedures and operations, along with a study of potential improvements in the current mainframe computer reports received from their computer consultant, resulted in several program development decisions. Figure 1 shows a facsimile of the main menu developed for the UCARTS microcomputer program. This main menu follows immediately after the display of two rather catchy, color graphic logos showing pictures of the State of Tennessee and a transit vehicle. The main menu in Figure 1 shows that the system user has five basic options. The user can enter trip data, modify or create various microcomputer data files, generate various reports for management decisions, post trip data to intermediate files, or terminate operations and exit the UCARTS program. Figure 2 shows three first-level menus and their associated selection possibilities. These first-level submenus are followed by other submenus asking for further clarification of desired actions such as the addition, modification, or deletion of various data (e.g., trip, vehicle, or client records). By systematically typing a one-digit number in response to menu prompts and user desires, the user can progress downward through the program to a desired task. The user then sees a screen requesting certain types of formatted data. Merely pushing the entry key on the microcomputer allows the user to return to the main menu, from which other functions can be performed depending on the action needed and the corresponding path selected.

MAIN MENU

KEY:	FOR:
1	DATA ENTRY
2	DATA BASE MANAGEMENT
3	PRINT REPORTS
4	POST TRIP DATA TO REPORT FILES
0	TERMINATE PROGRAM OPERATION

SELECT___

FIGURE 1 UCARTS main menu selections.

FIELD TESTING AND SYSTEM REFINEMENTS

The research project is now in the final stages of testing and refinement. Work has proceeded surprisingly smoothly. The researchers would like to think that this success is attributable to outstanding capabilities and proper planning. These traits may have helped, but expert dBASE II programming skills of computer consultants responding to transportation information desires, the luxury of redundant computer report capabilities, and no critical time constraints or deadlines probably contributed more to the overall success. The transferability of these lessons to other transit properties could be beneficial.

Rarely are transportation experts or system managers experienced computer programmers, and vice

DATA ENTRY MENU

KEY:	FOR:
1	TRIP DATA ENTRY
2	IN-KIND SERVICE DATA ENTRY
3	UNMET SERVICE DATA ENTRY

SELECT____

DATA BASE MANAGEMENT MENU

KEY:	FOR:
1	CLIENT DATA BASE
2	DESTINATION CODE DATA BASE
3	VEHICLE DATA BASE
4	FUNDING SOURCE DATA BASE
5	SYSTEM CONSTANTS
6	CLIENT AGE UPDATE
7	END OF MONTH/YEAR DATA RESET

SELECT____

REPORTING MENU

KEY:	FOR:
1	COUNTY SUMMARY DATA
2	VEHICLE SUMMARY DATA
3	FUNDING SOURCE SUMMARY DATA

SELECT____

FIGURE 2 UCARTS first-level submenu selections.

versa. Therefore, interaction and continuing feedback among all parties results in the most useful computer programs. The continuance of an existing mainframe computer contract in Algood and subsequent comparison and improvement of microcomputer reports have been beneficial. There is no immediate plan to cancel the existing computer contract until all field testing of UCARTS programs has been completed and full-scale microcomputer operations are running smoothly. In many other rural transportation operations the original technique for compiling information and generating reports is a manual one. Regardless of the existing methodology, current techniques should not be totally abandoned until an agency's microcomputer programs are refined and fully operational. Even then a backup or emergency contingency plan should be available.

A final luxury that this research has enjoyed is a freedom from major time constraints. Many government agencies find themselves in the unfortunate position of having to complete system installation in too short a time; adequate testing is not permitted; and old techniques are irreparably abandoned too soon after implementation of the new system.

Since the field tests were begun several months ago, two revisions to the original microcomputer program have improved it. Installing a default capability for the trip funding source code has saved many hours of key punching. Although UCARTS has several funding sources from which to request client trip reimbursement, the majority of all client trips are charged to the FHWA Section 18 program. The keypunch operator can now simply enter numeric trip destination codes for different clients and vehicles without repetitively entering code 018 after each Section 18 charged trip. The few trips reimbursed from other funding sources are recorded by simply overriding the 018 default value and entering 020 for Title XX or another prescribed funding code. The program has the flexibility to allow users to designate funding default values and other funding designations that correspond to their own operations.

Intermediate posting of client trips was a second improvement in the process that was warranted on the basis of field testing experiences. Although packing or updating several report files occurred rather rapidly, a disproportionate amount of the keypunch operator's total time was spent waiting while report files were updated after trip data for each client were entered. The intermediate posting allows trip data to be entered continuously until sufficient nonproductive time for posting (e.g., during lunch or at end of workday) is available. Thus, the operator requests an update when most desirable and time productivity is maximized by minimizing waiting time during normal working hours. Both improvements have greatly aided the data entry process and increased total system productivity.

A final refinement in field data collection has been the replacement of several data collection forms with a single form. Drivers have appreciated this change, which occurred only when UCARTS personnel started processing their own data. Before their analysis of data processing requirements, they were unaware of some of the repetitive and inefficient data collection procedures that were being used.

INTERIM CONCLUSIONS

The entire process of converting the data processing procedures of UCARTS to a microcomputer has been extremely successful. Previously inexperienced personnel have adapted well to microcomputer operations and enthusiasm about the derived benefits and expectations has remained high. The tailoring of commercially available data base management software to transportation management needs has been rewarding.

UCARTS personnel are even learning how to use dBASE II terminology to program and generate simplistic reports that answer site-specific management questions. These increased skills have given UCARTS personnel a useful, new management tool that allows them to compile data from numerous files in almost any imaginable format. These capabilities have been used to generate different client listings that are periodically updated by individual county dispatchers.

The last remaining major question before UCARTS converts totally to microcomputer operations has recently been answered. The question was about input time requirements. How much time is required to enter all the data for the 14-county system? Tests just recently completed have shown that one data keypuncher will be kept busy an average of 3 or 4 hours each day entering trip destinations and other updated data. Thus, other functions can be easily accommodated in the remaining 4 or 5 hours of a typical workday. Time requirements for data entry must be a serious consideration of any agency considering conversion to microcomputer operations. For example, additional personnel, equipment, or remote site entry by local dispatchers must be evaluated. Similarly, small transit agencies with few vehicles must carefully evaluate possible microcomputer time and cost savings and increased efficiencies against the total moneys and efforts required to implement these changes.

In retrospect, the decision to designate one person as having absolute control was apparently instrumental in preventing a disproportionate number of unnecessary users and computer use for word processing, recreation, experimentation, or other nonessential purposes. The addition of a microcomputer by some agencies has been followed by many people using it for word processing, even to the extent that its original intended purpose was never achieved or a second microcomputer had to be purchased. This potential problem was averted at UCARTS, primarily because the microcomputer was not viewed as the whole agency's machine but was assigned to a single individual.

ACHIEVED AND ANTICIPATED BENEFITS

The addition of the microcomputer to the UCARTS operation has had, and should continue to have, profound benefits. Benefits already received include

1. Increased availability of different management reports,
2. Practically instantaneous generation of management reports,
3. Better understanding of total operational procedures and data needs because of the internal reviews performed in connection with processing requirements, and
4. Improved data collection and monitoring procedures.

Benefits expected when the test period ends and full operation begins include

1. Financial savings,
2. Data management of other agency programs besides transportation by the UCARTS umbrella agency, the Upper Cumberland Human Resources Agency, and
3. Increased marketing and funding potentials.

The first two benefits need little explanation, but the increased marketing and funding potentials represent interesting strategies. The UCARTS transportation director anticipates that having better and more accurate records of the clients transported and trips provided in each county will enable the agency to better identify those counties that are not fully paying their share of the total transportation system costs. For example, county trip records can be used as leverage to prove to county judges or chief county executives that their constituents are being subsidized from other funding sources. Thus, any county official not willing to pay an adequate proportional share of total cost could face transportation service cutbacks to county citizens. This greater accountability and increased funding potential will greatly assist the operations of UCARTS.

FUTURE RESEARCH NEEDS

When the UCARTS software is fully operational, several additional functions could further expand program capabilities. Maintenance scheduling and routing modules should be investigated, along with any significant improvements in the recently released, updated data base management program called dBASE III. If useful maintenance scheduling or routing capabilities are available or the updated data base manager demonstrates significant improvements in capabilities or processing times, these improvements should be implemented.

As the operational procedures become routine, and if system travel demands increase, a final enhancement worthy of consideration is networking. Individual inputing of data from the busier remote county sites could become needed. Networking microcomputers present both unique opportunities and problems. Networking should be initiated cautiously and only when demand or logistics dictate multiple units at remote sites.

SUMMARY

Thus far, the entire research project has progressed efficiently and with no major problems. A more generic version of the tailored UCARTS program has been developed in conjunction with the UCARTS test project and will be available in the next few months. This program will be marketed by the U.S. Department of Transportation, Transportation Systems Center on a national basis and will be public domain software. A national training course using a test case example and the generic data base management programs is currently being put in final form. The training will introduce users to both the utility and the capabilities of these recent software developments.

The research and microcomputer programs described in this paper about Tennessee's experiences have been major contributors to the creation of widely available public domain programs that are adaptable to a variety of rural transportation operations. Subsequent papers will further document the utility of these generic programs, although their capabilities strongly resemble those tailored specifically to UCARTS operations and described in this paper.

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Small Transit Insurance Programs: Current Status and the Group Purchase Alternative

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ABSTRACT

The recent development of a competitive market for transit insurance provides an opportunity for small transit systems to achieve large savings in their insurance costs with a relatively small investment of time and resources to improve their insurance awareness and to develop an effective marketing strategy. Operating profiles, insurance expenditures, and accident rate information for 115 small transit systems are presented in order to provide a framework for a more detailed discussion of their insurance procurement procedures and overall risk management programs. Specific recommendations are developed on the basis of an analysis of insurance procurement procedures of the small systems and the carrier and agent service provided to them as well as a risk profile evaluation for them. The alternative of group purchase, including an effective implementation scheme, is also discussed. The results demonstrate that one group of six small transit systems in Maryland could have decreased their 1982 premiums for primary and excess liability coverage by $94,744--a decrease of 55 percent--if they had entered into a joint purchase program. A premium allocation scheme is presented, which meets fairness tests and assures all members that every member will attempt to maintain excellent safety and loss control programs.

In view of the continuing pressures to limit government spending at all levels, there is a definite need for small transit systems to investigate a variety of ways to decrease their operating costs. The recent development of a competitive market for transit insurance provides an opportunity for small systems to explore insurance costs as an area for reducing their overall costs, because these costs typically represent an important component of the total. The investigation of the insurance programs of small transit systems, including the possibilities of group purchase plans, is thus a timely endeavor.

Historically, there has been little effective competition among suppliers in the transit insurance market. Transit managers considered themselves fortunate if they were able to find any insurance carrier interested in handling their business. Transit managers, indeed, have asserted that the only insurance carriers seeking their business were those who believed that writing the transit business was a prerequisite for obtaining other city or county insurance business.

In the past several years, however, there has been a significant increase in competition for the transit insurance business among insurance suppliers. The majority of transit operators, especially of small systems, has not been aware of this increased competition for transit insurance business. As results reported in this paper indicate, transit operators have an opportunity to achieve large savings in their insurance costs with a relatively small investment of time and resources to improve their insurance awareness and to develop an effective marketing strategy. The major objective of this paper is to discuss the existing insurance programs of small transit systems nationwide and to make specific suggestions for their improvement.

DATA BASE

During the summer and fall of 1983 the College of Business and Management of the University of Maryland at the request of the state of Maryland's Mass Transit Administration investigated and evaluated the insurance purchasing programs of seven small urban and rural transit systems in the state.

As part of this investigation, operating profile, insurance expenditure, and accident rate data were collected for 115 small transit systems with up to 40 buses in their vehicle fleets. These systems were included in UMTA's National Urban Mass Transportation Statistics, Second Annual Report (1). The 115 firms in the data base were sent questionnaires requesting information on insurance procurement, carrier and agent services, insurance premiums, and losses from a recent year. Forty-eight (approximately 42 percent) answered the questions about insurance procurement and carrier and agent services. However, only 16 provided the data on insurance premiums and losses needed to perform a risk evaluation.

Throughout the paper, the primary focus will be on the 115 small urban and rural transit systems as well as on those who responded to the questionnaire seeking more detailed insurance information. The results of the specific investigation of the Maryland small transit systems, detailed in a separate report (2), will be referred to only for illustrative or comparative purposes.

OPERATING PROFILES: INSURANCE EXPENDITURES, AND ACCIDENT RATES

A statistical analysis of the 115 small transit operations was performed to produce a profile of relevant aspects of their operations in order to establish a context for a detailed discussion of insurance programs. The relevant variables available in the UMTA statistical report cited earlier are operating expenditures and number of buses as size indicators, average age of the bus fleet, total casualty and liability expenditures as a percentage of total operating costs, and total accidents per million vehicle-miles. The relationships involved are given in Table 1.

As the data in Table 1 indicate, the 115 small transit firms have an average annual operating expense of $880,310 and a median expense of $741,500, with values ranging from a low of $17,850 to a high of about $4.2 million. About 20 percent of the small transit systems have 10 or fewer buses, and another 20 percent have between 29 and 40 buses. The mean number of buses among the firms is 19.4. The average fleet age for the small transit firms is 8.8 years. Approximately 20 percent of the systems, however, have fleets with an average age of 5 years or less. At the other extreme, approximately 20 percent have fleets with an average age of 12 years or more, with a maximum fleet age of 27.7 years.

TABLE 1 Selected Operating and Financial Data: Small Transit Firms

Variable	Mean	Median	Maximum
Operating expenses ($)	880,310	740,500	4,199,370
No. of buses	19.4	18.6	40
Fleet age (years)	8.8	8.1	27.7
Casualty and liability expenses ($)	48,432	40,075	229,043
Casualty and liability expenses as percentage of operating expenses	6.0	5.5	14.6
Accidents per million vehicle-miles	48.3	41.6	206.8

Note: Number of transit firms = 115.

System outlays for casualty and liability expenses range from a low of $13,680 to a high of $229,043, with a mean expense of $48,432. Translating the absolute casualty and liability expenses into a percentage of total operating expenses provides an indication of the importance of this cost category. The 115 firms average 6.0 percent of their operating expenses devoted to casualty and liability expenses. However, about 10 percent of the firms devote at least 10 percent of their operating expenses to this category, with one firm spending 14.6 percent in this category.

Small transit firms have an average of 48.3 accidents per million vehicle-miles, ranging from a low of no accidents (11 percent of the firms) to a high of 207 accidents per million vehicle-miles. Eight percent of the firms had 100 or more accidents per million vehicle-miles.

The relationships among these variables are of interest, particularly the influence of various factors on casualty and liability outlays. A reasonable hypothesis or expectation is that casualty and liability expenditures in both absolute terms and relative to total operating expenses are influenced by system size, fleet age, and accident rate. According to the statistical analysis, however, only size shows a consistent relationship.

