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Contents

A Geodemographic Model for Bus Service Planning and Marketing

DAVID T. HUNT, STEPHEN E. STILL, J. DOUGLAS CARROLL, and ALAN O. KRUSE

ABSTRACT

A trip prediction model is developed that uses a combination of geographic, demographic, and transit service data to estimate bus ridership in northern New Jersey. When this model is combined with interactive computer graphics hardware, it becomes a powerful analytical tool for transit planning and marketing. First, a description is provided of the data bases used in the model and how they were integrated into a common file. Second, the model is described and its development is discussed. Finally, the model is used to predict potential ridership for a sample bus route in Newark, New Jersey. Potential ridership is predicted from both current demographic and service patterns, and from possible future patterns.

Most bus companies have a service region within which the location of residences and businesses continually changes; therefore, the location of potential riders also shifts. It is difficult to keep track of these shifts in larger urban regions and to be able to relate them to existing services. Without accurate data, the picture that planners or marketers have of the location and composition of their companies' service regions will be incomplete.

A description is provided in this paper of a system that uses census geography, interactive computer graphics, and statistics to provide a model or data base that can be acquired at a low cost, updated as new information becomes available and, with a little effort, related to existing service patterns. This data base will allow planners, marketers, schedulers, and managers to have access to a uniform set of data on their service regions.

This project was accomplished in New Jersey, in cooperation with the owner and manager of most of the bus services in the state, New Jersey Transit. The test region selected was Essex County in northern New Jersey, which has a population of 838,000 residents and 356,000 workers, and includes the city of Newark, Newark Airport, and many surrounding suburbs. Other counties will later be examined to verify the findings of this paper.

The following four basic data sets were integrated into a working system that was used to evaluate existing routes, explore the need for new route locations or frequency changes, and target potential markets:

- A digitized, computer-readable map of the boundaries of census tracts using a latitude and longitude coordinate system. Such maps can be purchased for most tracted regions of the United States.
- Census statistics that provide detailed descriptions of the households and residents in each tract.
- Census statistics that describe the workers in each tract. Tables of these characteristics are available for most urban regions from the Bureau of the Census to states and metropolitan planning organizations that ordered the Urban Transportation Planning Package (UTPP).
- A computerized map of each bus (street car, subway, or railroad) route that provides regular service in the region of interest. These service lines are digitized in the same coordinate system as the census tract maps.

The first objective of this project is to describe the service region in terms of potential users of transit service. The transit potentials of each tract can be established by using the data on the number and characteristics of its residents. It is then possible to estimate the potential number of transit users who will start a trip from their home tract based on the number and density of residents together with data on their income, car ownership, race, and other demographic characteristics. Then, by using the data on workers, in part as a proxy, it is possible to estimate the number of potential riders that will use transit to return to their homes (from nonresidential origins). The combination of these two items of information will provide an accurate description of the distribution of potential users.

Whether these potential riders actually climb aboard and pay a fare depends on whether or not transit service is available to them. The likelihood of use is also a function of the frequency and reliability of transit service. A description is provided of a technique that allows analysts to allocate service to tracts or, conversely, to assign potential riders from tracts or parts of tracts to routes.

A description is provided in the following sections of how each of these steps was accomplished in the study of the test county, and of the results and findings of the study. More work is needed to fine-tune ridership estimating formulas, and also to account more accurately for the effects of competitive bus service routes, as well as rail or rapid transit routes. Nevertheless, the results of the study are promising and worthy of further testing against actual usage data such as on-off counts or fare collections by route.

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DEVELOPMENT OF A GEODEMOGRAPHIC DATA BASE

Four separate data bases, containing geographic, transit service, residential, and worker information, are to be integrated into a common file that will be used in the development of the model.

Geographic Data

The geographic data base, or file, contains latitude and longitude coordinates that define census tract boundaries and standard Federal Information Processing Standards location codes that identify the regions (1). Each tract forms a separate closed polygon that allows for area calculations (used to find residential and worker densities) and the calculation of tract centroids. This file also allows for interactive computer graphic displays of the data for analysis and presentation purposes (see Figure 1). The census tract coordinate file is primarily used to calculate the transit service measure of coverage. It is possible to calculate where a route enters and exits a track by combining the tract file with a digitized bus network file. An allowance of a quarter of a mile walking distance to and from each route enables construction of service regions for the routes. From these service regions it is possible to determine the percentage of each census tract that receives bus service (i.e., that is within walking distance of a bus route). The construction of service regions is described in more detail in the following section.

Transit Service Data

The transit service data base for the geodemographic model comprises the previously mentioned digitized network of bus routes and the frequencies (headways) along each route. The bus network was entered into the computer from a series of maps supplied by New Jersey Transit. All major nodes (time check points, key intersections, transfer points, etc.) plus nodes necessary to keep the route geographically correct were assigned latitude and longitude coordinates. Links were constructed between the nodes to form bus routes and then such values as frequency and distance were assigned to the links (see Figure 2).

New Jersey Transit supplied the frequencies for each bus route by census tract. This level of detail was necessary because routes can exhibit different frequencies over the different patterns that compose a single route. In addition, a bus can operate in a closed-door manner (i.e., no passengers on or off) over a portion of its route, in which case the frequency for that portion of the route is effectively zero.

Residential Data

Two main sources of residential data from the 1980 census can be used interchangeably in this model. The source selected was the 1980 UTPP (2), which is a special tabulation of 1980 census data specifically organized for transportation planning purposes. It contains demographic information such as population, automobile ownership, income, race, ethnic origin, age, sex, mode of travel to work for each worker, and travel times to work. These data are available by place of residence and place of work.

The second source is the actual 1980 census data, specifically Summary Tape File 3A (3). Although this file provides a more detailed set of residential data, it lacks information about the place of work. It was therefore decided to extract both residential

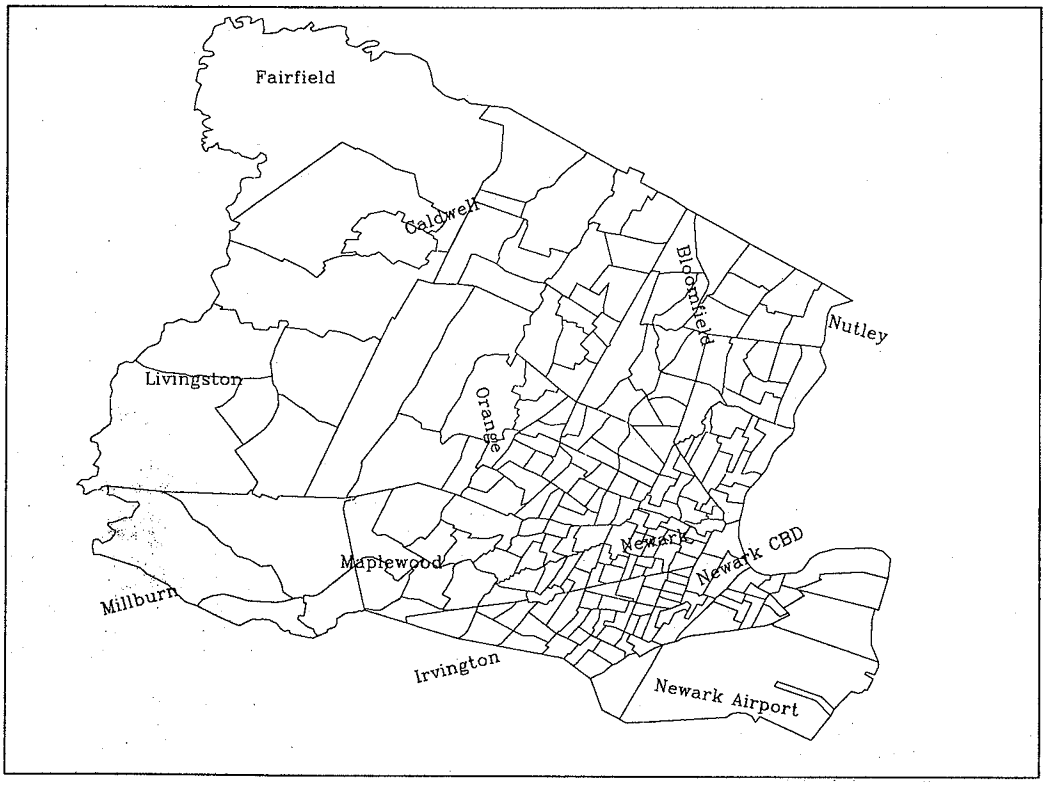

FIGURE 1 Essex County census tracts.