There is a strong positive relationship (with high correlation coefficients and statistical significance) between casualty and liability expenditures and (a) total operating expenses (R = .67), and (b) number of buses (R = .58). This simply confirms the expectation that the bigger the system in terms of operating expenses and number of buses operated, the greater the casualty and liability outlays. However, there is a significant relationship between the percentage these outlays are of total operating expenses and (a) operating expenses (R = -.31), and (b) the number of buses operated (R = -.35). As shown these coefficients are negative, indicating that smaller firms (as measured by these indicators) are generally required to devote a larger proportion of their resources to this function than are larger firms. This suggests either a threshold effect, which requires a minimum amount of expenditures for this purpose regardless of the smallness of the operation, or economies of scale, which stipulate that these expenditures do not increase proportionately with size, or both.

The extremely low and statistically nonsignificant correlation coefficients confirm the random relationship between casualty and liability expenditures (in terms of operating expenses) and fleet age (R = -.01) and accident rates (R = -.16).

The presentation of operating profile, insurance expenditure, and accident data from the small transit firms provides a framework for the more detailed discussion of the insurance programs of the small systems. The data confirm that insurance expenditures are an important identifiable component of total operating costs and therefore are a target for cost reduction. An analysis of the relationship among the variables does not confirm any expectations of a linkage between accident rates or fleet age and insurance expenditures. Thus, accident rates and fleet age are not good predictors of the share of a firm's operating expenses devoted to insurance premiums. The statistical analysis only confirmed a relationship between firm size and insurance burden, with smaller firms carrying a significantly greater insurance burden than do large firms.

INSURANCE PROCUREMENT AND CARRIER AND AGENT SERVICES

In this section are documented, for the small transit firms, (a) insurance procurement procedures and (b) carrier and agent services provided.

Insurance Procurement Procedures

A major issue concerning the insurance procurement procedures of small transit systems is the amount of attention that the issue receives at the firm level as indicated by the person who has the authority to purchase the insurance. There is no question that the transit managers, perhaps with the assistance of or input from insurance specialists, should have the primary knowledge of and ultimate responsibility for procurement of the system's insurance. Without such knowledge and responsibility, the manager is not in a position to develop the kinds of programs and policies that could make insurance procurement more cost-effective.

Although slightly more than half (51 percent) of the small transit systems reported in response to the questionnaire that the manager or director of the system has the insurance procurement authority, a sizable share of the transit managers do not have this authority. Table 2 gives the distribution of firms on the basis of who has the authority to purchase the system's insurance.

For most of the transit systems the managers of which lack the authority to purchase insurance, this authority rests with various departments or legislative bodies of the city or county in which the system is located. The city or county departments or bodies with the authority include the insurance department, the finance and purchase office, the government's purchasing agent, the city or county

TABLE 2 Individual with Authority to Purchase Transit Vehicle Insurance[a]

Title	Percentage of Firms
Manager, director of system	51.1
Insurance manager, city or county	17.8
City finance and purchase office	8.9
Board of directors	8.9
City council	4.5
General management company	2.2
Board of public works	2.2
State insurance purchasing board	2.2
Purchasing agent for city	2.2
Total	100.0

[a]Based on responses of 45 firms, 3 nonresponses.

TABLE 3 Basis for Premium: Small Transit Systems[a]

Rating Factors	Percentage of Firms Mentioning Factor
Revenue	14.6
Passenger- or vehicle-miles	50.0
Vehicle age and condition	33.3
Risk management program	12.5
Size of buses	25.0
No. of claims	33.3
Radius of operations	14.6
Loss ratio	41.7
Other (group purchase plan, composite rating)	18.8

[a]Data from the 48 transit firms who answered questionnaire.

council, the board of public works, and so forth. However, the authority for insurance procurement is too central to the task of transit management and too intertwined with other system policies to remove it from the transit manager's overall job responsibilities.

A strong indication of the potential for acquiring cost-effective transit insurance is given by whether the transit insurance is purchased on its own or in combination with insurance covering the vehicles of other government entities. Grouping transit vehicles with those of other government agencies prohibits the assessment of the cost of providing insurance to the transit vehicles by themselves and reflects the belief that insurance carriers will write policies for transit insurance only if it is combined with other business. Insurance companies with a major interest in transit insurance, however, are not interested in writing policies covering vehicles of nontransit government entities and will not bid on such combined business. Officials of three out of four small transit systems said in response to the questionnaire that they purchase their transit vehicular insurance as a separate policy instead of grouping it with other business.

Certainly, competitive bids are a prerequisite to obtaining cost-effective transit insurance. It is hoped that a competitive situation will provide the system with a choice of policies that fill its insurance needs. Officials of more than eight out of ten firms said that their insurance policies are subjected to a competitive bid process. No attempt was made to determine whether the companies have experienced a wider choice of policies with the competitive bidding process than they did before its adoption. Among the firms with competitive bidding, 58 percent have a 1-year bid frequency, 2.5 percent have a 2-year frequency, 37 percent have a 3-year frequency, and 2.5 percent have a 5-year frequency.

The questionnaire included an item asking the transit firms to identify the factors that the insurance carriers used as a basis for determining their transit vehicle insurance premiums. Table 3 is a checklist of possible influencing factors; it gives the percentage of the firms that checked each of the items listed on the questionnaire. More than half of the firms selected passenger- and vehicle-miles as the basis for premium determination and about 42 percent also specified loss rate. Other important factors mentioned by at least 30 percent of the firms are vehicle age and condition and number of claims.

Carrier and Agent Services

Any evaluation of an insurance program should include information on the type and level of services provided to the systems by the carriers and agents who handle the business. There are wide differences in the types of services provided. Those transit systems with significantly fewer services from their respective carrier or agent are at a distinct disadvantage in developing a cost-effective insurance program.

A critical component of an overall program to reduce insurance risk is effective safety and loss control inspections. Experienced insurance agents can provide transit systems with a great service by conducting safety and loss control inspections and making suggestions about actions that transit managers can take to reduce those losses. Only 4 percent of the transit systems reported that their insurance carriers or agents have no safety inspections during the course of a year (Table 3). About 61 percent have one or two inspections, an additional 7 percent have three, and 28 percent have four or more.

Another important aspect of loss control and prevention is an accurate picture of past losses so that problem areas can be identified. Approximately three out of four of the small transit systems reported that their carrier or agent provides them with regular loss experience reports. Certainly, every transit manager needs to be aware of the sources of insurance losses in order to prevent their recurrence.

If insurance carriers and agents do nothing more for the transit system, they should at least provide efficient handling of the system's complaints. More than nine out of ten of the transit systems responding to the questionnaire reported that their carriers or agents provide them with efficient claims handling.

Finally, there are specific activities that have been identified as components of an overall program to obtain cost-effective transit insurance through risk reduction. These include the establishment of driver award programs and detailed driver record checks as well as overall upgrading of system safety programs. Carriers and agents can provide significant assistance in these areas. Unfortunately, only 23 percent of the transit systems reported that their carriers or agents assist in driver award programs, 40 percent said that they provide driver record checks, and 50 percent mentioned that they help upgrade system safety programs.

RISK PROFILE EVALUATION

Adequate risk management programs, involving (a) risk identification, (b) risk control or elimination, (c) risk profile, and (d) the risk assumption decision, are important for the transit system manager. Although it is true that all transit managers have at least informal risk management procedures, a formal process will aid in clarifying the risk management process. Although some specific components of risk control or elimination (e.g., safety inspections, good driver awards, loss reports) have been addressed, a risk profile for small transit systems is provided in this section. The risk profile is a central tool to use in determining a firm's risk assumption capabilities as well as its insurance coverage requirements.

A risk profile is based on the detailed insurance premium and loss history information provided by personnel at 16 of the 48 small transit systems who responded to the questionnaire. Where appropriate, reference is made to the insurance premium and loss history information provided by the Maryland firms.

A risk profile focuses on six key measurements that are presented in the following paragraphs.

Cost-of-Risk Ratio

The cost of risk for a transit system, in general, is a measure that should be comprised of the following four components: (a) insurance premiums, (b) costs of safety and loss control programs, (c) costs of insurance administration, and (d) costs of uninsured losses for the year. The most important cost-of-risk ratio is the total cost of risk divided by the transit system's operating expenses.

Although total cost of risk includes all of the four components, this analysis focuses only on the cost of premiums. Data collection constraints prevented the use of the other components. This omission is not a serious problem because premiums usually comprise the largest proportion of these costs and are always the component of greatest interest.

Analysis of the 16 small transit systems indicates that their average cost-of-risk percentage is 3.33 with a standard deviation of 1.83. Thus, approximately 70 percent of the small transit systems should have a cost-of-risk ratio (based on premiums only) somewhere between 2.0 and 5.2 percent. The average cost-of-risk percentage for the Maryland firms is 9.1--high relative to the 16 sample firms.

Liability Premiums as a Percentage of Operating Expenses

Another measure of premium levels is liability premiums as a percentage of operating expenses. The 16 small transit systems have an average of 2.62 for this ratio, whereas the average for the Maryland transit systems is 7.62 percent.

Collision and Comprehensive Premiums

Not unlike the ratio of liability premiums to operating expenses, the ratio of collision and comprehensive premiums to operating expenses is lower for the 16 small transit firms than for the Maryland transit systems. The average ratio for the Maryland systems is 1.76 compared to the average ratio of 0.68 for the 16 small transit systems.

Casualty and Liability Losses

One measure of a firm's ability to withstand losses is the ratio of total losses to the firm's operating expenses. One recent study on transit insurance reports: "One guideline is that fluctuations of 1% to 5% of the annual budget will not be considered materially or financially dislocating. . . . The casualty and liability cost category of the transit budget is the relevant item for a transit system" (3,p.27). The study recommends that transit systems adopt 1 percent of operating expenses as their risk retention guideline. For the 16 small transit systems casualty and liability losses represent 0.7 percent of total operating expenses. For the Maryland firms this figure increases to 1.1 percent.

Collision Deductibles as a Percentage of Operating Expense

Deductible levels are among the most difficult aspects of transit insurance to analyze, yet deductibles represent the most facile form of insurance retention. The previous subsection provided some general guidelines for deductibles.

The average collision deductible for the small transit systems is $983. (However, one of the 16 small transit systems has a collision deductible of $10,000. If this is included, the average collision deductible for the small systems is $1,676.) The Maryland firms have an average deductible of $650.

For the small firms, deductibles as a percentage of operating expenses average 0.09 (or 0.13 with the firm with a $10,000 deductible included), whereas the average for the Maryland firms is 0.16. It is clear that the 16 small transit systems as well as the Maryland systems have an opportunity to increase their collision deductibles considerably without violating the risk self-retention guidelines mentioned in the previous subsection.

Loss Ratios

Loss ratios, central to an insurance analysis, compare the amount of loss paid out in claims for 1 year with the premiums paid for a particular layer of insurance. They can be expressed as loss dollars divided by premium dollars times 100.

Tracking loss ratios can be helpful to a transit system in several ways. First, they can aid in determining whether the system is in good position for greater risk assumption. Second, loss ratios can be used as a simple measure of the effectiveness of a system's loss control program when properly tracked over time. Third, loss ratios may aid the transit manager in choosing alternative coverage levels.

The 16 small transit firms have an average primary liability loss ratio of 22.4 percent (excluding one firm with a 775.0 percent ratio), whereas the average for the Maryland firms is only 9.5 percent. The loss ratio represents data for only 1 year. Although it is more important to observe time trends and variability in loss ratios than to simply look at performance during 1 year, small transit managers have difficulty enough producing data for 1 year. It is hoped that greater recognition of the importance of loss rate information will lead to more comprehensive data collection.

SUMMARY AND CONCLUSIONS

A set of general principles regarding the risk management process as well as their application to the small transit system are presented. The general principles are based on previous reviews of transit insurance as well as knowledge gained from this study of the small transit systems nationwide as well as the Maryland systems. The final principle presented deals with the advantages of a joint purchase alternative and a specific course of action for its implementation.

Purchase of Insurance

Transit managers should have direct responsibility for the purchase of their vehicle insurance and maintain required supporting records of coverage levels, premiums, deductibles, loss histories, and methods of premium determination.

Nearly half of the small transit systems who responded to our questionnaire indicated that no individual in the transit system has responsibility for the purchase of transit vehicle insurance. Many small systems give this responsibility to city or county insurance directors who have responsibility for the purchase of all county insurance. Transit vehicle insurance is only a small part of their total work effort.

Many small transit systems rely on insurance agents to keep all their insurance records. Transit systems, however, should not depend on agents but should maintain their own insurance records including specifically premiums, coverage levels, and loss histories so they can calculate the straightforward ratios previously described. The agent should provide the system with documentation about these matters in a form that permits their ready use in a risk management program.

Specifications

Transit managers should be actively involved in the preparation of insurance specifications as part of the bidding process.

Many small transit systems rely heavily on their agents to determine their coverage levels, deductibles, and other insurance matters. It is not uncommon for the agent who currently has the transit company's vehicle insurance policy to review or even collaborate in the writing of specifications for the subsequent year's policy even though the agent will be bidding for that business. The self-interest of an agent who works on a commission basis may not coincide with the best interests of the transit system. On the basis of the analysis of the Maryland systems, the agents do not advise the systems about alternative levels of coverage and deductibles. There is no evidence that the agents calculate for the systems the type of ratios presented in the last section for consideration in determining coverage levels and deductibles.

Services

Carrier and agent services provided to transit systems should include all of the following: safety inspections, loss reports, efficient claims handling, assistance with driver awards, checking of driver records, and assistance with a safety upgrade program.

The survey of small transit systems revealed that only 23 percent receive assistance with driver awards from their agents, only 40 percent have agents who check driver records, and only 50 percent have agents who assist with safety upgrade programs. It is recommended that all transit systems become aware of these services and include their agent's willingness to provide them in an overall evaluation of the agent.

Excess Liability

Small transit systems should obtain excess liability coverage so that their total coverage ranges between $2.5 million (minimum) and $5 million.

The level of excess liability that should be held by a transportation system is an extremely judgmental matter. Many experts indicate that there has been an upward drift in types of risk in which a loss could bankrupt a system. They encourage transit systems to obtain a minimum of $5 million in total liability coverage; this is probably too conservative for many small transit systems. The detailed analysis of the Maryland systems indicated that excess liability should range between $2.5 million and $5.0 million.

Self-Retention of Risks

Small transit systems should pursue the option of self-retention of liability risks.

Assuming that there are no legal obstacles to a self-retention risk program, the only apparent problem is budgetary. Transit managers avoid self-retention programs because of concern that amounts budgeted and not used for paying claims will be eliminated from the following year's budget.

If this obstacle can be overcome, transit managers should give serious consideration to the adoption of the 1 percent guideline for risk retention. Previous studies indicate substantial premium savings available from modest increases in deductible levels (3,p.8).

Lower Cost Insurance

Small transit systems should be able to use their favorable loss ratios as a bargaining chip in their effort to obtain lower cost insurance.

Insurers, in general, attempt to achieve a loss ratio of 60 percent and use the other 40 percent of the premium dollar for expenses and profit. As detailed earlier, the loss experience of the small transit systems is generally favorable. The 16 small transit systems reporting detailed information had an average loss ratio of 22.4 percent (excluding one outlier firm).

Although data form the 16 firms covered only 1 year, the small transit systems have achieved remarkably low loss ratios. The detailed analysis of loss ratios for the Maryland systems, covering multiple years, confirmed an overall low loss ratio for the small transit systems. It can be concluded that providing transit insurance to the small transit systems has been a highly profitable endeavor. The implication is that favorable loss ratios should enable small transit systems to individually obtain lower cost insurance.

Joint Purchase Program

A joint purchase program to tap the competitive market for transit insurance should be investigated.

The recent large increases in insurance premiums have stimulated interest in joint purchase programs in order to pool risks and to offset otherwise high premiums. This interest has encouraged a number of insurance carriers, in cooperation with transit associations, to offer a variety of such insurance packages that have numerous advantages in terms of cost savings and improved services.

One such association, the United Bus Owners Association (UBOA), provided premium quotations for a joint program covering six small Maryland transit systems. Under the UBOA program, some Maryland transit systems could increase their liability protection and all could decrease their premiums as a group by a total of $94,744--a decrease of 55 percent compared to 1982 premiums.

Given the significant cost advantages associated with a group purchase plan as demonstrated in the example of the Maryland systems, it is important to understand why small transit systems have been slow to respond to the opportunity for substantial savings. In addition to the problem of a lack of awareness of insurance matters in general as well as of the specifics of group purchase on the part of small transit operators, there are three explanations for the lack of response to the group purchase alternative on the part of the small transit systems. First, legal and institutional barriers may prohibit a group purchase program. Second, there are problems concerning allocation of the joint premium among the individual systems. Third, there is the problem of moral hazard.

Legal and institutional barriers could be of several different types. Some states have statutes that simply prohibit government agencies from entering into joint ventures for insurance procurement purposes. In addition, provincialism or regional pride, which would simply prevent such agreements, might exist. For example, a small system's good relationship with a local broker would be threatened in a group purchase scheme. More important, buyer ignorance, as this study has shown, is widespread throughout small transit systems. Most transit systems simply have not realized that substantial savings could be achieved in insurance procurement through a joint purchase program.

Although the legal barrier could be overcome by action of the state legislature, provincialism is a more difficult obstacle to resolve. However, in the future, as the potential savings increase, this barrier might also be overcome. Widespread diffusion of information about the insurance options that are available has begun to raise the level of awareness of potential buyers. As this information continues to spread, buyer ignorance will tend to disappear.

The problem of fair allocation of the joint premium among the systems and moral hazard at first seem inexorable ones. Unless each individual transit system in the joint agreement receives some savings from the economies of scale, which it considers fair, it will leave the group program. Moreover, there has to be some mechanism that assures all members that every member will attempt to maintain excellent safety and loss control programs. That is, the moral hazard problem must be eliminated. The joint purchase program presented hereafter addresses the problems of fair allocation and moral hazard.

Initially, the joint premium should be allocated on the basis of premiums paid by each system before entering the joint agreement. (The exact allocation formula to be used will be discussed later.) Subsequently, every 3 years (or any other time period agreed on), each system would be required to seek bids for insuring that system alone. The lowest bid that each system received would serve as a basis for computing the portion of the joint premium each system must pay. As will be shown, this method not only provides for fairness in allocation of the joint premium but, more important, rewards those systems that improve or maintain safety and loss control.

To demonstrate the workings of this system, assume that there are three small transit systems--A, B, and C. Further, assume that the individual bids they received for insurance are as given in Table 4 and that the premium for entering various joint purchase agreements are as given in Table 5. Thus, if all three transit systems purchased insurance jointly, their premium would be $60,000 and substantial savings would be achieved. One simple method that might be used to allocate the $60,000 would be to compute allocation factors based on the premiums paid assuming no subcoalitions such as A + B, B + C, C + A could be formed. Under this method, the allocation factors, using only data in Table 4, would be computed as follows:

TABLE 4 Hypothetical Insurance Premiums: Lowest Bid

System	Lowest Bid Premium ($)
A	50,000
B	25,000
C	35,000
Total	110,000

TABLE 5 Hypothetical Insurance Premiums for Joint Agreements

System Combination	Premiums for Joint Agreements ($)
A + B	45,000
A + C	45,000
B + C	50,000
A + B + C	60,000

F(A) = 50,000/110,000 = 0.45
F(B) = 25,000/110,000 = 0.23
F(C) = 35,000/110,000 = 0.32
Total 1.00

where F(i) is the allocation factor for the ith transit system. Under this scheme, transit systems A, B, and C would pay 45, 23, and 32 percent, respectively, of the $60,000 joint premium. That is, the premiums paid by A, B, and C under the joint agreement would be $27,000, $13,800, and $19,200, respectively.

This simple allocation rule satisfies the following axioms of fairness:

1. No transit system pays more than the lowest bid individual premium that it could achieve by itself.
2. Every transit system shares in the savings due to the joint purchase agreement.
3. The sum of the individual allocations is equal to the joint purchase agreement premium.
4. The allocation is homogeneous of degree one in premiums. That is, a 10 percent increase in the lowest individual premium for all transit systems results in a 10 percent increase in the final allocation to each transit system.

Although this allocation rule satisfies some important fairness criteria, if the assumption of no subcoalition formation is relaxed, the rule might have a possible shortcoming. The first column in Table 6 gives the premiums that would be paid by both individuals and subcoalitions if this simple rule were used (note that the subcoalition numbers such as A + B are simply the sum of the premiums allocated to A and B (i.e., for A + B, $27,000 + $13,800 = $40,000). Column 2 gives the lowest bid premiums that individual operators and subcoalitions could achieve.

From the data in Table 6 it is clear that all subcoalitions except A + C would be better off by entering the joint purchase agreement (i.e., A + C, by forming a subcoalition by themselves and not joining the coalition A + B + C, would pay only $45,000 in premiums. Under the allocation rule, A + C by joining with C must pay $46,200).

TABLE 6 Comparison of Premiums Under Allocation Rule to Lowest Possible Premiums

System or Combination	Premiums Under the Allocation Rule ($)	Lowest Possible Premium ($)
A	27,000	50,000
B	13,800	25,000
C	19,200	35,000
A + B	40,800	45,000
A + C	46,200	45,000
B + C	43,000	50,000
A + B + C	60,000	60,000

Thus, although this simple rule works well where no subcoalitions such as A + C can be formed, the rule occasionally fails when the complexities of subcoalitions are added. When the simple rule fails, slightly more complex rules can be used such as the Shapely Value and the Generalized Shapely Value. The formula for premiums under the Shapely Value is

$$P_i = \Sigma[(s-1)!\,(m-s)!/m!]\ [v(s) - v(s-i)]$$

where

P_i = premium for individual transit system i;
s = number of members of subcoalitions (in this case, s can equal 1, 2, or 3);
m = total number of possible transit systems in the joint purchase agreement (in this example, m = 3);
v(s) = insurance premium for subcoalition s (e.g., for A + B in this example, v(A + B) = $45,000); and
v(s-i) = premium that coalition s would have to pay if individual member i dropped out (e.g., v(A + B + C - A) = $50,000).

The premiums for members of the joint purchase agreement as computed by the Shapely Formula would be $25,000, $14,991.17, and $19,999.83, for A, B, and C, respectively. Although just barely satisfying subcoalition A + C, the Shapely Value allocations do satisfy all subcoalitions. The allocations also satisfy the first three axioms of fairness. In addition, axiom 4 would be altered to read: The allocation is homogeneous of degree one in incremental changes in premiums.

Table 7 gives the actual liability premiums paid by six small urban and rural transit systems in Maryland in 1982 (Column 2). Column 3 provides the allocation factors based on a joint purchase plan that had a premium (for both primary and excess liability) of $77,550. Column 4 contains the premiums that would be paid under the joint agreement, and Column 5 gives the savings for each system. This simple example illustrates that each system had the potential to cut its insurance premium by anywhere from 45 to 57 percent with the group purchase alternative.

TABLE 7 Illustrative Example of Savings Potential Associated with Joint Purchase Agreement

System	1982 Premium ($)	F(i)	Allocation Under Joint Purchase ($)	Potential Savings ($)
1	24,316	.14	11,008.22	13,307.78
2	16,536	.10	7,443.25	9,092.75
3	9,984	.06	4,493.83	5,490.17
4	26,624	.15	11,983.54	14,640.46
5	14,600	.08	6,571.50	8,028.50
6	80,324	.47	36,154.05	44,169.95
Total	172,294		77,550.00	94,744.00

The illustrative example demonstrates that potential problems associated with a group purchase plan can be resolved. The rewards for the resolution of the problems are substantial. It is believed that small transit systems across the country could successfully implement a group purchase program if they invested some additional time and effort in studying their insurance policies and their overall risk management program.

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Goals for Bus Transit Scheduling

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ABSTRACT

Like other transit agencies, the Southern California Rapid Transit District schedules buses using a peak point constraint on crowding. As a way of clarifying implicit scheduling goals of maximizing seat use while minimizing crowding, two indicators were studied, load factor and standee factor. Riding checks carried out on many lines over an extended period allowed computation of 24-hour averages of these indicators for three types of lines: urban local, suburban local, and express. Weighted linear regressions produced a relation between standee factor and load factor for each service type. Elasticities were estimated to give predictions of increases in crowding due to ridership growth. A scattergram of standee factor versus load factor can be used as a diagnostic tool for scheduling management to indicate which lines should be given attention and improvement or deterioration following schedule revisions. The loci of hour-by-hour values of standee factor and load factor give both manager and scheduler a quick overview of the reasonableness of a schedule. Periods of schedule deficiency are readily apparent.

Transit agencies are attempting to increase service productivity in various ways. Although the scheduling function is usually central to any productivity improvements, traditional scheduling practices may not be well suited to maximizing service productivity.

Scheduling practice is typically based on meeting certain service standards. For the high-volume conditions that are of most interest in this paper, standards are usually expressed in terms of maximum loads at peak points. For peak travel periods, the scheduler arranges for flows of buses that just meet the standard.

The implicit goals of scheduling are to provide the highest quality of service and to use the least amount of resources. These goals are expressed in terms of simple measures of quality and productivity. Relationships between these measures are explored, and a means of problem identification is described.

TRADITIONAL LOAD STANDARD

The Southern California Rapid Transit District (SCRTD) has no explicit objective function for scheduling but, like other transit agencies, uses a load standard or crowding constraint. The official statement of loading standards is

> In order to provide an accessible and dependable transit system. . . . All parts of the transit system should . . . have adequate capacity for safety and to attract and keep riders.
>
> (1) Loading ratios for individual lines should not exceed 140% measured for the peak 20 minutes at the maximum load point.
>
> (2) Loading ratios should not exceed 100% for base periods and evenings.
>
> (3) Loading ratios for long distance freeway and busway services should not exceed 100% measured for the peak half-hours.

Such a load standard, by focusing on extreme situations, diverts attention from the range of normal operations. Only 30 percent of the bus trips reach a maximum load that exceeds the seating capacity, so the other 70 percent tend to be disregarded. Even within the 30 percent, inconsistencies abound. Two lines could just meet this standard, yet one could have standees for 3 min of each trip and the other could have standees for 20 min. The policy is addressed only to what happens at a peak point. If crowding occurs elsewhere than at a declared peak point, it may be ignored.

INDICATORS OF SERVICE PRODUCTIVITY AND QUALITY

Even though the underlying goal of scheduling has always been to arrange buses in such a way that the least resources are used to produce a given level of service, it is not clear that the usual constraint-based practices are likely to lead to optimum productivity. Further, these practices scarcely address the quality-of-service issue.

What seemed to be needed was a way of expressing the goals of scheduling in terms of indicators that would tell how well a bus line is scheduled overall--over the entire route and throughout the day.

If the objective is to maximize the use of seats while minimizing crowding, the simplest indicators of use and crowding are load factor and standee factor, respectively, defined as

L = load factor = passenger-miles/seat-miles

S = standee factor = standee-miles/passenger-miles

L is a reasonable measure of productivity. Availability of a seat is generally regarded by the rider as a paramount measure of service quality. Therefore, the standee factor is assumed to be a good (inverse) representation of service quality.

EXPLORATION OF THE INDICATORS

Obviously, these indicators are not independent of each other. In the case of a single bus at a single instant of time, S is a deterministic function of L. There are no standees until all seats become full, at which point L = 1.0 and S = 0. Then the standee factor rises asymptotically toward 1.0 according to

$$S = (L - 1.0)/L$$

until the load reaches the physical limit of crowding. For a 40-ft bus with 43 seats the limit is around L = 2.5.

For scheduling, interest is less in instantaneous values of S and L than in averages: over a bus trip, for a stream of buses, or for a bus line operating over some period of time. Averaged over time and space, the dependence of S on L is statistical not deterministic.

For a typical bus trip, the range of possible values of S and L is much smaller than the range of instantaneous values. The load factor will normally be much less than 1.0 because it is an average of a load that varies as the bus travels along the route. The standee factor will not be close to the maximum attainable instantaneous value because there is usually a considerable excess of seats near the ends of the route. However, because all standee-miles are accounted for, S will be greater than zero if there is any standing anywhere along the route.

Accordingly, the range of (L,S) combinations for 1 hr of line operation would be smaller than the range for single bus trips, and the range for 24 hr of operation would be smaller still. The expected ranges would be somewhat as shown in Figure 1. With each successive level of aggregation, the range diminishes.

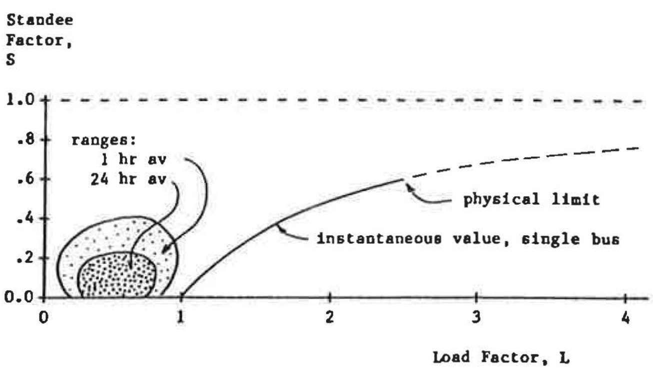

FIGURE 1 A priori relationship of L and S.

The intent of this study was to quantify relationships between the two indicators L and S. Is there a clear functional relationship? How would the relationships vary with service type? How does growth of ridership affect crowding?