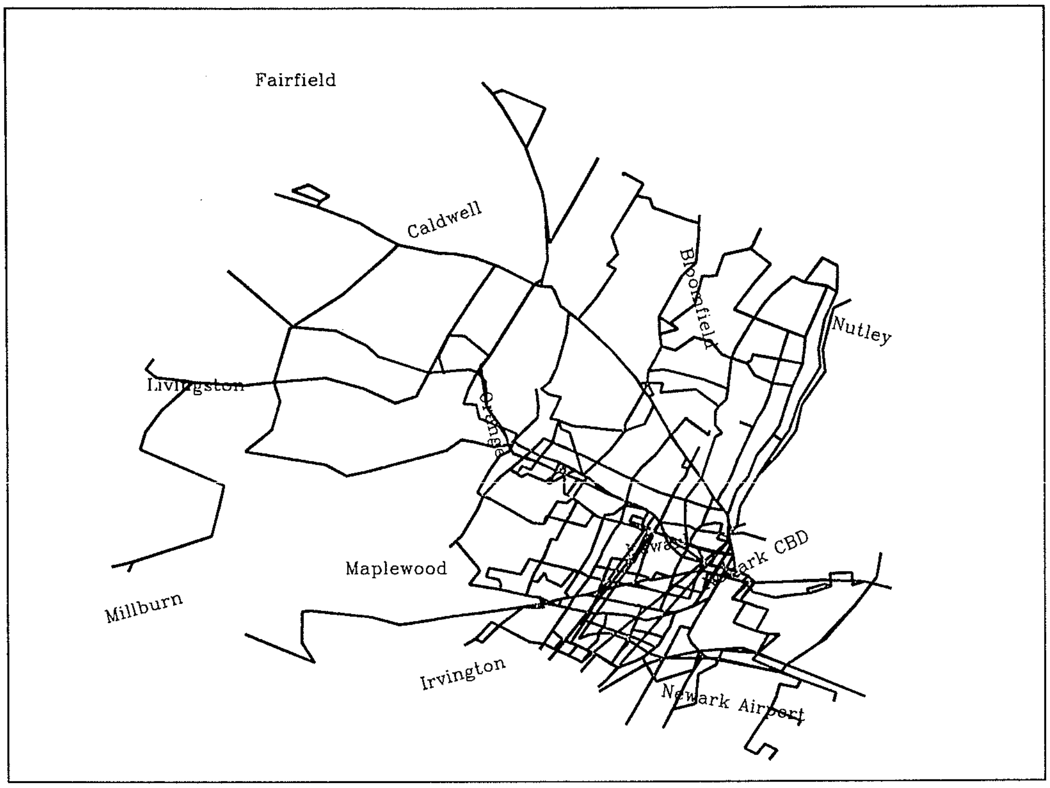

FIGURE 2 Essex County bus routes.

and worker data from the UTPP (or journey-to-work files).

A combination of residential and geographic data is shown in Figures 3 and 4. The percentage of households without automobiles for each tract of residence is shown in Figure 3. As was expected, tracts near the Newark central business district (CBD) have the highest percentage of households without automobiles. Figure 4 shows residential population density. The region of highest density surrounds the Newark CBD. Both of these data groups (households without automobiles and high-density residential patterns) are known to be associated with greater use of buses.

Worker Data

The source of demographic data by place of work is the 1980 UTPP for New Jersey. As with the residential file, the most important characteristics for determining the potential number of transit trips are workplace density, family automobile availability, and minority characteristics. Density by place of work (workers per square mile) is shown in Figure 5. Few dense tracts dominate the heart of the Newark CBD and relatively few significant tracts are outside of the CBD.

One problem with the UTPP files is that they contain only work trips, which constitute on average less than half of all bus trips. Therefore, the 1977 Nationwide Personal Transportation Study (NPTS) was used to observe non-work-based trips (4). The NPTS file is a survey of 13,000 households across the nation that determines travel patterns for all trip purposes. A similar 1983 file is being prepared but was not available at the time of this study.

By noting the ratio of weekday nonwork trips to weekday work trips in the 1977 study, a factor of 1.5 was obtained to estimate total bus ridership in this model. This factor is equivalent to three nonwork bus trips for every two bus work trips. It is possible to use this factor to estimate total bus riders in each tract as a function of work trips.

INTEGRATION OF TRANSIT SERVICE AND GEODEMOGRAPHIC DATA

Once the geographic, demographic, and transit service data bases are assembled, they must be combined into a common file to be analyzed. Combining the geographic and demographic data bases into one file is a straightforward task because they are both coded at the census tract level. It is therefore easy to identify and display census tracts that contain a high density of residents or workers, a high minority population, low automobile availability, or any other factors associated with the use of transit (Figures 3-5). It is more difficult to allocate transit service to each census tract and, conversely, to apportion demographic data to transit routes because transit services were not naturally coded to census tracts.

Assigning Transit Service to Census Tracts

As mentioned earlier, a methodology for constructing service regions around a bus route and calculating the percentage of each tract receiving bus service was developed (5) that consisted of

- Preparing maps of transit routes at the same scale as census tract maps;
- Constructing service regions for each route;
- Determining which tracts are served by a given route;

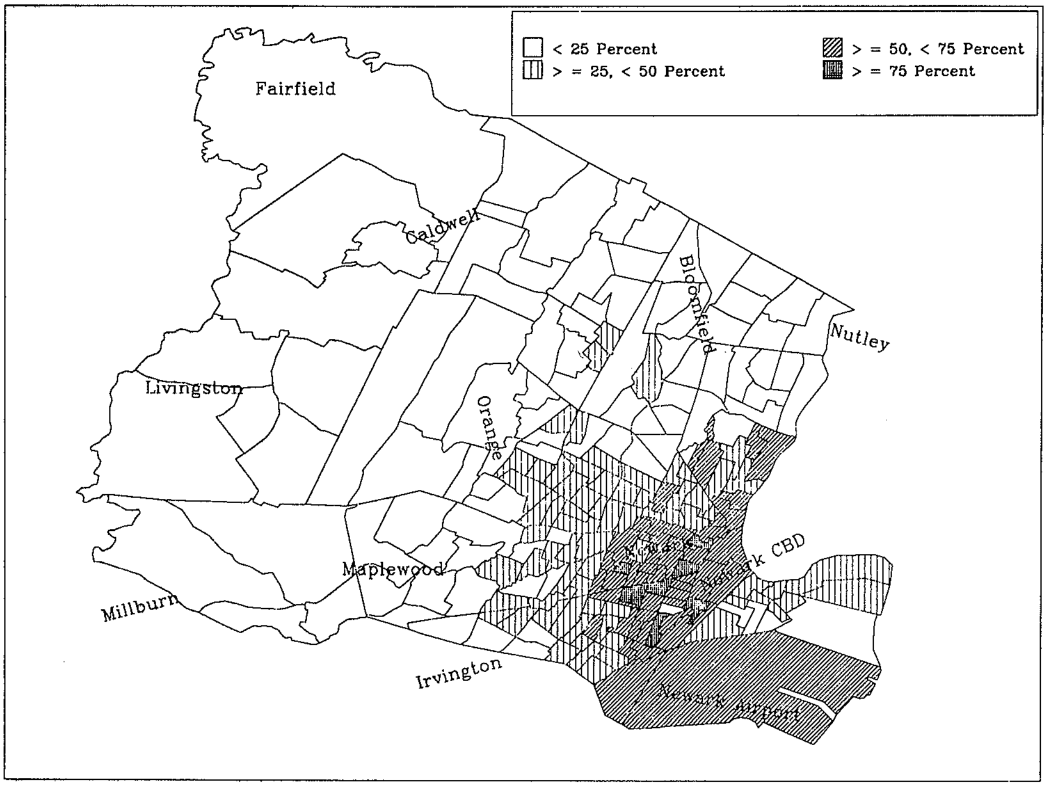

FIGURE 3 Percent of households without automobiles.

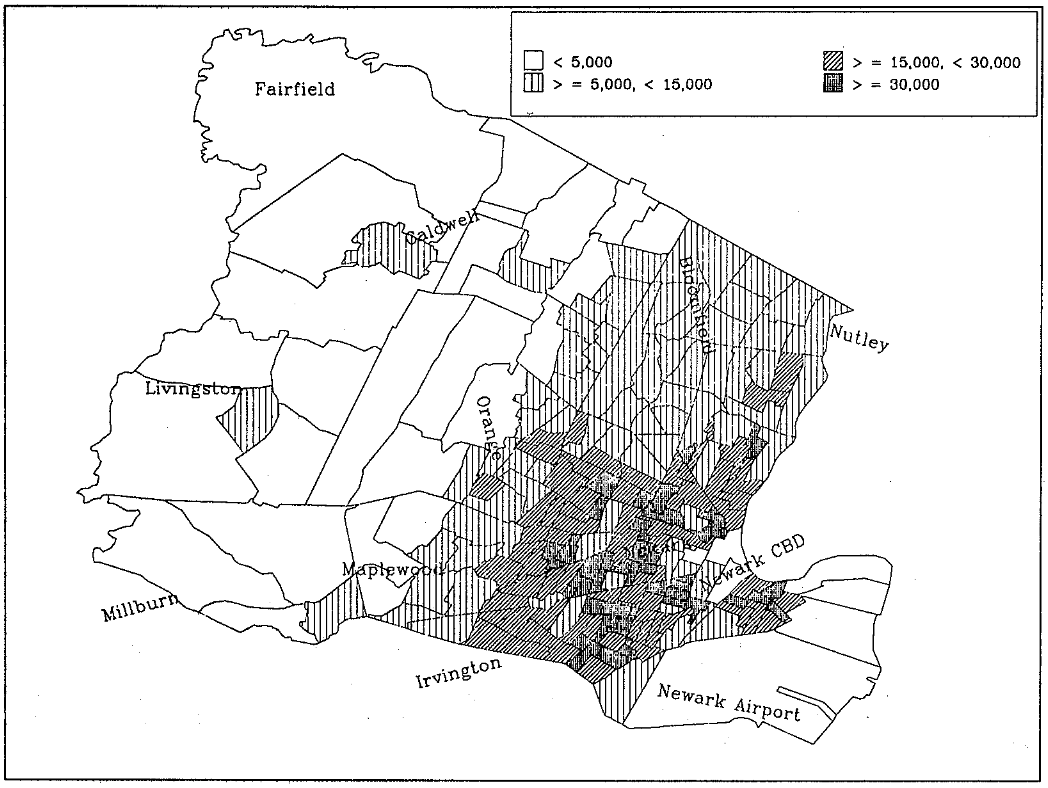

FIGURE 4 Residential density.

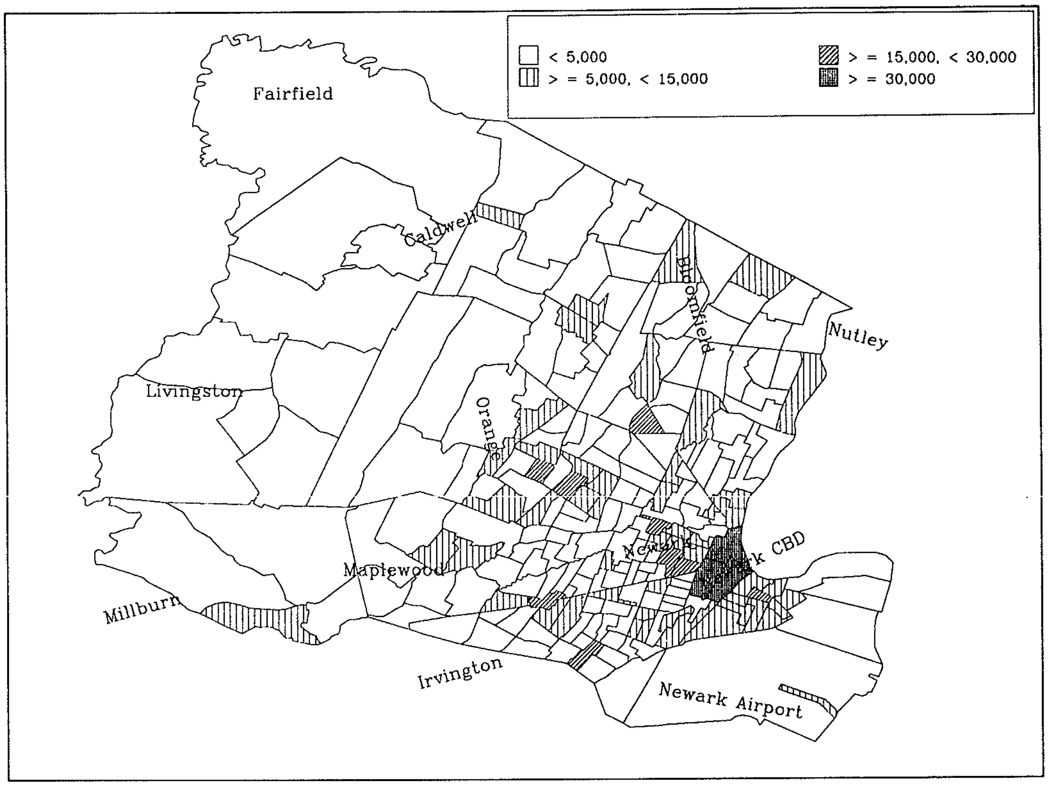

FIGURE 5 Worker density.

- Recording the service characteristics of each route; and
- Summing the total service provided to each census tract or apportioning the travelers from census tracts to each route.

The service region of a bus route is defined as the region that falls within an acceptable walking distance of the route. For the purposes of this study, a distance of a quarter of a mile on either side of the bus route was selected (6). A computer algorithm was then used to construct two parallel lines around each route, which effectively created a one-half-mile ribbon around the route (see Figure 6).

Once the service region for a route was defined, the tracts receiving service had to be identified. This involved finding all tracts whose boundary was pierced by the ribbon of any given route. Thus, the bus itself did not have to enter the tract to provide service; only its ribbon (i.e., service region) had to cross the boundary.

The percentage of coverage provided to a census tract is found by using the following equation:

$$\mathrm{cov}_i = \sum_{k=1}^{n} \left(r_{ik} \not\subset R_{i(k-1)} \right) / A_i \qquad (1)$$

where

$R_{i0} = \phi$,
cov_i = proportion of tract_i within walking distance of a bus route,
r_{ik} = service region around route_k in tract_i,
R_{ik} = union of the service regions for the set of routes in tract_i, and
A_i = total area of tract_i.

Equation 1 simply states that the percentage of coverage provided to a tract equals the sum of the service region around each route, minus overlapping regions, divided by the total area of the tract. The coverage of New Jersey Transit's bus routes in Essex County is shown in Figure 7.

A measure of frequency is also assigned together with the coverage of transit service in each tract. As with coverage, any tract whose boundary is pierced by the service region of a route is considered to be served by that route. Thus, the total frequency of service provided to a tract is found by using the following equation:

$$\mathrm{freq}_i = \sum_{k=1}^{n} H_{ik} \qquad (2)$$

where freq_i is the total frequency of service in tract_i and H_{ik} is the number of buses per day on route_k in tract_i.

Because service patterns can vary along a route throughout the day, a single value for frequency per route cannot be applied to the entire route. Frequencies were therefore recorded for each route at the census tract level.

Assigning Demographic Properties to Transit Routes

Demographic properties can be assigned to a route by using the service region for that route. Basically, the section of route_k passing through tract_i is assigned the demographic characteristics of tract_i equal to the percentage of tract_i served by route_k.