The Data

With a computer it is relatively simple to account for all passenger-miles, seat-miles, and standing-miles, wherever they occur. Ride checks are the source of the data. In a ride check, a checker notes how many people get on and off at each stop. The number of people on board between stops is obtained by subtraction of cumulative totals. If the checker knows the distance between stops, seat-miles and passenger-miles can be accumulated, as well as standee-miles. Ride checks are done routinely at SCRTD and at most other transit properties for purposes of planning and scheduling.

The software developed at SCRTD moves stop by stop through the record for each trip, accumulating vehicle-miles, passenger-miles, and the excess of passengers over seats. These numbers are aggregated by line and by direction, but segregated for each hour of the day. The indicators L and S are then tabulated by direction for each hour and for the full service day, stop-by-stop and for the full route.

It should be noted that data obtained from riding checks tend to understate standee factors, because service is known to operate more regularly when it is being monitored. This is likely to cause a moderate but consistent bias.

Analysis

Analyses of the relation of S to L were based on data aggregated to the line level. Because management overview is the primary concern here, 24-hr aggregates of L and S are used, with each direction of the line treated as a separate case. In other words, each case or data point consists of a 24-hr average load factor and a 24-hr average standee factor representing a single line in one direction on a weekday.

Differences Among Service Types

There are three basic types of service at SCRTD: urban local, suburban local, and express. Regressions were carried out separately for each type, with the cases weighted by size of line, expressed in seat-miles, to get a truer reflection of the system as a whole. The results are given in Table 1. The coefficients of determination (r^2) are not very high, yet scatterplots appear to indicate a linear relationship between L and S.

TABLE 1 Coefficients of Regression Lines, S = a + b L

Line Type	Cases	a	b	r^2
Urban local	74	−2.077	.1535	.263
Suburban local	124	−1.859	.1344	.629
Express	60	−3.318	.1522	.476
All	258	−2.450	.1512	.552

The regression lines are plotted in Figure 2. Also shown are rectangles representing the ranges of the variables for each line type, as well as dots on the regression lines showing the mean load factor values.

Urban local and express buses are scheduled for the demand, so the load factors are higher than are those for suburban local buses. Because express service usually has a flatter load profile, it can be scheduled closer to a full seated load over more of its length. This allows a higher L relative to S. On the other hand, the policy is not to have standees on express services, ostensibly because of safety considerations in freeway operations. As will be seen, scheduling for a load factor anywhere near 1.0 will result in standees, unless patrons are prohibited from boarding when there are no seats available.

It might be of interest to note that hourly averages of L can be as high as 90 percent for urban local service and 110 percent for express service. Hourly highs of S are 20 percent for urban local service and 18 percent for express service.

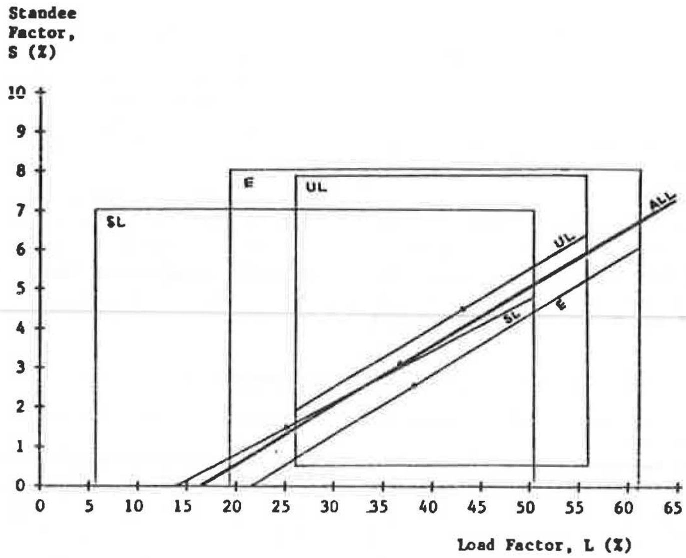

FIGURE 2 Regression lines for various services.

Predicting Increases in Crowding

At the system level, how much would crowding (i.e., standing) increase as ridership rose due to a fare decrease? This can be answered in terms of elasticities of crowding with respect to ridership levels, calculated for the system average or for the averages of the component service types:

$$\text{elasticity} = e = (\Delta S/S)/(\Delta L/L) = (\text{slope of the regression line}) \times (\bar{L}/\bar{S})$$

Calculated values are given in Table 2. This is called the cross-sectional estimate.

One way to test the cross-sectional estimation of elasticity is to compute actual percentage increases in L and S over a period of time. From the 258 cases used here, 170 were selected in which the checks could be matched with earlier checks taken in the year before the fare reduction. Because the aggregate of this subset would not have exactly the same characteristics as the larger set from which it is drawn, cross-sectional estimates of elasticity were calculated for before and after versions of the subset. The elasticities were 3.4 and 2.9, from the pre-decrease data and the post-decrease data, respectively. These could then be compared with the actual elasticity of the subset. Calculated directly as percentage growths in overall S relative to percentage growth in L, the actual elasticity was 2.8.

If the actual elasticity (i.e., time related) is lower than the prior cross-sectional estimate, it might be concluded that the lines involved have improved in productivity more than they have degraded in service level. (A zero elasticity would imply that increased loadings were accommodated without increased crowding.) The precision of these estimates is probably not sufficient to allow any such conclusions to be drawn, but the consistency of the numbers is heartening.

TABLE 2 Elasticities of Crowding with Respect to Ridership

Service	No. of Cases	Mean Load Factor L (%)	Mean Standee Factor S (%)	Slope of Regression Line	e
Urban local	74	43.2	4.55	.153	1.46
Suburban local	124	25.1	1.41	.133	2.37
Express	60	37.9	2.44	.152	2.36
Overall	258	36.4	3.06	.151	1.80

USE OF INDICATORS FOR SCHEDULING

How can this information be used to manage the scheduling function, to bring about improvements in economy and quality of service? For the most advantageous use of scheduler manpower, the load factor-standee factor combination of indicators is used at five levels of aggregation to progressively narrow the search for schedule revision opportunities. These aggregation levels are

1. All lines composite, whole day	Used only to indicate whether the scheduling process is improving over long periods of time
2. All lines composite, by hour	Provides a norm or frame of reference for individual lines
3. Whole line, single direction, whole day	Provides an overview of line abnormalities and indications of need for new schedules
4. Whole line, single direction, by hour	Tells the scheduler which part of the schedule is causing overload problems and where a detailed analysis is needed
5. Stop-by-stop, single direction, by hour	Tells the scheduler which portions of the lines are overloaded, especially as an indication of desirability of deadhead trips or short turns

It will be recalled that the coefficient of determination for the relationship between S and L was not particularly high. One inference that may be drawn is that the service is not as consistently scheduled as it could be. A corollary is that the poor-performance lines might be rescheduled to more nearly match the high-performance lines.

Consider the scattergram of S versus L shown in Figure 3 with the regression line displayed. If average bus lines are on the regression line, poorer-than-average lines are above it. In other words, their standee factors are too high for their load factors. If a schedule is improved in quality, the next check should show a migration toward or even across the regression line.

If all lines were being improved, the regression line itself would move to the right. As a diagnostic tool for management, the scattergram indicates the lines that should receive the most scheduling effort.

The scattergram can be used to infer potential productivity improvements due to improved schedules. If average load factor is an indicator of productivity and standee factor is an (inverse) indicator of level of service, horizontal rightward shifts of points on the scattergram imply a pure productivity improvement without a loss in level of service.

The scheduler can use the hour-by-hour data for a single line and direction to see where to focus on specific problems. Figure 4 shows the loci of 1-hr points as well as the 24-hr-average point for a fairly typical heavy line. The urban route regression line is superimposed for reference. The loci indicate that the schedule is reasonable in the sense that the highest standee factors are in the peaks and the most crowded peak is in the morning. However, the location of the 24-hr-average point indicates that some improvement in the schedule is possible, either by bringing down the standee factor or by increasing the load factor.

The scheduler might choose to look for the reasons for such a high standee factor in the morning peak. For that she would make the traditional analyses of point check data at peak points and turn-back locations or look at specific trips in the line profile data.

GENERIC ACTIONS

The approach to schedule evaluation described here can be regarded as a way of looking for the most extreme schedule deficiencies. Alternatively, it can be viewed as a way of searching for opportunities to apply generic actions (1). If quality can be represented by the likelihood of finding a seat on the next bus to arrive and productivity by the percentage of seats filled, adroit scheduling can reduce

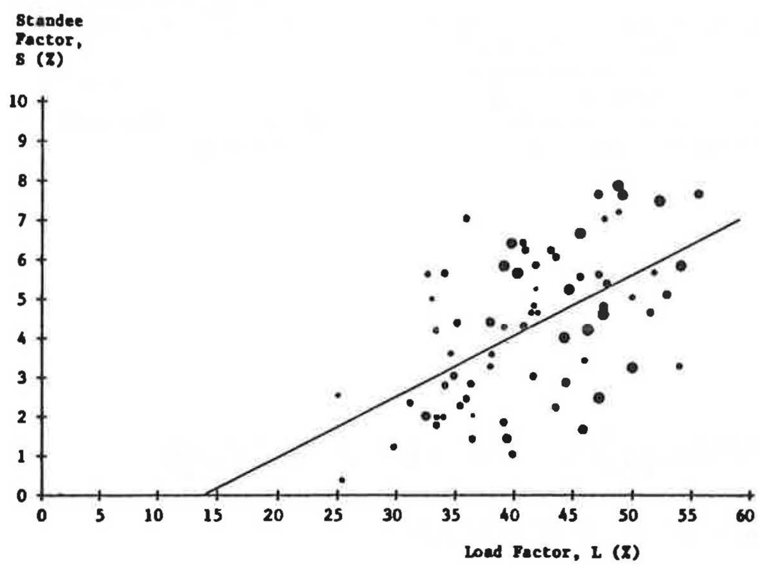

FIGURE 3 Scattergram of urban local lines.

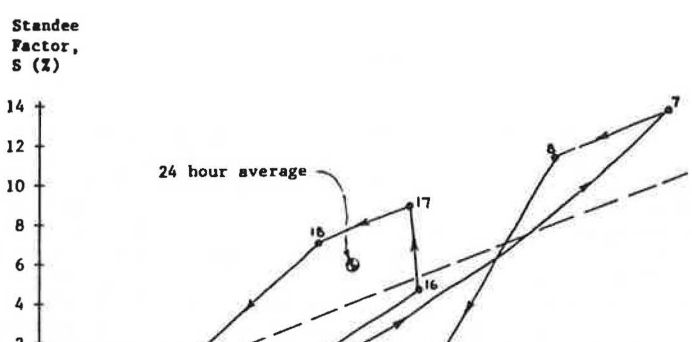

FIGURE 4 Loci of (L, S) for a single line in a single direction over a 24-hr period.

the chance of not finding a seat while bringing the average percentage of seats filled closer to 100.

Examples of generic actions that can reduce standee factor without reducing load factor are shortlining, partial deadheading, and headway offsets.

By shortlining, or running buses over only a segment of the route, capacity can be shifted from a portion of a line on which the seats are seldom filled to another segment on which people frequently must stand.

Headway offsets are a way to even the loads on successive trips, where one trip regularly tends to have standees and a succeeding trip is regularly light.

Partial deadheading is a technique for saving buses by running a fraction of the buses without passengers (and consequently faster) in a light direction, in order to add a few trips in the heavy direction. Correctly done, this raises the overall load factor and reduces the standee factor.

CONCLUSION

The intent of this study was to gain a better understanding of two indicators of scheduling performance before setting quantitative goals. Something has been learned about the current system. Considering the common perception that the system is overcrowded, the 24-hr averages of both load factor and standee factor are surprisingly low. The load and standee factors clearly show how overcrowding is a matter of time of day and line segment.

In setting goals for scheduling, what is subject to scheduler influence must be borne in mind. Although the scheduler should endeavor to increase load factors, she typically has little direct control over them--they are more directly a result of budget balancing. Within the overall load factors, however, schedulers should attempt to reduce standing as much as possible.

With this in mind, an informal goal of scheduling has been formulated on the basis of the elasticity results of this study. The goal is to hold rises in standee factor to less than 1.6 percent for every 1 percent rise in load factor. A similar goal statement could be made for declining load factors, but a decline is unlikely to occur in the face of pressures for greater productivity.

The transit industry knows relatively little about how well it could do. Quantifying how well it is doing now is just a first step toward determining what is possible. What is needed next is a concerted attempt to push the state of the art of service design and operation. This could give a better indication of just how high the load factors could be in combination with low standee factors.

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Computer Application for Determining Bus Headways and Timetables

AVISHAI CEDER

ABSTRACT

One component of an extensive program to develop applications for bus automatic data collection systems (ADCSs) is presented. Current procedures for determining bus timetables are reviewed, and alternative methods for creating timetables using passenger load data are proposed. The major objectives set forth are to evaluate timetables in terms of required resources; to improve the correspondence of bus departure times with passenger demand; to allow headway-smoothing techniques (similar to what is done manually); to integrate different headway-setting and timetable construction methods; and to permit direct bus frequency changes for possible exceptions (known to the scheduler), which do not rely on passenger demand data. The final product of the study consists of a set of computer programs that perform (a) conversion from the bus property mainframe files to an adequate input file, (b) analysis of four methods for setting bus headways, and (c) creation of alternative public timetables at all the route time points. These programs are tested on a heavily traveled bus line in Los Angeles, and the derived alternative frequencies and timetables are interpreted and discussed.

Passenger demand at the route level is generally ascertained at one or more selected stops along the route where the bus carries its heaviest loads (point check). A more comprehensive method is based on load profile and running time information gathered along the entire length of the bus route (ride check). Point checks are typically conducted several times a year; ride checks are often performed only once or twice during the year.

The methods used by bus properties worldwide are commonly based on the following service standards: (a) adequate space will be provided to meet passenger demand and (b) an upper bound is placed on the headway to assure a minimum frequency of service (policy headway). The first requirement is adequate for heavy ridership hours (peak periods), and the second for light ridership hours. The first requirement is usually met by the peak load factor method--the required number of buses is obtained by dividing the maximum observed passenger flow by a load standard (desired occupancy, number of seats). The second requirement is met by establishing policy headways (maximum allowed headways) that usually are 30 or 60 min.

Several researchers have approached the bus headway determination problem through mathematical programming techniques (1-3). However, these mathematical programming models have not been generally adopted by transit schedulers because the models are not sensitive to a great variety of system-specific operational constraints. For example, they cannot simultaneously determine evenly spaced headways and unevenly spaced headways for situations involving scheduling exceptions.