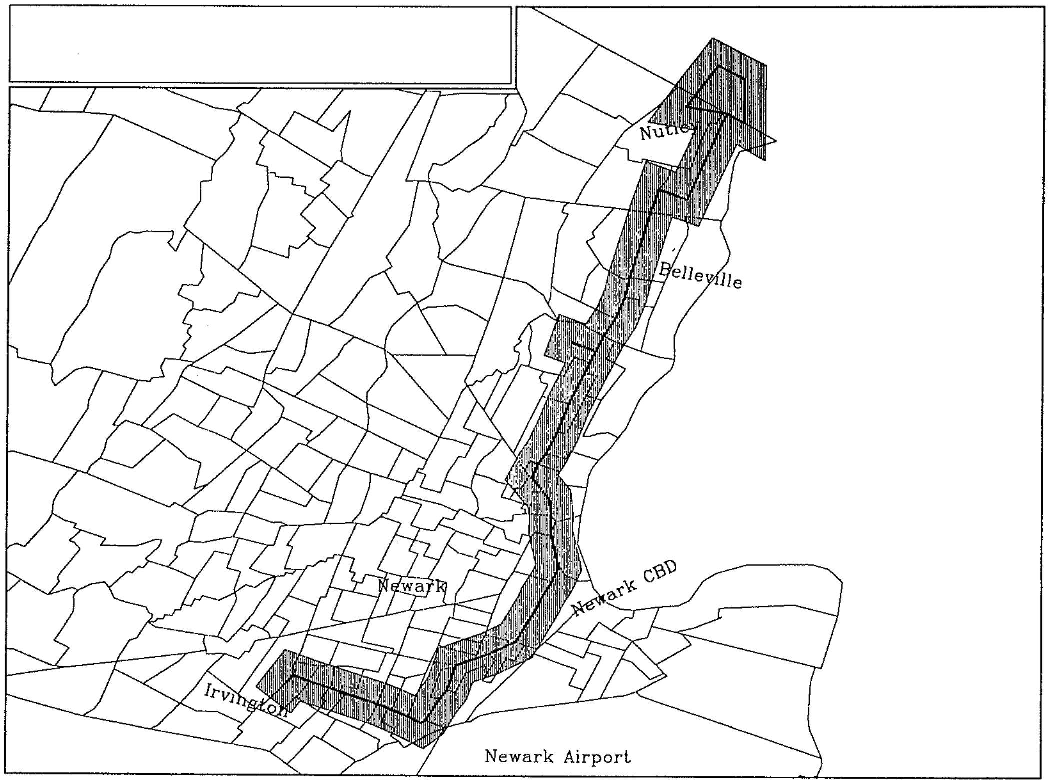

FIGURE 6 One-quarter-mile service area for Route 27.

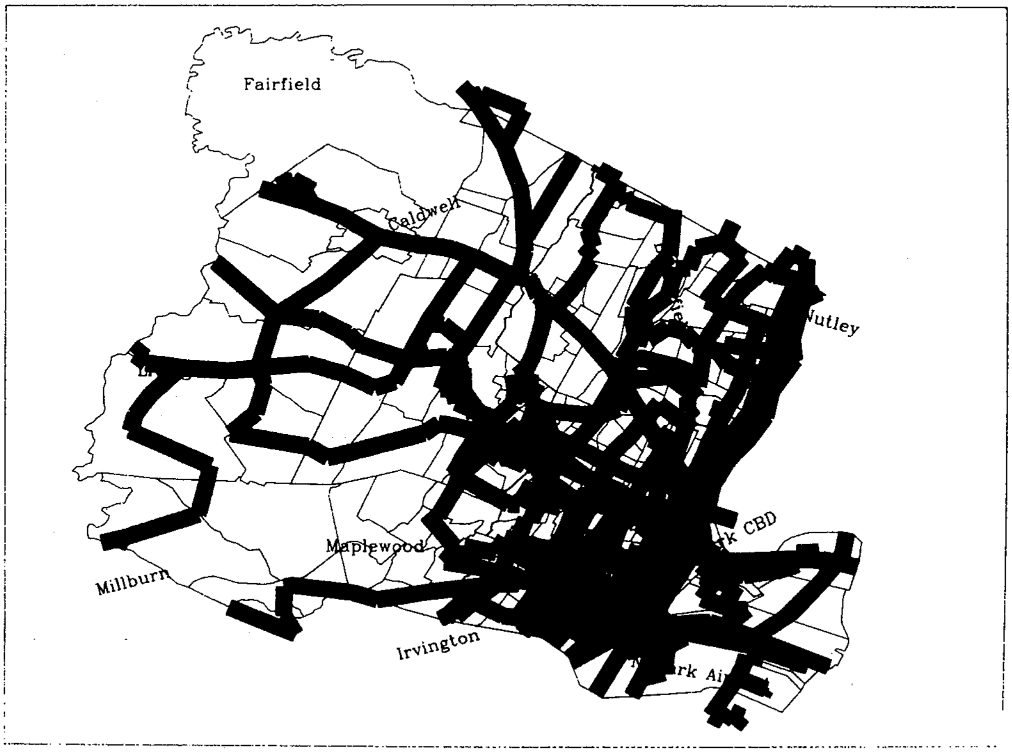

FIGURE 7 Bus coverage for Essex County.

For example, if route A's service region covers 50 percent of tract 1, which has a population of 10,000, then a population of 5,000 is assigned to the section of route A that serves tract 1.

The main assumption in this method is that demographic properties are homogeneously distributed across a tract. This assumption works well for residential data because households are typically distributed uniformly throughout tracts. The assumption does not work as well when worker data are used because work places are often highly concentrated in parts of tracts. Moreover, census tracts were designed to have roughly equal residential populations, whereas worker populations are usually distributed with large concentrations in a few regions, such as CBDs or industrial zones.

A BUS PATRONAGE ESTIMATION MODEL

A model for predicting bus patronage is an essential planning and marketing tool. Although it is desirable to have detailed information on current ridership, decision makers must also have accurate estimates of projected ridership. Such estimates may be demanded, for instance, in the face of changing demographic patterns or in anticipation of proposed shifts in service patterns or levels of service.

A model of bus ridership is developed in this section that is sensitive to a variety of important factors, including transit service frequency and coverage, and key characteristics of the population, including density and automobile ownership. The model uses readily available data and can therefore be applied to a wide range of municipalities and operating authorities.

Approach to Model Development

The primary level of analysis for this research is the census tract. The objective, therefore, is to estimate ridership at the tract level, from which route-specific ridership profiles can then be generated.

The variety of trip-making activities was condensed into the following three major categories for a given census tract:

- Work trips of residents in the tract,
- Work trips of employees in the tract, and
- Nonwork trips of residents or employees in the tract.

The first of these categories, total work trips of residents in tract i, is expressed by the following equation:

$$R_i = p_i \, r_i \tag{3}$$

where

R_i = work trips by bus from residents of tract_i,
p_i = proportion of workers resident in tract_i using bus as mode of travel to work, and
r_i = workers resident in tract_i.

The total number of resident workers, r, is available from the census demographic data. The proportion of workers using a bus, p, is a function of the form:

$$p_i = p(s_i, f_i) \tag{4}$$

where s_i is the socioeconomic characteristics of tract_i and f_i is the characteristics of bus service in tract_i.

The census data provide a variety of tract-level socioeconomic data, including automobile ownership, income, race, age, and occupation. With the addition of geographic data, other important variables such as population density can be computed. The major characteristics of bus service, including frequency and route coverage, are generally available from published schedules. With this wealth of information, the function expressed in Equation 4 can be estimated with the standard statistical technique of linear regression.

The second category, work trips by bus of employees in the tract, is expressed by the following equation:

$$W_i = q_i \, w_i \tag{5}$$

where

W_i = work trips by bus of employees in tract_i,
q_i = proportion of workers employed in tract_i using bus as mode of travel to work, and
w_i = workers employed in tract_i.

The census data provide the employment levels, w, for each tract. As was done in Equation 4, the proportion of workers using a bus, q, can be estimated in the form:

$$q_i = q(s_i, f_i) \tag{6}$$

Information on employee income, race, age, automobile ownership, and occupation is available from the census data. Worker density (employees per square mile) can be computed from geographic data. Bus service by tract is expressed by total frequency and coverage. Total work trips by bus for tract_i is then expressed as the following sum:

$$T_i = R_i + W_i \tag{7}$$

where T_i is the total work trips by bus for tract_i.

Nonwork trip characteristics--the third category--are not explicitly provided in the census data. Although nonwork trip data may be available to some analysts in their particular area of study, that was not the case in this analysis. Accordingly, aggregate nationwide data from the 1977 NPTS was used to estimate nonwork ridership. It was postulated that nonwork trips are subject to the same influences of socioeconomic and service characteristics as work trips. Accordingly, nonwork trips can be expressed in proportion to work trips for each tract as follows:

$$N_i = T_i \, \bar{x} \tag{8}$$

where N_i is nonwork trips by bus for tract_i and $\bar{x}$ is proportion of nonwork trips to work trips.

The total number of trips for tract_i is then expressed as the following sum:

$$M_i = T_i + N_i \tag{9}$$

As will be shown, route ridership profiles can then be constructed from the total trips, as expressed earlier.

Work Trip Model Calibration

Specific forms of the work trip mode split functions (Equations 4 and 6) were adopted after considerable analysis of all available data. For example, this analysis included least-squares regression of the percentage of bus ridership versus corresponding socioeconomic and service variables. The major objectives were (a) to identify the appropriate functional form whether or not it was linear in its parameters, and (b) to isolate the important independent variables that best explain the proportion of bus use by tract.