PREPARATION OF TIMETABLES

In current practice schedule changes are made using a mix of manual and computer-generated reports. The use of computerized reports has been established in many large bus properties [e.g., Southern California Rapid Transit District (SCRTD) in Los Angeles, Toronto Transit Commission in Toronto, EGGED in Israel]. The procedure employed by SCRTD to develop timetables will be used as an example. On the basis of ride- and point-check data, the following steps are performed by the SCRTD scheduling department:

1. Running times are established for each route by time of day (using the most recent ride-check data).
2. Calculated bus speeds are examined for each time period and route segment in order to correct special cases of speeding up and slowing down of buses (e.g., drivers may speed up toward the end of the route in order to extend their layover time).
3. Headways are determined at the peak point. This is usually the time point at which maximum passenger flow is observed; a time point is generally a bus stop at a major intersection or facility that appears on the public timetable.
4. Initial departures (passage) times are set at the peak point.
5. Departure times are set at all route time points including the departure and arrival terminals by using the established running times and the headways at the peak point.
6. Departure (passage) times are adjusted at the peak point to take into account two additional considerations: trips with short turns and the vehicle block construction procedure.
7. The final route timetable is completed.
8. After the updating of the schedule, the changes (or the new timetable) are marked on the timetable print instruction sheet that is transferred to marketing.

The scheduling departments at various bus properties including SCRTD are seeking improvements at three different levels:

- Elimination of manual steps,
- Improved accuracy, and
- Cost saving and productivity gains.

The first improvement is anticipated to take place in the relatively near future, due to the acceptance of a computer in the scheduling department. However, it is understood that, even with the computerized process, many decisions will be made on the basis of the scheduler's judgment (e.g., the development of timetables for periods with special activities such as sporting events). The second improvement is directly related to the data collection methods. With greater use of an automatic data collection system (ADCS), it is anticipated that this improvement could be easily attained. The third improvement is related to new and more efficient scheduling methods; the data collected will provide a reliable basis for the scheduler's decision. For example, the ADCS might provide the required data, but, without appropriate statistical models, the data would be meaningless. The statistical models should accurately reflect the variations of both the passenger demand and the vehicle performance measures. [For a statistical analysis of bus running time data see Ceder (4).]

This study provides alternative methods for determining bus timetables using passenger load data. The major objectives set forth are (a) to evaluate timetables in terms of required resources; (b) to improve correspondence of bus departure times with passenger demand; (c) to allow headway-smoothing techniques (similar to what is done manually); (d) to integrate different headway-setting and different timetable construction methods; and (e) to permit direct bus frequency changes for possible exceptions (known to the scheduler), which do not rely on passenger demand data.

METHODS FOR SETTING BUS HEADWAYS

Earlier work (5), which is strongly related to the procedures described in the following sections, is presented and clarified in this section. This early work describes four alternative bus frequency determination methods to fulfill two major objectives:

- Setting of bus frequencies both to maintain adequate service quality and to minimize the number of buses in the schedule and
- Efficient allocation of resources to gather passenger load data.

The first objective is to evaluate alternative methods of determining bus frequencies in conjunction with saving resources. The second objective compares the costs and benefits of information obtained from point checks and ride checks. The ride check provides more complete information than the point check, but it is more expensive because either additional checkers are needed to provide the required data or an automatic passenger counter is used. There is also the question of whether the additional information gained justifies the expense. Certainly, for bus properties that have ADCS this question is also relevant because only part of the overall fleet will be equipped with ADCS. The ADCS may be rotated among several groups of routes, depending on whether it is worthwhile to gather point-check as opposed to ride-check data.

The four frequency determination methods in Ceder (5) can be summarized by the following four equations:

- Two point-check methods for time period j

$$\text{Method 1: } (\text{Frequency})_j = (\text{Load at the daily maximum load point})_j / (\text{Desired occupancy})_j \quad (1)$$

$$\text{Method 2: } (\text{Frequency})_j = (\text{Load at the hourly maximum load point})_j / (\text{Desired occupancy})_j \quad (2)$$

- Two ride-check methods for time period j

$$\text{Method 3: } (\text{Frequency})_j = \text{MAX}\left(\left\{(\text{Area under the load profile in passenger-km})_j / [(\text{Desired occupancy})_j \times (\text{Route length})]\right\} (\text{Load at the hourly maximum load point})_j / \text{Bus capacity}\right) \quad (3)$$

Method 4: $(\text{Frequency})_j$ is the same as in Method 3 but is subject to a constraint that limits the length of the route over which the load may exceed the product of $(\text{Frequency})_j \times (\text{Desired occupancy})_j$.

Note that hourly or other time periods that coincide with j may be used in Equations 2 and 3 and that passenger-miles may be used instead of passenger-kilometers in Equation 3.

The first method is based on data gathered at one point during the day. This point is usually determined from old ride-check data or from information given by a mobile supervisor. It represents the stop with the heaviest daily load along the route. The second method is based on the maximum load observed in each time period (usually an hour) instead of the whole day. Certainly, it is less costly and more convenient to station an observer (when the data are collected manually) at one point during the entire working day than to assign observers to different points every time period. When ride-check data are available (collected either manually or by ADCS), the program established in Ceder (5) compares Methods 1 and 2, and, as a result, the scheduler can decide about the appropriate point-check procedure.

The third method is based on load profile information. The load profile is plotted with respect to the distance traveled from the departure point. Thus, the area under this curve serves as a productivity measure in passenger-kilometers (or passenger-miles). This area divided by the route length is the average load as opposed to the maximum load in each period j in Method 2. Method 3 also guarantees, in an average sense, that the passengers on board on the maximum load segment will not experience crowding above the given bus capacity (number of seats plus maximum allowable standees). This method is useful for situations in which the scheduler wishes to know the number of bus runs that can be saved by raising the desired occupancy standard without incurring overcrowding. However, Method 3 can result in unpleasant travel for an extended distance over which the average load is above the desired occupancy. To control this undesirable situation, it is possible to establish a level of service criterion by restricting the total route distance that has loads greater than the desired occupancy. This is in essence Method 4.

A Programming Language, Version 1 (PL/1) program has been written for all four methods. This program compares the results of Methods 1 and 2 and uses a load profile density measure in a preliminary examination of the point- and the ride-check methods. The investigation of the load profile density measure suggests the use of a point-check procedure for relatively flat profiles and a ride-check procedure otherwise (5). The program calculates the bus frequency for each time period and for each method. Three criteria are selected for Method 4: 10, 20, or 30 percent of the route length is allowed to have an observed load exceeding the desired one (these criteria can obviously be varied).

ALTERNATIVE TIMETABLES

There is always a trade-off between increasing passenger comfort and reducing the cost of service. Bus schedulers certainly understand the need to accommodate the observed passenger demand as well as possible. However, at the same time, their effort is also directed to the minimization of vehicle and driver costs. Different bus properties use different scheduling strategies based on their own schedulers' experience. As a result, it is unlikely that two independent bus properties will use exactly the same scheduling procedures at the detailed level. In addition, even at the same bus property, the schedulers may use different scheduling procedures for different groups of routes. Consequently, there is a need, when developing computerized procedures, to supply the schedulers with alternative schedule options along with an interpretation and an explanation of each alternative. Undoubtedly, it is desirable that one of the alternatives coincide with the scheduler's manual procedure. In this way, the scheduler will be in a position not only to expedite the manual tasks but also to compare his methods with others in terms of the trade-off between passenger comfort and operating cost.

Current timetable determination procedures provide the basis for establishing the spectrum of alternative timetables. Three categories of options can be identified: (a) selection of type of headway, (b) selection of a method or combination of methods for the setting of frequencies, and (c) selection of special requests. These three groups of options are shown in Figure 1. A selected path in this figure provides a single timetable. Hence, there is a variety of timetable options.

In the first category, alternative types of headway are considered. An equal headway simply means constant time intervals between departures in each time period, or evenly spaced headway. A balanced headway refers to unevenly spaced headways in each time period so that the observed passenger loads on all buses are similar. A smoothed headway is simply an average headway between the equal and balanced headways. It is an option in cases in which the available data are not sufficient for concrete conclusions about balanced headways but in which the scheduler believes that equal headways will result in significantly uneven loads. Such uneven load situations occur around work and school dismissal times and for trips with short turns. The theoretical work and the detailed procedures for this category appear elsewhere (6).

In the second category it is possible to select different frequency or headway determination methods. This category allows for the selection of one method as well as combinations of methods for different time periods. The methods considered, indicated in Figure 1, are the two point-check and the two ride-check methods described in the fist section. In addition, there might be procedures used by the scheduler that are not based on data but rather on observations made by the road supervisors and inspectors as well as other sources of information.

The third category allows for special scheduling requests. One characteristic of existing transit

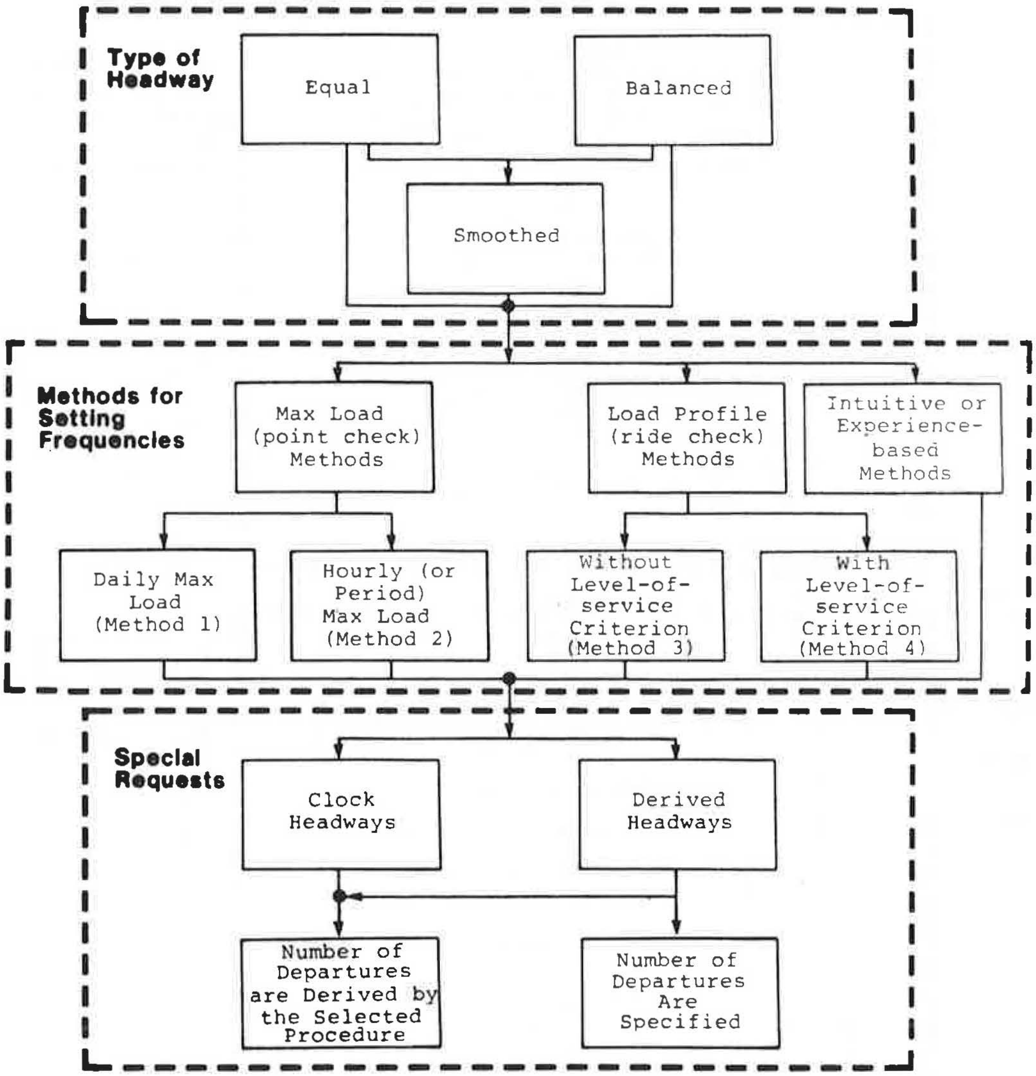

FIGURE 1 Alternative timetables.

timetables is the repetition of departure times, usually every hour. These easy-to-memorize departure times are based on "clock headways" of 1, 2, 3, 4, 5, 6, 7.5, 10, 12, 15, 20, 30, 40, 45, and 60 min. Note that schedules do not generally consider that headways of less than 6 min influence the timing of passenger arrivals at a bus stop. However, for a general timetable determination procedure, there might be peak periods in which the headways are less than 6 min but need to be marked explicitly on the timetable.

The second possible special request is to allow the scheduler to prespecify the total number of bus departures during a time period. This request is most useful in crises in which the scheduler needs to supply a working timetable for operation on the basis of tightly limited resources (buses or drivers, or both). By using his intuition and controlling the total number of departures, the scheduler may achieve better results than by simply dropping departures without any systematic procedure. Also, there might be cases in which the scheduler would like to increase the level of service by allowing more departures. Such situations occur when there is a belief that passenger demand can be increased by providing improved (more frequent) service. Certainly, the latter special request can also be approached through varying the desired occupancy values, and it is up to the scheduler to decide whether to control the passenger loads or the number of departures, which directly governs the required fleet size.

It is important to emphasize that not all the paths in Figure 1 regarding clock headways are meaningful. Selection of balanced or smoothed headways cannot be performed if there is a clock headway constraint. Also, as shown in Figure 1, the number of departures cannot be specified for clock headways due to the specific time restrictions on those headways.

COMPUTER PROGRAMS AND TEST RUNS ON AN SCRTD ROUTE

In this section the product of the analysis, which demonstrates that all the study objectives set forth in the first section are fulfilled, is discussed. The product is a set of computer programs that perform

- Conversion from the bus property mainframe files to adequate input files,
- Analysis of four methods for setting bus frequencies, and
- Creation of a public timetable at all the route time points.

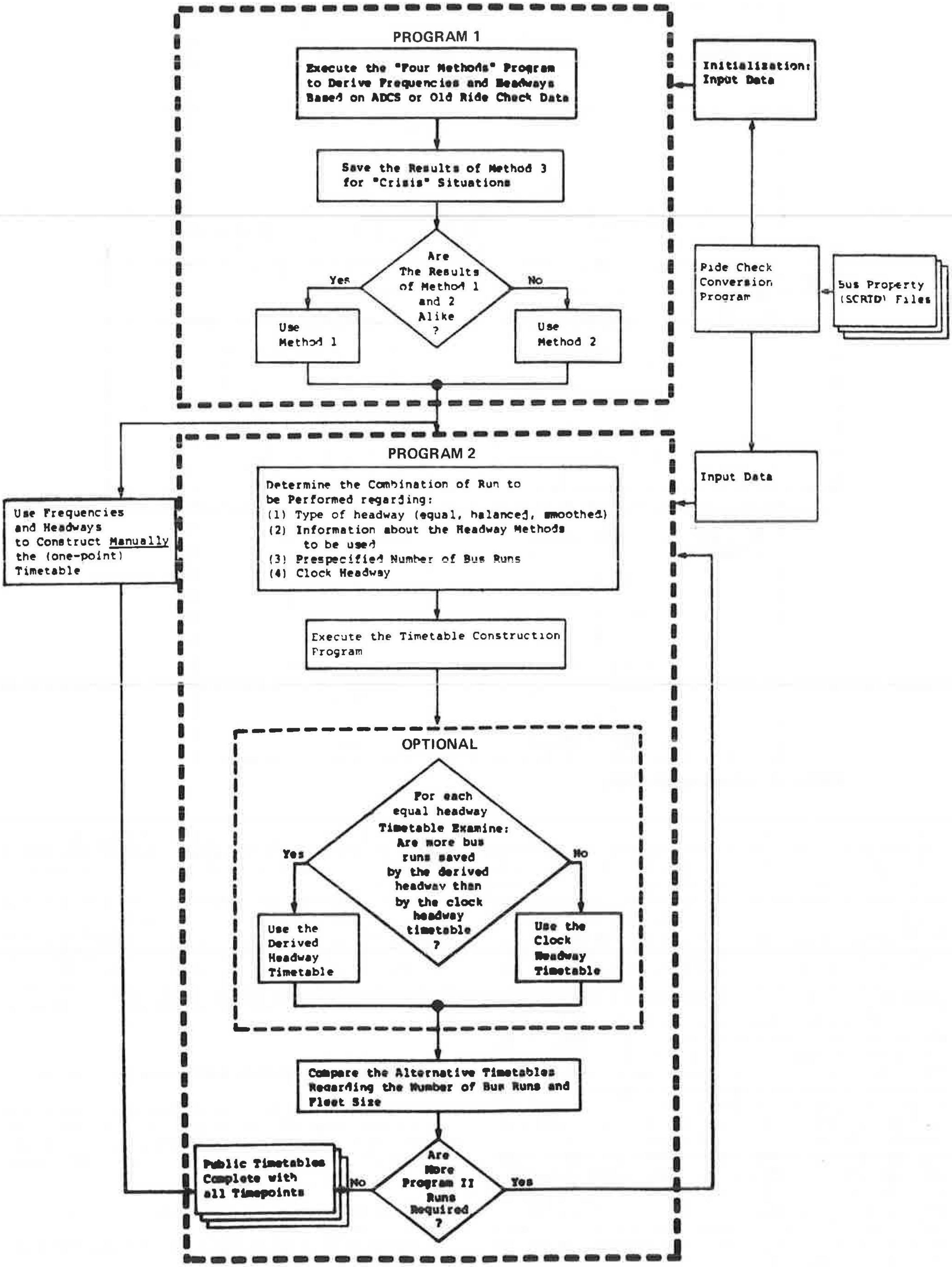

FIGURE 2 Flowchart of Program 1 (setting alternative frequency and headways) and Program 2 (constructing alternative timetables).

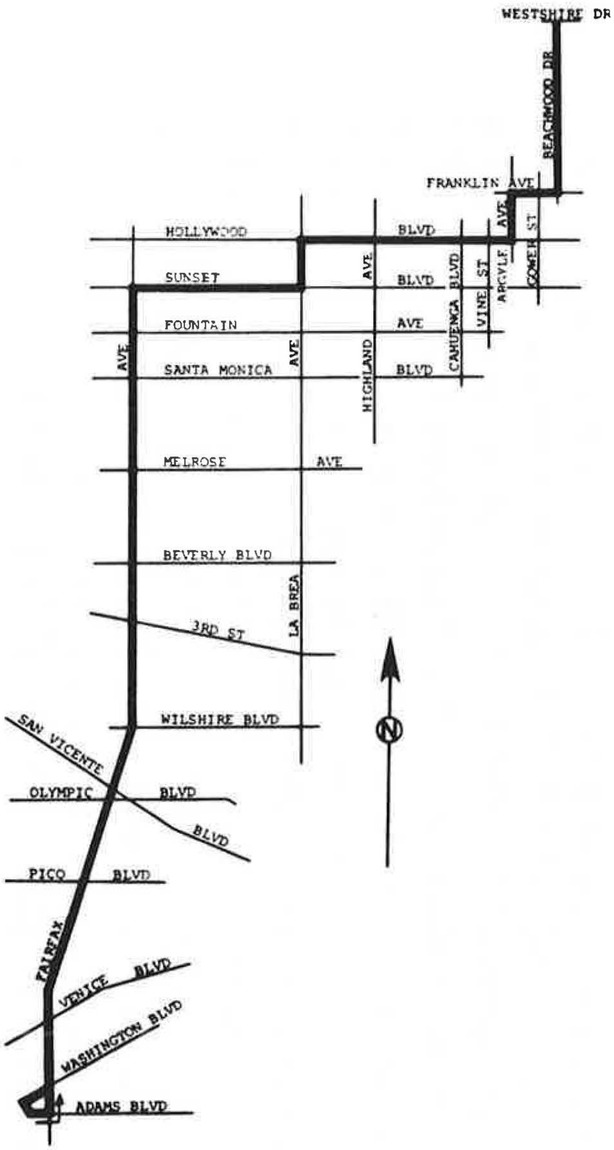

FIGURE 3 Geometry of SCRTD Line 217.

Recent ride-check data from SCRTD Line 217 are used to demonstrate the programs. The use of real-life data provides the possibility of studying the full range of the programs' implementation potential.

Description of the Programs

The construction of alternative timetables is mainly based on two PL/1 programs:

- Program 1--setting frequencies and headways by four methods and
- Program 2--setting alternative bus departure times at the base stop (maximum load point) and all the route time points.

The basic user input to Program 1 consists of

- Route (line) number;
- Bus type;
- Direction of travel;
- Bus capacity (number of seats plus maximum allowable standees).
- Number of time periods;
- Name of each stop (or time point);
- Distances between adjacent stops (or time points) along the route;
- Number of observed departures in each time period;
- Minimum frequency (policy headway in terms of the minimum required number of buses in each time period);
- Desired occupancy (load factor or load standard) in each time period; and
- Loads between each two stops (or time points); averages are preferred in each planning period (i.e., Monday through Friday, Saturday, Sunday and holidays, and exceptions).

The basic input to Program 2 consists of

- Description of time periods including their length;
- Round-trip time including layover and turn-around times in each time period;
- Determined (noninteger) frequencies from Program 1 including possible user changes and additional frequencies (e.g., inserted by the scheduler) for each time period;
- Running times from the base stop (usually at the daily maximum load point) to each time point that appears on the public timetable (negative times are assigned to time points that precede the base stop);
- Observed average departure (or passage) times for each individual bus at the base stop;
- Observed average headway for each bus; and
- Observed average loads for each bus based on the selected frequency setting methods (e.g., load at the daily maximum load point for Method 1, load at the hourly maximum load point for Method 2, and load profile for Methods 3 and 4).

A schematic overview of the computerized system is shown in a flowchart in Figure 2. This flowchart, aside from describing the programs, advises the user on the various available options. It is anticipated that initialization will be at the mainframe computer files of a bus property. A conversion program has been written to prepare adequate input data for Programs 1 and 2. This program assumes that ride-check data are available in the bus property files.

The analyses made by Program 1 are explained elsewhere (6) and further interpreted by Ceder (5). In Program 2 the user can request various alternative timetables according to the options shown in Figure 1. For each computer run using Program 2, the user simply keypunches requests as follows:

1. Type of headway:
   - 1 for equal headways,
   - 2 for balanced headways, and
   - 3 for smoothed headways;
2. "Number" of methods to be used (among the inserted frequency-setting methods);
3. For each method used the user specifies
   - Method "number,"
   - Time period "number" in which to start using the method, and
   - Last time period "number" to use the method in the considered combination (i.e., the same method can be used several times for different time periods and each combination must be specified);
4. Clock headway
   - 0 for not required and
   - 1 for required; and

TABLE 1 Initial Data for Line 217 (northbound)

NUMBER OF PASSENGERS PER INTERVAL

TIME INTERVAL		600 700	700 800	800 900	900 1000	1000 1100	1100 1200	1200 1300	1300 1400	1400 1500	1500 1600	1600 1700	1700 1800	1800 1900	1900 2000	2000 2100	2100 2200	2200 2300	2300 2400	2400 2500	TOTAL
NO OF BUSES		6	10	8	8	8	7	8	8	8	10	8	9	6	5	3	3	2	2	2	
MINIMUM NO OF BUSES		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	
RECOMENDED NO OF PASS		60	70	70	60	50	50	50	50	50	60	70	70	60	60	50	50	50	50	50	
DIST	ST NAME																				
0 18	ADAMS /WASHINGT	13	27	115	24	11	11	6	4	10	9	16	23	18	8	2	3	2	5	1	308
0.26	FAIRFAX /ADAMS	21	68	148	39	16	27	26	8	16	19	24	38	23	12	3	7	2	5	1	503
0 27	FAIRFAX /WASHINGT	22	89	160	48	22	32	29	15	23	20	35	40	23	15	3	8	6	5	1	596
0 28	FAIRFAX /APPLE	25	101	163	51	26	34	29	16	23	23	40	45	24	14	3	8	6	5	1	637
0 27	FAIRFAX /VENICE	29	112	183	53	37	43	37	22	26	34	60	51	32	19	3	8	9	5	2	765
0.27	FAIRFAX /VENICE F	37	124	217	84	52	44	51	38	36	48	78	60	37	21	7	8	10	6	3	961
0 24	FAIRFAX /18TH	40	119	188	83	51	45	52	39	37	57	78	61	37	20	8	8	9	6	3	939
0.24	FAIRFAX /AIRDROME	40	121	192	89	52	49	54	42	38	60	77	65	35	19	8	11	9	7	3	981
0.24	FAIRFAX /PICKFORD	45	151	195	94	48	50	54	42	40	60	78	67	35	19	9	12	9	7	3	1018
0.24	FAIRFAX /SATURN	48	167	211	97	58	50	55	45	39	60	73	63	31	18	9	13	9	7	3	1056
0.24	FAIRFAX /PICO	56	217	246	116	83	78	84	95	73	94	105	97	49	30	11	12	14	8	4	1472
0 26	FAIRFAX /PACKARD	59	228	252	120	91	80	87	98	76	96	105	98	47	30	11	12	15	8	4	1517
0.26	FAIRFAX /WHITWORT	63	250	257	125	98	87	90	100	78	96	104	98	53	31	14	12	15	9	4	1584
0 00	FAIRFAX /OLYMPIC	59	244	275	130	108	98	103	120	99	86	122	99	54	38	16	12	18	10	5	1696
0 24	OLYMPIC /OGDEN	59	332	278	152	123	99	116	142	103	104	129	115	64	39	16	12	18	10	5	1916
0 22	FAIRFAX /SAN VICE	70	355	325	171	144	124	141	181	142	149	151	134	73	40	17	15	19	12	6	2269
0 24	FAIRFAX /8TH ST	66	357	330	175	150	128	145	188	164	156	170	158	77	42	18	16	19	13	6	2378
0 29	FAIRFAX /WILSHIRE	54	363	349	236	288	250	354	356	[illegible]	397	382	343	190	91	40	24	36	18	8	4121
0 29	FAIRFAX /6TH ST	55	369	351	238	291	257	363	365	347	398	386	343	189	94	41	27	34	18	8	4174
0 29	FAIRFAX /DREXEL	54	376	355	234	291	258	381	378	350	398	391	339	191	93	42	27	34	18	9	4219
0 29	FAIRFAX /3RD ST	48	401	370	234	261	258	338	381	367	[illegible]	454	367	205	101	56	37	38	19	9	4356
0.29	FAIRFAX /1ST ST	48	400	366	232	265	256	339	385	373	422	440	368	206	104	54	37	39	19	9	4362
0.34	FAIRFAX /BEVERLY	44	392	354	232	249	252	314	362	353	409	459	377	218	98	59	44	44	20	9	4289
0 35	FAIRFAX /OAKWOOD	52	391	351	237	271	282	315	366	352	416	467	370	220	106	57	48	51	22	9	4383
0 34	FAIRFAX /ROSEWOOD	49	370	326	246	288	292	327	376	367	418	481	371	214	102	57	50	51	20	8	4413
0 35	FAIRFAX /MELROSE	46	113	175	165	245	265	308	378	365	427	439	370	201	101	51	47	50	20	8	3774
0 34	FAIRFAX /WILLOWGH	44	112	173	155	238	246	291	358	344	406	411	353	191	91	51	45	48	19	8	3584
0 35	FAIRFAX /SANTA MO	33	90	140	148	154	174	216	292	273	322	353	299	171	97	45	50	51	19	4	2931
0 35	FAIRFAX /FOUNTAIN	35	92	134	153	149	172	208	281	244	300	321	283	157	89	42	49	49	20	4	2782
0 29	FAIRFAX /SUNSET	32	70	95	132	127	144	172	249	210	270	280	264	144	80	44	48	48	20	4	2433
0 29	SUNSET /GENESEE	31	69	90	133	125	143	170	248	206	269	287	259	146	80	42	48	47	20	4	[illegible]
0.29	SUNSET /STANLEY	30	71	92	135	127	135	171	248	206	260	288	253	145	77	43	46	48	18	4	2397
0.29	SUNSET /GARDNER	31	73	85	132	117	124	165	240	210	249	274	241	138	83	43	46	45	17	4	2317
0 29	SUNSET /MARTEL	32	75	82	131	110	116	164	228	208	236	263	228	128	82	40	47	45	17	4	2236
0 29	SUNSET /POINSETT	33	73	77	127	118	115	171	220	193	232	260	222	129	81	38	55	46	18	4	2212
0 30	LA BREA /SUNSET	36	65	70	122	113	106	163	211	177	222	252	218	132	86	39	54	45	17	2	2130
0 18	LA BREA /HOLLYWOO	36	62	68	118	116	98	156	199	172	213	242	206	127	81	36	56	42	16	1	2045
0 18	HOLLYWOO/SYCAMORE	36	65	67	118	116	104	155	192	165	208	225	194	122	78	38	56	45	17	1	2002
0.18	HOLLYWOO/ORANGE	32	62	66	112	112	107	152	176	166	197	204	179	113	75	36	54	43	17	1	1904
0 18	HOLLYWOO/HIGHLAND	19	33	49	84	90	94	130	147	154	185	146	146	88	65	33	55	35	16	2	[illegible]
0 18	HOLLYWOO/LAS PALM	16	26	45	77	83	89	120	126	140	168	141	139	85	58	31	55	34	15	2	1450
0 18	HOLLYWOO/WHITLEY	15	22	42	62	67	76	111	92	116	144	129	116	68	43	27	53	31	13	2	1229
0 18	HOLLYWOO/WILCOX	14	21	40	54	62	66	105	84	108	131	119	98	58	38	18	44	27	13	2	1102
0 19	HOLLYWOO/CAHUENGA	11	20	36	44	61	66	90	80	96	123	107	85	50	40	16	41	25	13	1	1005
0 19	HOLLYWOO/IVAR	9	16	33	33	50	57	73	61	84	111	98	84	47	35	14	29	24	10	1	869
0 19	HOLLYWOO/VINE	3	14	19	17	31	39	35	33	68	87	73	67	47	25	14	24	17	9	1	623
0 19	ARGYLE /HOLLYWOO	4	20	17	20	31	35	32	44	69	91	83	66	47	20	16	24	15	10	0	644
0 19	ARGYLE /YUCCA	3	20	17	19	30	28	32	44	68	81	79	64	44	15	13	21	11	9	0	598
0 27	FRANKLIN/ARGYLE	2	16	17	16	21	22	29	34	47	64	59	47	25	11	10	17	8	6	0	451
0 11	GOWER /FRANKLIN	2	8	13	11	10	16	21	21	27	53	38	30	10	8	8	6	0	0	0	282
0 16	BEACHWOO/FRANKLIN	2	11	11	12	8	9	15	12	25	49	21	24	7	4	6	3	0	0	0	219
0 18	BEACHWOO/MIDWAY	2	11	11	11	8	6	14	12	25	48	19	19	5	2	5	3	0	0	0	201
0 18	BEACHWOO/SCENIC	2	10	11	10	7	5	13	11	16	44	17	18	4	2	5	3	0	0	0	178
0 16	BEACHWOO/TEMPLE H	2	9	10	9	7	4	10	9	14	44	14	13	3	2	3	3	0	0	0	156
0 18	BEACHWOO/WINANS	1	7	10	9	7	4	5	6	13	39	13	12	1	1	3	3	0	0	0	134
0 18	BEACHWOO/CHEREMOY	1	7	9	8	7	3	5	4	10	34	11	7	1	1	3	3	0	0	0	112
0 18	BEACHWOO/GLEN ALD	1	7	7	6	6	3	4	4	8	30	10	5	1	1	2	1	0	0	0	96
0 19	BEACHWOO/GLEN OAK	1	7	7	6	6	3	2	4	8	26	8	4	1	1	2	1	0	0	0	87
0 21	BEACHWOO/WESTSHIR	0	7	6	6	2	3	2	3	0	5	5	2	1	0	0	0	0	0	0	42
0 00	BEACHWOO/WESTSH F	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