The wealth of available data provided a great variety of possible explanatory variables to include in the model. Variables that were tested in one functional form or another included the following:

- Socioeconomic variables
  - Proportion of households with no automobiles available,
  - Median and average income,
  - Median and average age,
  - Proportion of the population under 18,
  - Proportion of the population over 60,
  - Proportion of female workers, and
  - Proportion of white population.
- Service variable
  - Percent of tract within service region of routes (one-quarter-mile ribbons), and
  - Frequency combined for all buses in tract.
- Synthesized variables
  - Population density (residents per square mile), and
  - Worker density (employees per square mile).

The conclusions of this analysis are provided in the following paragraphs. In general, it was found that model forms that were linear in their parameters had the highest levels of statistical performance.

For the resident work trip model, the following functional form was employed:

$$p_i{}^{.5} = a_1 + b_1\ \text{popden}_i + b_2\ \text{white}_i + b_3\ \text{zerocar}_i + b_4\ \text{cov}_i{}^{.5}\ \text{freq}_i{}^{.5} \qquad (10)$$

where

popden = population density (thousand residents per square mile),
white = proportion of white population resident in tract,
zerocar = proportion of households with no automobiles available,
cov = percentage of tract area included in one-quarter-mile ribbons around bus routes, and
freq = combined frequencies of bus routes in tract.

Calibration results of the model are summarized in Table 1. The overall level of fit for the model was very high ($R^2 = .84$) and was generally much better than expected for aggregate mode split models. The proportion of households with no automobiles was a highly significant variable, as was the proportion of whites in the population. All remaining variables including those relating to service were significant at the 95 percent confidence level. (Significance is indicated by the value of the t-statistic noted in Table 1. As a rule of thumb, values greater than 2 are highly significant for samples of this size.)

The fractional exponents were applied to p, cov, and freq after careful analysis of the model residuals (predicted minus observed values). The exponents tend to account for the diminishing returns of additional service applied to a given tract.

TABLE 1 Patronage Model Calibration Results

Independent Variable	Coefficient	t-Statistic[a]
Resident Model[b]		
Constant	.3052	16.69
Popden	.0010	3.38
White	−.1261	−7.66
Zerocar	.2993	8.15
$\text{Cov}^{.5}\ \text{freq}^{.5}$	.0010	3.10
Worker Model[c]		
Constant	.0847	3.96
Wrkden	.0010	2.04
White	−.0790	−3.23
Zerocar	.3741	5.92
Freq	.0007	2.07

Note: Results based on observations of 216 tracts.

[a] Significant at the 95 percent confidence level.

[b] Dependent variable is $p^{.5}$; $R^2 = .84$.

[c] Dependent variable is q; $R^2 = .41$.

A similar functional form was adopted for the prediction of work trips to employment centers in each tract:

$$q_i = a_1 + b_1\ \text{wrkden}_i + b_2\ \text{white}_i + b_3\ \text{zerocar}_i + b_4\ \text{freq}_i \qquad (11)$$

where

wrkden = employment density (thousand employees per square mile),
white = proportion of work force that is white,
zerocar = proportion of households in work force with no automobile available, and
freq = combined frequencies of bus routes in tract.

The calibration of this model was less successful than with the resident counterpart (see Table 1). This is due to some degree to the concentration of employment opportunities in discrete centers. Accordingly, variables such as coverage become less important than they were in the resident case. Still, all important variables such as automobile ownership were found to be significant at a high statistical confidence level.

Nonwork Trip Estimation

Using national averages, the number of nonwork trips was estimated in proportion to the total number of work trips. Using NPTS data, this proportion was calculated to be 1.50. Accordingly, from Equation 8, the nonwork trips, N, for tract$_i$ are expressed as a multiple of work trips, T, as follows:

$$N_i = T_i\ 1.50$$

The proportion of nonwork trips was calculated for all bus trips less than 25 mi in distance. The NPTS does not have a wealth of data for large metropolitan regions. Therefore, the nonwork trip proportion may not be representative for this area of study.

Use of the Ridership Model in Prediction

The prediction of total bus ridership in a given tract is straightforward given the following:

- Relationships provided in Equations 3 through 11;
- Settings of independent variables in Equations 10 and 11; and
- Estimated coefficients shown in Table 1.

For example, the change in total tract bus trips can be calculated given changes in improved frequencies or coverage. Alternatively, the long-range effect of shifting demographics including population density and automobile ownership can be estimated. Therefore, the model becomes an important tool for operations planning, long-range planning, and marketing programs.

The model was used to replicate base-level (1980) ridership patterns to test its predictive ability. In Figure 8 a comparison is made between actual and predicted bus ridership percentages for the residential model. As is shown, the model performs well in replicating differences in ridership trends among tracts. Its value as a predictive tool has therefore been demonstrated.

Predicted tract-level ridership at average settings of the independent variables is shown in Table 2. For the region studied, the average population density is 18,260 residents per square mile, and the average percentage of households with no cars is 32.1. Therefore, for a tract with average characteristics, 15.3 percent of the residents in the tract and 8.6 percent of the employees working in the tract are expected to take the bus to work.

It is useful to understand the sensitivity of the model to changes in the independent variables. The response in tract ridership from a 10 percent increase in the independent variables is shown in Table 3. Each variable is tested independently to measure its effect on bus ridership.

In both the resident and worker models, the proportion of households with no automobiles (zerocar) and the proportion of white residents (white) appear to have the greatest impact on bus ridership. Note for example that a tract with an incidence of households with no automobiles that is 10 percent above the average is likely to have a bus ridership that is 5 percent above the average. Another interpretation for use in forecasting is that a 10 percent

TABLE 2 Model Predictions for the Average Tract

Independent Variable	(1) Average Tract Value	(2) Regression Coefficient	(1) x (2)
Resident Model[a]			
Intercept	n/a	(a_1) .3052	.3052
Popden	18.260	(b_1) .0010	.0183
White	.524	(b_2) −.1261	−.0661
Zerocar	.321	(b_3) .2993	.0961
Cov$^{.5}$ freq$^{.5}$	38.152	(b_4) .0010	.0381
Worker Model[b]			
Intercept	n/a	(a_1) .0847	.0847
Wrkden	5.401	(b_1) .0010	.0054
White	.685	(b_2) −.0790	−.0541
Zerocar	.101	(b_3) .3741	.0377
Freq	17.5	(b_4) .0007	.0125

Note: n/a = not applicable.

[a] Dependent variable is the square root of the proportion of bus riders (resident workers); $p^{.5} = .3916$; and $p = .153$ (15.3 percent).

[b] Dependent variable is the proportion of bus riders (employees in tract); $q = .086$ (8.6 percent).

TABLE 3 Sensitivity Analysis of Model Parameters

Independent Variable	Value at 10% Above Average	Change in Ridership from Average (%)
Resident Model		
Popden	20.09	.94
White	.576	−3.34
Zerocar	.353	4.97
Cov$^{.5}$ freq$^{.5}$	41.97	1.96
Worker Model		
Wrkden	5.941	.65
White	.753	−6.26
Zerocar	.111	4.42
Freq	19.25	1.45

Note: Variables were tested one at a time. All other variables were maintained at average values while a given variable was tested.

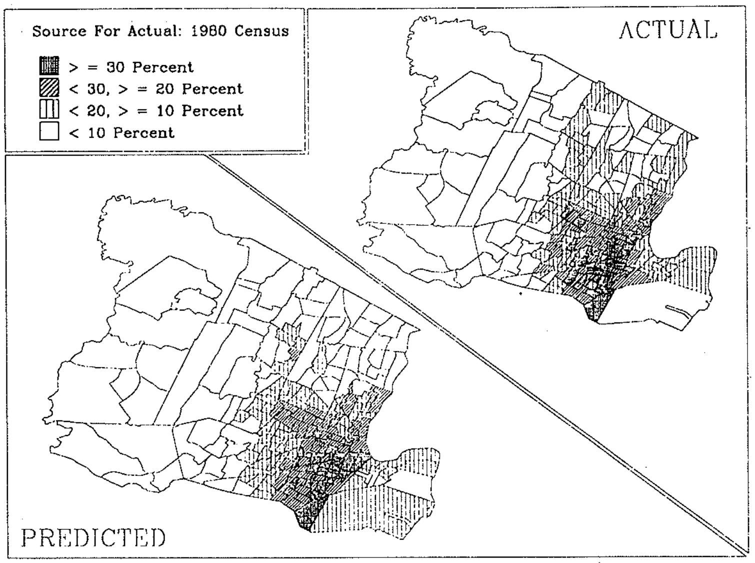

FIGURE 8 Actual versus predicted percentage of bus riders.

increase in a tract's households without automobiles will generate an additional 5 percent increase in bus ridership.