5. Prespecified number of departures:
   - 0 for no need and
   - "Given number" of departures for using the constraint.

For the equal headway timetable, an optional decision exists about the comparison between the derived and the clock headways. Finally, Figure 2 indicates that there is always a possibility of manually determining the timetable based on the headways derived by Program 1.

Frequency Setting Methods (Program 1) for SCRTD Line 217

Line 217 in Los Angeles has been selected to examine the computerized system. Line 217 is considered a heavy line that carries a relatively large number of passengers. It is interesting to note that this line includes ADCS equipment. However, the ride-check data were collected manually and keypunched into SCRTD files. At present, the absence of reliable data from the ADCS precludes recommending its use. It is anticipated, however, that the recurring ADCS equipment problems will be resolved in the near future and that this will create opportunities for further examination of the computerized systems developed.

The geometry of Line 217 is shown in Figure 3. This line is characterized by 60 stops and 9 time points. Most of its trips are initiated at the departure terminal and terminate at the arrival terminal. Also, all of the trips cross the daily maximum load point from which the alternative timetables are to be created.

The basic input data, which are arranged by Program 1 in a table form, are given in Table 1 for northbound Line 217. This ride-check information includes, for each hour, the observed number of buses in the third row, the minimum required frequency, and the desired occupancy in the fourth and fifth rows, respectively. The first and second columns in the tables are the distances (in kilometers) between each two adjacent stops and the stop name. The last column represents the total load across the whole day for each stop where each entry in Table 1 is a representative load for a given hour and stop. It is expected that these entries will usually be based on average values across several checks. A complete description of the input, including that for southbound Line 217, appears elsewhere (6).

The intermediate results of Program 1 are given in Table 2. The data in Table 2 indicate that the daily maximum load point for the northbound direction is the Fairfax/Rosewood stop with a total of 4,413 observed passengers during the whole day. Also, computer-generated load profiles are provided for each time period to allow the scheduler to visually observe the load variation among stops. An example is shown in Figure 4. Each asterisk in this figure represents five passengers. The area under scale is not sensitive to distances of less than 0.5 km for this visual display and, therefore, it appears that the stops are evenly spaced along the entire route. The output of Program 1 includes a measure of density for each load profile: the area under the profile curve divided by the maximum observed load times the route length. This density measure is 41.9 percent for Figure 4. Low densities mean low productivity (relatively high empty seat-kilometers) and may indicate the advisability of considering short turns.

The frequency and headway results of Program 1 are given in Table 3. The statistical (chi-square test) comparison between the results of Method 1 and Method 2 reveals that, at the 95 percent significant level, the null hypothesis about equal methods is rejected for both directions of Line 217. Consequently, for a point-check method, it is recommended that the data be gathered at the hourly maximum load points. The results of Method 4 in Table 2 are shown for three different constraint levels: 10, 20, and 30 percent of the route length (13.9 km) is allowed to have an observed load exceeding the desired occupancy. In the remaining parts of this section, Method 4 is associated with the 20 percent constraint. Bus capacity for Methods 3 and 4 is considered to be 80 passengers (see Equation 3).

The graphic comparison of the frequency results of three methods and the observed frequency is shown

TABLE 2 Maximum Load Information for Line 217 (northbound)

MAXIMUM LOAD POINT BY METHOD 1 IS FAIRFAX /ROSEWOOD --- 4413 PASSENGERS FOR DAY

INTERMEDIATE RESULTS FOR METHOD 2

TIME INTERVAL	MAXIMUM LOAD POINT	NO. OF PASSENGERS
0600 0700	FAIRFAX /SAN VICE	70
0700 0800	FAIRFAX /3RD ST	401
0800 0900	FAIRFAX /3RD ST	370
0900 1000	FAIRFAX /ROSEWOOD	246
1000 1100	FAIRFAX /6TH ST FAIRFAX /DREXEL	291
1100 1200	FAIRFAX /ROSEWOOD	292
1200 1300	FAIRFAX /DREXEL	381
1300 1400	FAIRFAX /1ST ST	385
1400 1500	FAIRFAX /1ST ST	373
1500 1600	FAIRFAX /MELROSE	427
1600 1700	FAIRFAX /ROSEWOOD	481
1700 1800	FAIRFAX /BEVERLY	377
1800 1900	FAIRFAX /OAKWOOD	220
1900 2000	FAIRFAX /OAKWOOD	106
2000 2100	FAIRFAX /BEVERLY	59
2100 2200	LA BREA /HOLLYWOO HOLLYWOO/SYCAMORE	56
2200 2300	FAIRFAX /OAKWOOD FAIRFAX /ROSEWOOD FAIRFAX /SANTA MO	51
2300 2400	FAIRFAX /OAKWOOD	22
2400 2500	FAIRFAX /DREXEL FAIRFAX /3RD ST FAIRFAX /1ST ST FAIRFAX /BEVERLY FAIRFAX /OAKWOOD	9

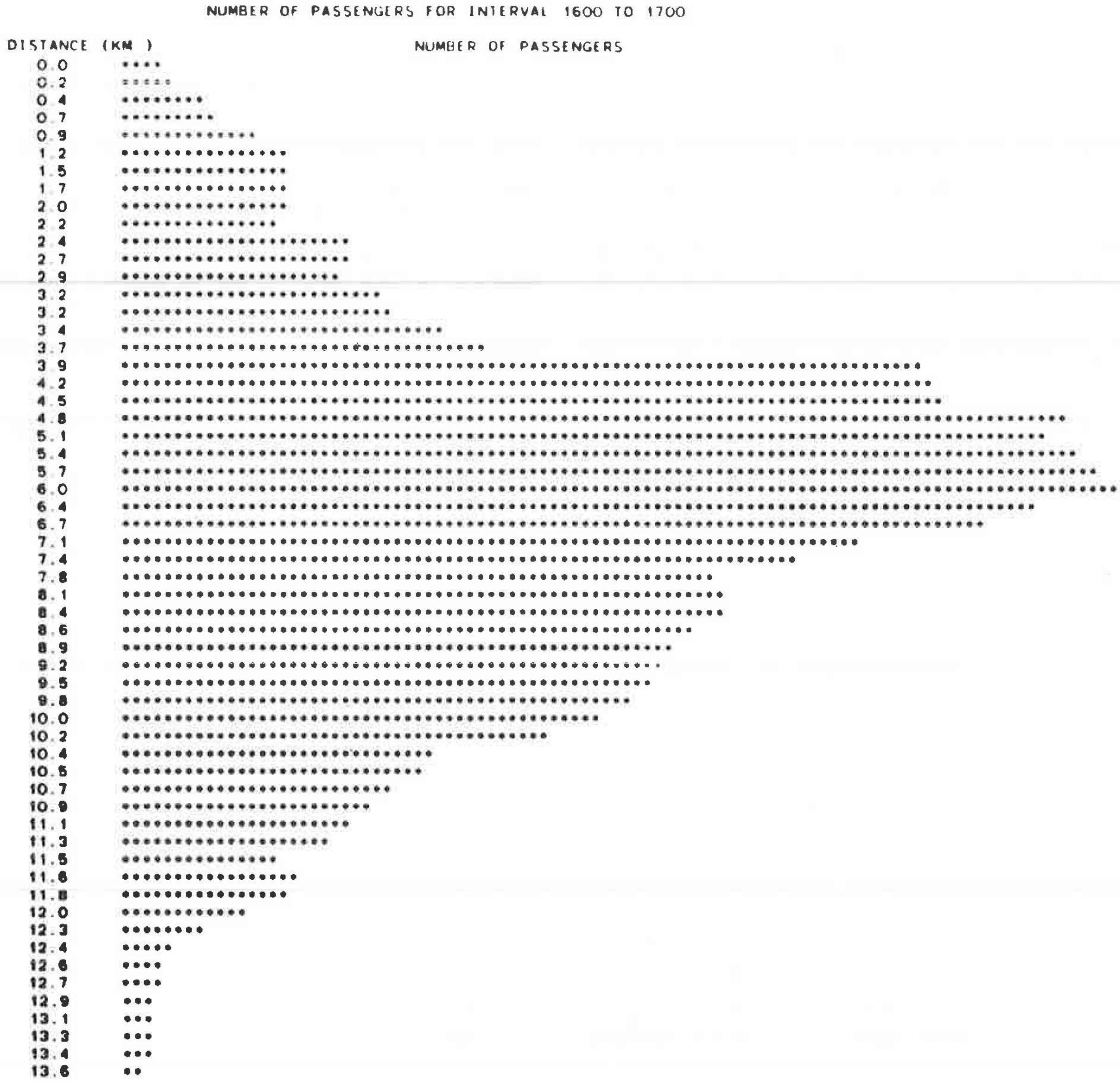

FIGURE 4 Afternoon peak load profile for Line 217 (northbound).

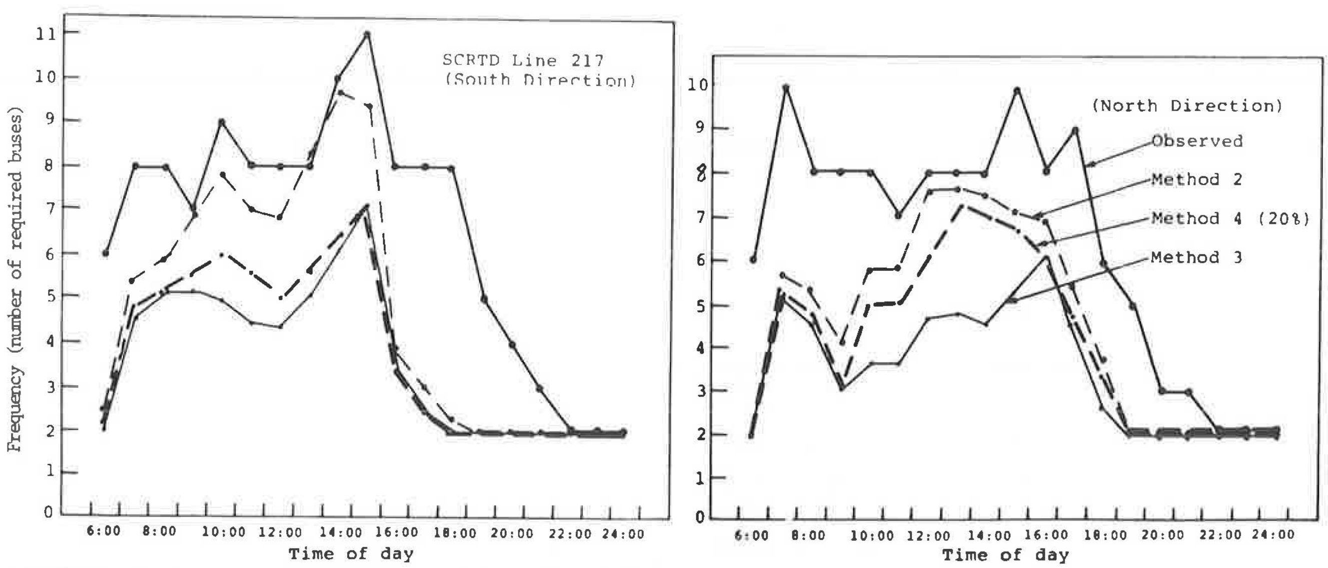

FIGURE 5 Graphic comparison of observed and derived frequencies.

TABLE 3 Frequency and Headway Results for Line 217 (northbound)

TIME INTERVAL		METHOD 1		METHOD 2		METHOD 3		METHOD 4					
								BY 10 %		BY 20 %		BY 30 %	
		NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY	NO. OF BUSES	HEADWAY
06:00	07:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.
07:00	08:00	5.28	11 MIN.	5.72	10 MIN.	5.01	12 MIN.	5.41	11 MIN.	5.11	12 MIN.	5.01	12 MIN.
08:00	09:00	4.65	13 MIN.	5.28	11 MIN.	4.62	13 MIN.	5.02	12 MIN.	4.72	13 MIN.	4.62	13 MIN.
09:00	10:00	4.09	15 MIN.	4.09	15 MIN.	3.07	20 MIN.	3.97	15 MIN.	3.07	20 MIN.	3.07	20 MIN.
10:00	11:00	5.75	10 MIN.	5.82	10 MIN.	3.63	17 MIN.	5.43	11 MIN.	4.93	12 MIN.	3.63	17 MIN.
11:00	12:00	5.83	10 MIN.	5.83	10 MIN.	3.65	16 MIN.	5.25	11 MIN.	5.05	12 MIN.	3.65	16 MIN.
12:00	13:00	6.53	9 MIN.	7.61	8 MIN.	4.76	13 MIN.	6.76	9 MIN.	6.16	10 MIN.	4.76	13 MIN.
13:00	14:00	7.51	8 MIN.	7.69	8 MIN.	4.81	12 MIN.	7.61	8 MIN.	7.21	8 MIN.	5.01	12 MIN
14:00	15:00	7.33	8 MIN.	7.46	8 MIN.	4.66	3 MIN.	7.06	8 MIN.	6.96	9 MIN.	4.66	13 MIN.
15:00	16:00	6.96	9 MIN.	7.11	8 MIN.	5.33	11 MIN.	6.93	9 MIN.	6.73	9 MIN.	5.33	11 MIN.
16:00	17:00	6.87	9 MIN.	6.87	9 MIN.	6.01	10 MIN.	6.31	10 MIN.	6.01	10 MIN.	6.01	10 MIN.
17:00	18:00	5.30	11 MIN.	5.38	11 MIN.	4.71	13 MIN.	5.31	11 MIN.	4.91	12 MIN.	4.71	13 MIN.
18:00	19:00	3.56	17 MIN.	3.66	16 MIN.	2.75	22 MIN.	3.45	17 MIN.	3.25	18 MIN.	2.75	22 MIN.
19:00	20:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN	2.00	30 MIN.	2.00	30 MIN.
20:00	21:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.
21:00	22:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN	2.00	30 MIN	2.00	30 MIN	2.00	30 MIN.
22:00	23:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN	2.00	30 MIN	2.00	30 MIN	2.00	30 MIN.
23:00	24:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN	2.00	30 MIN	2.00	30 MIN	2.00	30 MIN
24:00	25:00	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.	2.00	30 MIN.