The ridership models are therefore amenable to the testing of a variety of scenarios, including the impact on ridership of the following:

- Trends in automobile ownership,
- Centralization or decentralization of development,
- Improvement in level of service of buses, and
- Shifting ethnic concentrations.

In the following section, examples of applications extend the bus patronage model to the individual route level.

GENERATION OF ROUTE-SPECIFIC RIDERSHIP ESTIMATES

A local bus route that serves the Newark CBD and several surrounding towns was selected to illustrate the usage of the bus patronage model developed earlier. Route 27 runs from Irvington in the southeastern portion of Essex County, up its eastern edge through Newark, Bloomfield, Belleville, and on to Nutley. This route is approximately 13 mi long one way, has 10-min or better headways during peak periods, and has an average weekday ridership of approximately 10,000.

Potential Route-Level Ridership

It is possible to estimate the potential number of daily bus boardings along each route by using the bus patronage model. This involves calculating the potential passengers for each census tract of interest (those served by the route), factoring the totals to consider coverage and competition for the specific route, and assigning the estimated passenger potentials to the route.

Once it is determined which tracts are within the service region of the route, a subset of demographic and transit service data can be created. This subset forms a matrix with one row for each tract served, and residential, worker, and service information forming the columns. The following specific items are necessary to accomplish this task:

- Residential data
  - Population density,
  - Percent of population that is white, and
  - Percent of households with no automobiles.
- Worker data
  - Worker density,
  - Percent of workers that are white, and
  - Percent of households that have no automobiles.
- Transit service data
  - Frequency and
  - Coverage.

To obtain the total passenger potentials for the tracts, it is necessary to run the residential, work, and nonwork models described in the previous section. The result is a vector of potential passenger boardings for each census tract included in the input matrix. Since these values contain totals for the tracts, they must be multiplied by two factors to obtain the potential boardings for a specific route. One factor considers coverage and the other considers competition.

The coverage factor is used to select the potential passengers within the service region (a quarter of a mile walking distance) of the route. To obtain this factor, a ribbon is constructed around the route and the percentage of coverage of that route in each tract is calculated (as opposed to calculating total coverage of all routes in each tract as was done before). The passenger potential for each tract (M_i) is multiplied by the percentage of coverage of the specified route to obtain the number of potential bus passengers served by that route, as follows:

$$m_{ik} = M_i \, cov_{ik} \tag{12}$$

where m_{ik} is the potential passengers in service area of route$_k$ in tract$_i$, and cov_{ik} is the proportion of tract$_i$ served by route$_k$.

The second factor, competition, reduces the potential (m_{ik}) based on the number of buses available to the potential passengers. This factor is simply a ratio of the number of buses on the specified route (k) divided by the total number of buses available (see Equation 2).

$$Q_{ik} = m_{ik} H_{ik} / freq_i \tag{13}$$

where

Q_{ik} = potential passengers on route$_k$ in tract$_i$,
H_{ik} = number of buses per day on route$_k$ in tract$_i$, and
$freq_i$ = total frequency of service in tract$_i$.

Assigning the potential passengers to the transit route is the final step in the process. This involves assigning all potential passengers for route$_k$ in tract$_i$ to the centroid of tract$_i$. These passengers are then loaded onto the section of route$_k$ closest to the centroid of tract$_i$. The results of this procedure as it was performed on Route 27 are shown in Figure 9. The total predicted boardings for the route (10,206) closely match the actual ridership data provided by New Jersey Transit. As was expected, the majority of potential bus riders for Route 27 is in the Newark CBD.

Effects of Demographic Changes

As residential and worker land-use patterns change with time, it is desirable to study the effects of these changes on transit demand. These changes either can be very concrete, such as the building of a large residential development or employment center, or they can involve trends like an increasing minority population. The methodology described in this paper enables a fast and accurate analysis to be performed as new demographic data become available.

As an example of changing demographic properties, major employment centers (those that create 10,000 jobs) were introduced into Nutley. The total number of workers and worker density for the tract containing Nutley were revised and the model was rerun. As can be seen from comparing Figures 9 and 10, this change created 280 additional trips on Route 27 (2.8 percent of the new workers). This is significantly less than the 9 percent average for Essex County obtained from the UTPP. The main reason for this small increase in ridership is that the demographic characteristics of Nutley are not as favorable for work trips by bus as they are in the high-density Newark region. Another reason is that a corresponding increase in transit service was not assumed to accompany the increase in workers. Finally, it should be noted that the 10,000 new workers were equally distributed over the tract and were not considered as point loads on routes in order to be consistent with the census data, which is at the tract level.

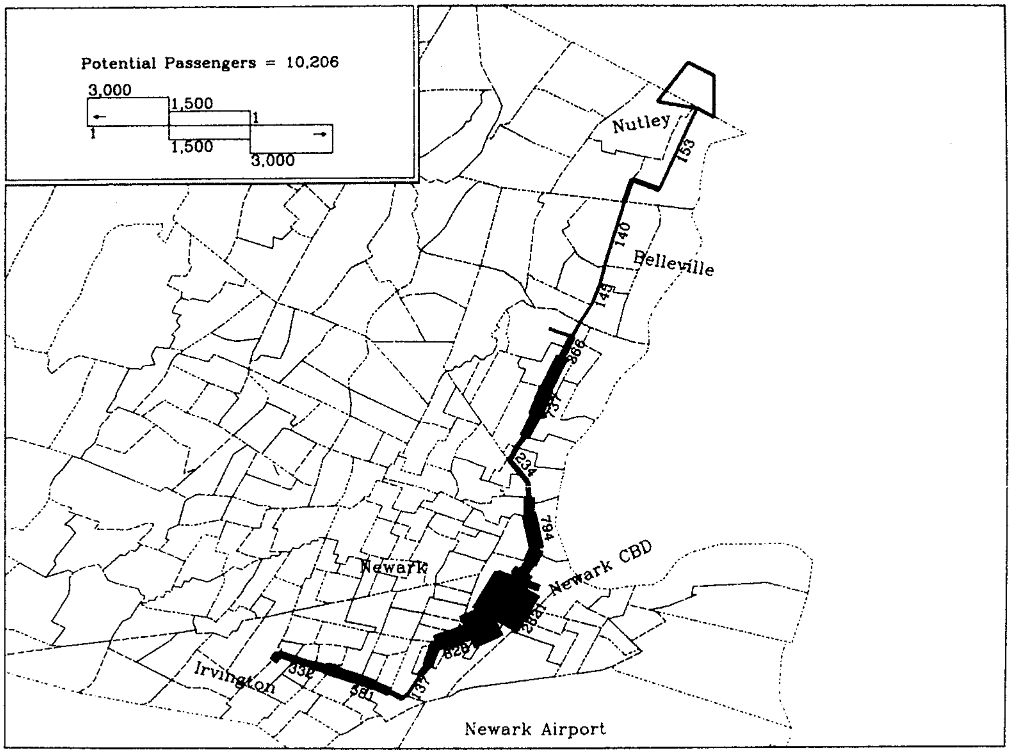

FIGURE 9 Potential daily boardings on Route 27.

Effects of Transit Service Changes

Equally important to changing demographic patterns is to observe the effects on potential riders from changing service characteristics. Two main transit service changes can be analyzed with this model: headways and routing.

Since headways are an input to the model, they can be altered to test the effects on potential ridership. Headways on the route being studied and headways on competing routes can both be manipulated.

This model also allows for the prediction of potential passengers after a routing change, which can involve either changing sections of an existing

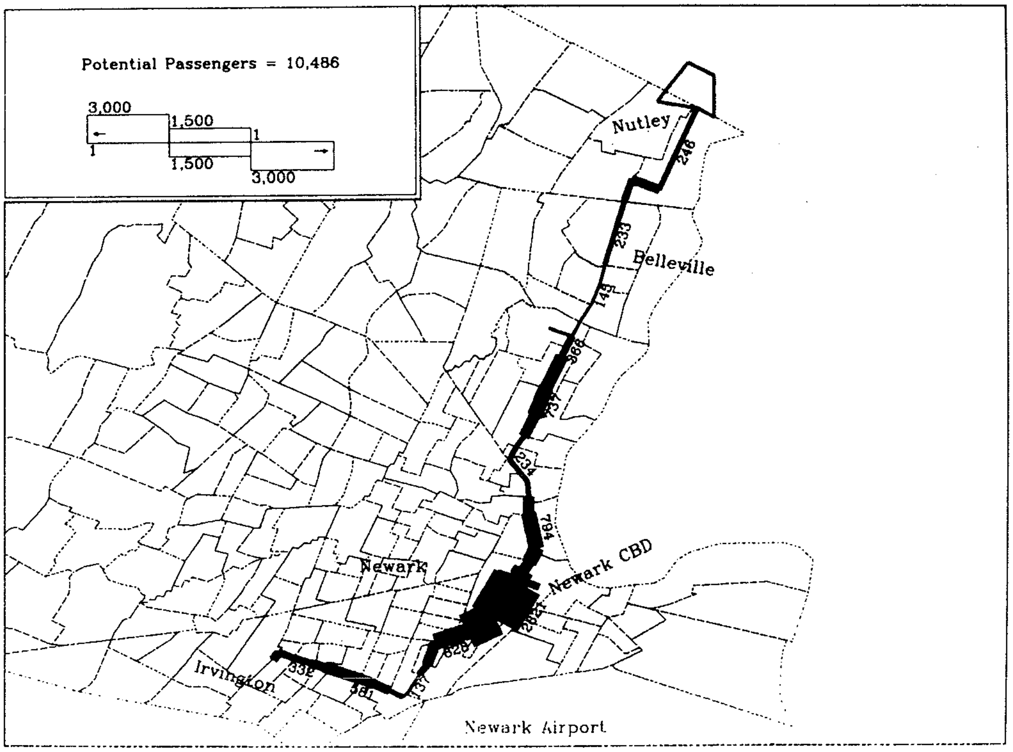

FIGURE 10 Potential daily boardings after employment center is added to Nutley.

route or creating an entirely new route. The new route can be interactively entered into the computerized transit network. Calculating the potential passengers then involves finding the new service region and tracts served and rerunning the model. An iterative interactive computer graphics procedure can thus be used to design new transit routes.

CONCLUSION

When this project was being planned, the intent was to develop a geographic, demographic, and transit service model that, when combined with an interactive computer graphics system, would provide the transit planner and marketer with a powerful analytical tool. This paper outlines a system that meets this requirement. Perhaps the most valuable aspects of this system are the flexibility to perform a variety of jobs and the ability to continue adding new features and enhancements.

Potential Uses

The bus patronage model can potentially be used to

- Identify underserved or overserved regions,
- Observe demographic trends over time,
- Analyze new residential and business centers,
- Test new route configurations, and
- Test headway changes.

The ability to discover underserved (low service, but high potential) and overserved (high service, but low potential) regions is important to both the planner and the marketer. From the viewpoint of the planner, these regions indicate a need for a reduction or increase in service. From the veiwpoint of the marketer, areas of high potential and low ridership indicate a need for increased marketing efforts.

Demographic changes and their effects on transportation can be viewed either in the short term or long term. Short-term changes, such as the opening of a new business center, can readily be analyzed by the model to test the changes of the demand for transit. Long-term demographic trends and their interaction with existing or future service patterns can also be explored.

This model allows the planner to test different service scenarios in view of changing land-use patterns. Has the addition of new residential and business developments created enough demand for a new route or will increased headways and rerouting of existing routes be sufficient? These are the types of questions than can be answered by using this model.

Future Work

Several aspects of this model could be improved or refined by

- Determining whether census tracts are small enough to feel the effects of demographic and service changes or whether a smaller geographic base should be used;
- Analyzing the effects of competition from railroads, subways, and other carriers;
- Extending the study of the effect of competition between routes;
- Extending the model beyond a trip generation phase to a trip distribution phase (i.e., linking origins and destinations);
- Translating potential riders into a gain or loss in revenue;
- Comparing this model to actual on-off counts; and
- Transferring the model to other counties and states.

The aspects of the model are continually being developed.1 The model has proved to be a good estimator of existing ridership patterns and appears to be providing good predictions for future scenarios. Its future development is promising.

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Birth of a Transitway: Katy Freeway (I-10W), Houston, Texas

JOHN M. MOUNCE and NANA M. KUO

ABSTRACT

The Texas State Department of Highways and Public Transportation and the Metropolitan Transit Authority of Harris County have jointly pledged to develop an extensive system of highway transit facilities to improve mobility in Houston, Texas. These facilities, or transitways, are exclusive, physically separated lanes that are located within freeway medians for use by such authorized high-occupancy vehicles as buses, vanpools, or carpools. The objective of these transitways is to maximize person throughput within a freeway corridor at an affordable cost and in a minimum time period of implementation. Phase 1 of the Katy Freeway (I-10W) Transitway, which was opened for operation on October 29, 1984, is described. Design, construction, and operational procedures relative to the facility are discussed; tables and figures show utilization trends; and subsequent improvements and modifications are outlined. After 9 months of operation, the transitway is being used for approximately 5,200 passenger trips a day. As the length of the transitway is extended, the current annualized 9-month passenger growth rate of 43 percent per year is anticipated to increase.

The Katy Freeway (I-10W) is a major interstate highway that serves the western part of the city of Houston and Harris County (Figure 1). Extensive commercial and residential development has occurred as far west as 35 mi from downtown Houston. Traffic congestion within sections of the Katy Freeway corridor inhibits peak-hour speeds to less than 20 mph. In some portions of the corridor, average daily traffic is 175,000 automobiles in a six-lane section. In the vicinity of State Highway (SH) 6, the volume of traffic has been increasing at an annual rate of 25 percent for the past several years and is now in the range of 90,000 vehicles per day. In 1983, a bus trip from SH 6 to downtown Houston would have taken 45 min over a distance of approximately 17 mi.

Present and projected future volumes, as well as the extent of traffic congestion, overwhelmingly justify the provision of an exclusive transitway on the Katy Freeway. Recognizing this need and the fact that there were no other plans at the time to expand capacity in the corridor, the Texas State Department of Highways and Public Transportation (SDHPT) and the Metropolitan Transit Authority (METRO) of Harris County entered into a cooperative agreement to develop a median transitway on the Katy Freeway. This transitway would be developed as part of an already scheduled major pavement rehabilitation project. SDHPT, in conjunction with FHWA, agreed to pay all freeway overlay improvement costs, to award all contracts, and to supervise construction. METRO, using primarily local funds, agreed to pay the additional transitway costs that would be incurred from the project. This concerted effort facilitated the construction and implementation of the Katy Freeway Transitway in a relatively short time period, and thus minimized traffic disruption and the combined cost of the project.

Details are provided in this paper of project development and implementation, and the first 9 months of operation of the Katy Freeway Transitway are documented. Subsequent facility improvements and vehicle authorization modifications that were made during the first year are also presented along with a summary discussion of growth trends.

PROJECT DESCRIPTION

The Katy Freeway Transitway is being developed and operated in three phases. Phase 1 was constructed between I-610 and Gessner Drive, a distance of 4.75 mi. Completion of the first phase reduced peak-period travel time for users of the transitway by 5 to 9 min depending on freeway conditions. Phases 2 and 3 will subsequently extend the transitway another 6.75 mi to beyond SH 6. When fully completed, the transitway will extend a total of 11.5 mi (see Figure 1).

The Katy Freeway Transitway is being constructed in the median of the freeway, separated from general traffic lanes by concrete median barriers. The transitway is reversible (it is operated inbound in the morning and outbound in the evening); it includes an emergency breakdown shoulder along most sections; and it is designed to accommodate buses, vanpools, and other high-occupancy vehicles. As is shown in the typical "before-and-after" transitway construction cross-sections of Figure 2, the transitway has little impact on the freeway cross-section. The number of mixed-flow lanes and the availability of an outside shoulder remain intact. Only small adjustments to lane widths and the elimination of the inside shoulder are necessary to accommodate the placement of the 19.5-ft wide transitway within the freeway median.

Access to the transitway differs at each terminal location. At the western terminus, a series of concrete median barriers creates slip ramps to provide access and egress from the inside freeway lane (Figure 3). During inbound operation, the median shoulder upstream of the transitway entry serves as a concurrent flow lane. In the afternoon, the outbound vehicles exiting the transitway use the inside shoulder to merge into the mixed-flow lanes. At the eastern terminus near I-610, an elevated flyover ramp leaves the median and ties into an arterial street inter-

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Texas Transportation Institute, Texas A&M University System, College Station, Tex. 77843.