TABLE 4 Computer-Generated Timetable of the First 30 Departures for Line 217 at all Time Points and at the Base or Maximum Load (Fairfax/Rosewood) Stop

```
THIS PROGRAM IS BASED ON THE FOLLOWING INPUT
********************************************
TYPE OF HEADWAYS :EQUAL (1)

TYPE OF TIMETABLE:ONE METHOD (1)
METHOD NUMBER:    4    FROM INTERVAL:    1    TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)
                                    TIMETABLE
                                    *********
```

DEP. NUM	ADAMS WASHINGT	FAIRFAX OLYMPIC	FAIRFAX BEVERLY	FAIRFAX ROSEWOOD	FAIRFAX SANTA MO	LA BREA SUNSET	HOLLYWOO VINE	GOWER FRANKLIN	BEACHWOO WESTSH F
1	5.45	5.52	5.59	6.00	6.02	6.07	6.14	6.16	6.21
2	6.15	6.23	6.29	6.30	6.32	6.38	6.44	6.46	6.51
3	6.41	6.51	6.58	7.00	7.03	7.10	7.17	7.19	7.25
4	6.52	7.03	7.10	7.12	7.15	7.22	7.29	7.31	7.37
5	7.04	7.15	7.22	7.24	7.27	7.34	7.41	7.43	7.49
6	7.16	7.27	7.34	7.36	7.39	7.46	7.53	7.55	8.01
7	7.28	7.39	7.46	7.48	7.51	7.57	8.05	8.07	8.13
8	7.40	7.51	7.58	8.00	8.03	8.10	8.17	8.19	8.25
9	7.51	8.02	8.10	8.13	8.16	8.24	8.32	8.34	8.40
10	8.04	8.15	8.23	8.26	8.29	8.37	8.45	8.47	8.53
11	8.18	8.29	8.37	8.39	8.43	8.51	8.59	9.01	9.07
12	8.31	8.42	8.50	8.52	8.56	9.04	9.12	9.14	9.20
13	8.47	8.58	9.06	9.08	9.12	9.20	9.28	9.30	9.36
14	9.06	9.17	9.25	9.27	9.31	9.39	9.47	9.49	9.55
15	9.26	9.37	9.45	9.47	9.51	9.59	10.07	10.09	10.15
16	9.43	9.53	10.02	10.04	10.08	10.16	10.25	10.27	10.33
17	9.55	10.06	10.14	10.16	10.20	10.29	10.37	10.39	10.45
18	10.07	10.18	10.26	10.29	10.32	10.41	10.49	10.52	10.57
19	10.20	10.30	10.39	10.41	10.45	10.53	11.02	11.04	11.10
20	10.32	10.43	10.51	10.54	10.57	11.06	11.14	11.16	11.22
21	10.44	10.54	11.03	11.06	11.09	11.18	11.27	11.29	11.35
22	10.56	11.06	11.15	11.18	11.21	11.30	11.39	11.41	11.47
23	11.09	11.19	11.28	11.30	11.34	11.43	11.52	11.54	12.00
24	11.21	11.31	11.40	11.42	11.46	11.55	12.04	12.06	12.12
25	11.33	11.43	11.52	11.54	11.58	12.07	12.16	12.18	12.24
26	11.44	11.54	12.03	12.05	12.09	12.18	12.27	12.29	12.35
27	11.53	12.03	12.12	12.15	12.18	12.27	12.36	12.38	12.44
28	12.03	12.13	12.22	12.25	12.28	12.37	12.46	12.48	12.54
29	12.13	12.23	12.32	12.34	12.38	12.47	12.56	12.58	13.04
30	12.23	12.33	12.42	12.44	12.48	12.57	13.06	13.08	13.14

TABLE 5 Computer-Generated Timetable of the Whole Day for Line 217 at all Time Points and at the Base or Maximum Load (Fairfax/Rosewood) Stop

THIS PROGRAM IS BASED ON THE FOLLOWING INPUT
****

TYPE OF HEADWAYS : BALANCED (2)

TYPE OF TIMETABLE:ONE METHOD (1)
METHOD NUMBER: 4 FROM INTERVAL: 1 TO INTERVAL: 19

CLOCK HEADWAYS: NO (0)

TIMETABLE
****

DEP. NUM	ADAMS WASHINGT	FAIRFAX OLYMPIC	FAIRFAX BEVERLY	FAIRFAX ROSEWOOD	FAIRFAX SANTA MO	LA BREA SUNSET	HOLLYWOO VINE	GOWER FRANKLIN	BEACHWOO WESTSH F
1	5.45	5.52	5.59	6.00	6.02	6.07	6.14	6.16	6.21
2	6.21	6.29	6.35	6.36	6.38	6.44	6.50	6.52	6.57
3	6.43	6.53	7.00	7.02	7.05	7.12	7.19	7.21	7.27
4	7.01	7.12	7.19	7.21	7.24	7.31	7.38	7.40	7.46
5	7.15	7.26	7.33	7.35	7.38	7.45	7.52	7.54	8.00
6	7.24	7.34	7.42	7.43	7.46	7.53	8.00	8.02	8.08
7	7.32	7.43	7.50	7.52	7.55	8.01	8.09	8.11	8.17
8	7.40	7.51	7.58	8.00	8.03	8.10	8.17	8.19	8.25
9	7.46	7.57	8.05	8.07	8.11	8.19	8.27	8.29	8.35
10	7.56	8.07	8.15	8.17	8.21	8.29	8.37	8.39	8.45
11	8.12	8.23	8.31	8.34	8.37	8.45	8.53	8.55	9.01
12	8.23	8.34	8.42	8.45	8.48	8.56	9.04	9.06	9.12
13	8.43	8.54	9.02	9.04	9.08	9.16	9.24	9.26	9.32
14	8.59	9.10	9.18	9.21	9.24	9.32	9.40	9.42	9.48
15	9.17	9.28	9.36	9.39	9.42	9.50	9.58	10.00	10.06
16	9.42	9.53	10.01	10.03	10.07	10.16	10.24	10.26	10.32
17	9.56	10.07	10.15	10.18	10.21	10.30	10.38	10.41	10.46
18	10.10	10.21	10.29	10.31	10.35	10.44	10.52	10.54	11.00
19	10.20	10.31	10.39	10.42	10.45	10.54	11.02	11.04	11.10
20	10.33	10.43	10.52	10.54	10.58	11.06	11.15	11.17	11.23
21	10.45	10.55	11.04	11.06	11.10	11.19	11.28	11.30	11.36
22	10.54	11.04	11.13	11.16	11.19	11.28	11.37	11.39	11.45
23	11.09	11.19	11.28	11.30	11.34	11.43	11.52	11.54	12.00
24	11.18	11.28	11.37	11.39	11.43	11.52	12.01	12.03	12.09
25	11.32	11.42	11.51	11.53	11.57	12.06	12.15	12.17	12.23
26	11.43	11.53	12.02	12.04	12.08	12.17	12.26	12.28	12.34
27	11.51	12.01	12.10	12.12	12.16	12.25	12.34	12.36	12.42
28	12.02	12.12	12.21	12.24	12.27	12.36	12.45	12.47	12.53
29	12.12	12.22	12.31	12.34	12.37	12.46	12.55	12.57	13.03
30	12.19	12.29	12.38	12.40	12.44	12.53	13.02	13.04	13.10
31	12.29	12.39	12.48	12.50	12.54	13.03	13.12	13.14	13.20
32	12.41	12.51	13.00	13.02	13.06	13.15	13.24	13.26	13.32
33	12.45	12.55	13.04	13.07	13.10	13.19	13.28	13.30	13.36
34	12.53	13.03	13.12	13.15	13.18	13.27	13.36	13.38	13.44
35	13.03	13.13	13.22	13.24	13.28	13.37	13.46	13.48	13.54
36	13.12	13.22	13.31	13.33	13.37	13.46	13.55	13.57	14.03
37	13.24	13.34	13.43	13.46	13.49	13.58	14.07	14.09	14.15
38	13.32	13.42	13.51	13.54	13.57	14.06	14.15	14.17	14.23
39	13.39	13.50	13.59	14.02	14.06	14.15	14.25	14.28	14.33
40	13.45	13.56	14.05	14.08	14.12	14.21	14.31	14.33	14.39
41	13.53	14.04	14.13	14.16	14.20	14.29	14.39	14.42	14.47
42	14.07	14.17	14.27	14.29	14.33	14.42	14.52	14.55	15.01
43	14.14	14.24	14.34	14.36	14.40	14.49	14.59	15.02	15.08
44	14.25	14.35	14.45	14.47	14.51	15.00	15.10	15.13	15.19
45	14.32	14.43	14.52	14.55	14.59	15.08	15.18	15.21	15.27
46	14.41	14.52	15.01	15.04	15.08	15.17	15.27	15.30	15.36
47	14.53	15.04	15.13	15.15	15.20	15.29	15.39	15.42	15.48
48	14.57	15.08	15.17	15.20	15.24	15.33	15.43	15.46	15.52
49	15.08	15.19	15.28	15.31	15.35	15.44	15.54	15.57	16.03
50	15.14	15.25	15.34	15.37	15.41	15.50	16.00	16.03	16.09
51	15.24	15.35	15.44	15.46	15.51	16.00	16.10	16.13	16.19
52	15.36	15.47	15.56	15.58	16.03	16.12	16.22	16.25	16.31
53	15.45	15.56	16.05	16.08	16.12	16.21	16.31	16.34	16.40
54	15.58	16.09	16.18	16.21	16.25	16.34	16.44	16.47	16.53
55	16.08	16.19	16.28	16.31	16.35	16.44	16.54	16.57	17.03
56	16.20	16.31	16.40	16.42	16.47	16.56	17.06	17.09	17.15
57	16.26	16.37	16.46	16.49	16.53	17.02	17.12	17.15	17.21
58	16.37	16.48	16.57	17.00	17.04	17.13	17.23	17.26	17.32
59	16.47	16.58	17.08	17.10	17.14	17.23	17.33	17.37	17.42
60	16.58	17.09	17.18	17.21	17.25	17.34	17.44	17.47	17.53
61	17.10	17.21	17.30	17.33	17.37	17.46	17.56	17.59	18.05
62	17.29	17.40	17.49	17.52	17.56	18.05	18.15	18.18	18.24
63	17.41	17.52	18.00	18.03	18.07	18.15	18.26	18.28	18.35
64	17.56	18.07	18.15	18.18	18.22	18.31	18.41	18.43	18.50
65	18.15	18.26	18.34	18.37	18.41	18.49	19.00	19.02	19.09
66	18.35	18.46	18.54	18.56	19.01	19.09	19.20	19.21	19.29
67	19.09	19.18	19.26	19.28	19.30	19.38	19.47	19.49	19.55
68	19.39	19.48	19.55	19.57	20.00	20.08	20.17	20.19	20.25
69	20.04	20.12	20.19	20.21	20.23	20.31	20.39	20.41	20.47
70	20.41	20.49	20.56	20.58	21.00	21.08	21.16	21.18	21.24
71	21.10	21.18	21.25	21.27	21.29	21.37	21.45	21.47	21.53
72	21.42	21.50	21.57	21.58	22.01	22.09	22.17	22.19	22.25
73	22.11	22.19	22.26	22.27	22.30	22.37	22.46	22.48	22.54
74	22.42	22.50	22.57	22.59	23.01	23.09	23.17	23.19	23.25
75	23.00	23.08	23.15	23.16	23.19	23.27	23.35	23.37	23.43
76	23.43	23.51	23.58	23.59	0.02	0.10	0.18	0.20	0.26
77	0.55	0.03	0.10	0.12	0.14	0.22	0.30	0.32	0.38
78	0.43	0.51	0.58	1.00	1.02	1.10	1.18	1.20	1.26

in Figure 5 for both directions of Line 217. It can be easily seen that the provided frequencies in both directions represent an excessive number of bus runs. The desired occupancy for each time period appears in Table 1 in the fourth row and was set forth by SCRTD schedulers. The use of these load factors and either Method 2 or Method 4 can result in significant resource savings. It is interesting to note that Method 4 results in much lower frequency than Method 2, particularly in the southbound direction. The absolute minimum frequency to accommodate the passenger load while neglecting the load factors is presented by Method 3, and in most hours is half the presently provided frequency.

Alternative Timetables (Program 2) for SCRTD Line 217

The PL/1 Program 2, which is based on the procedures described in Ceder (6), is used for the SCRTD Line 217 to construct alternative timetables.

Eighteen different combinations of runs have been selected for each direction of travel. Tables 4 and 5 are computer-generated timetables for the northbound direction. Table 4 (for equal headway) gives only the first 30 departures, and Table 5 presents the whole day's timetable. Nonetheless, it is possible to examine the differences between the equal and the balanced headway timetables.

Several observations can be made on the basis of results presented elsewhere (6). The results of Method 4 indicate significant resource saving in comparison with the results of Method 2, particularly in the southbound direction. This can also be seen in Figure 5. The combinations of methods used indicate that the use of Method 4 during peak periods only does not result in significant saving in comparison with Method 2 results. Consequently, Method 4 may be particularly useful during off-peak hours. For the southbound direction, the clock headway timetable using Method 2 results in the same number of departures and fleet size measure as Method 2 without clock headway. This may provide an opportunity to introduce the clock headway timetable at the main (daily maximum load) Fairfax/Beverly stop. It is worth mentioning that the clock headway pattern is not maintained along the entire route because of different running times between time points.

Certainly, the large number and variety of timetables may complicate the decision-making process for schedulers. However, it provides an opportunity to examine rapidly different timetable and frequency scenarios. It is anticipated, however, that the skilled scheduler, while recognizing the full potential of the procedures, will select only a few alternatives to compare.

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