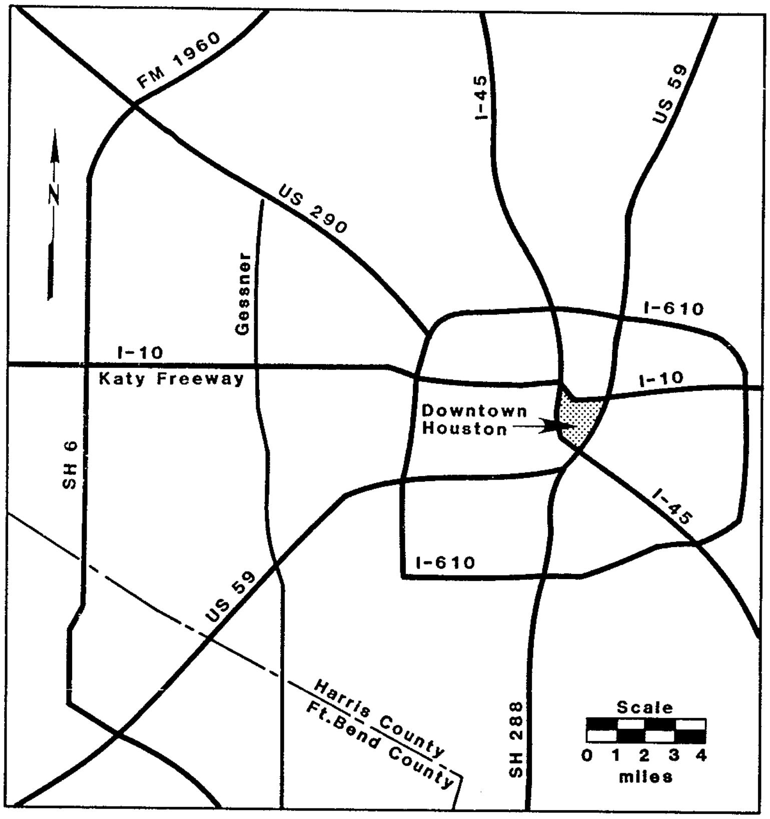
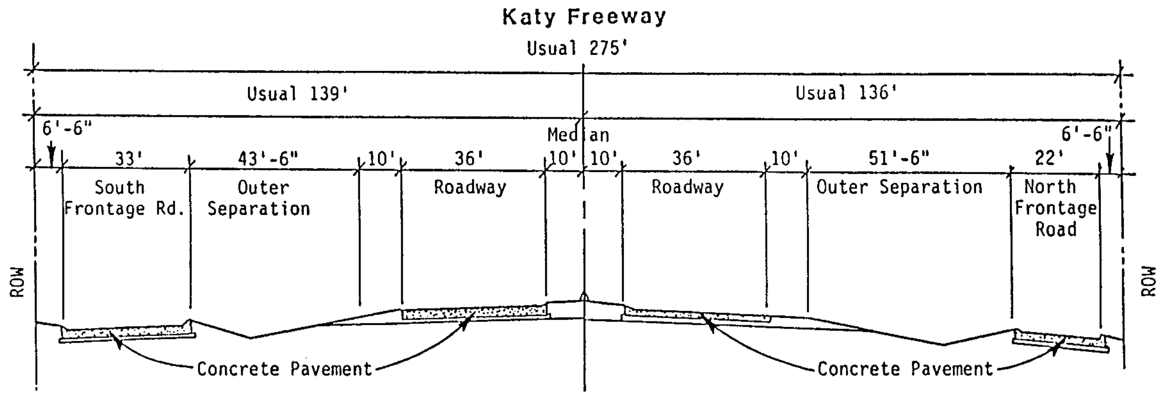
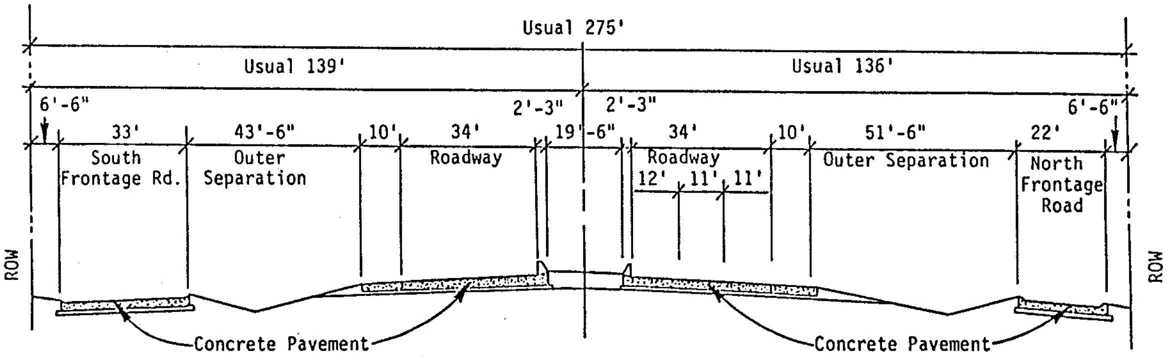


FIGURE 1 Katy Freeway (I-10W), Harris County, Texas.



Prior Typical Section



Constructed Typical Section

FIGURE 2 Before and after transitway freeway cross sections.

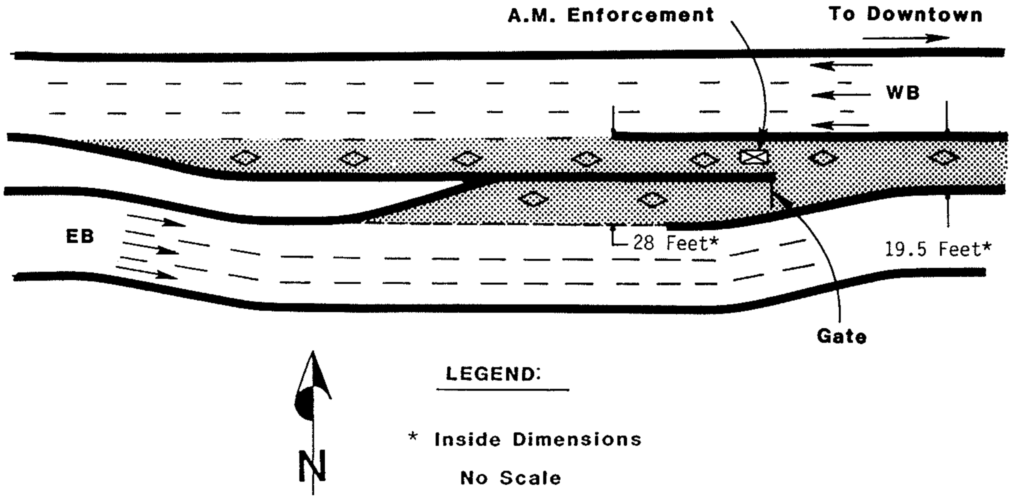


FIGURE 3 Western terminus, Katy Freeway Transitway.

section (Figure 4). At that intersection, authorized high-occupancy vehicles can either travel south to major employment centers or continue east to reenter the Katy Freeway in mixed-flow lanes to reach downtown Houston.

IMPACT OF CONSTRUCTION

Construction on Phase 1 of the Katy Freeway Transitway began in April of 1983. The introduction of a transitway facility into the median required special retrofit construction processes that constrained adjacent freeway sections that were already serving high volumes of traffic. A primary concern was to minimize the adverse traffic impacts associated with this type of construction.

In order to accomplish the transitway construction, work was sequenced independently within each project segment. The work sites were developed in the median and to the north and the south sides of the freeway mainlane cross-section. Traffic was routed around the work sites through narrow lanes that varied from 10 to 11 ft in width, with no shoulders on either side of the lane. Temporary concrete median barriers protected and separated the work sites from freeway traffic.

Construction on Phase 1 of the Katy Transitway was completed in October of 1984, approximately 4 months ahead of the estimated construction time. An evaluation of the impacts of the transitway construction indicated that mainlane traffic volumes and speeds were minimally affected, and that after an initial 1-month adjustment period, accident rates were not significantly different during transitway construction than they were the year before (1).

INITIATION OF SERVICE

The Katy Freeway Transitway formally began service on October 29, 1984. High-occupancy vehicles authorized to use the transitway were restricted to buses and vanpools. Within the first few weeks of operation, a total of 78 buses per day (carrying 2,860 passengers) and 160 vanpools per day (carrying 1,303

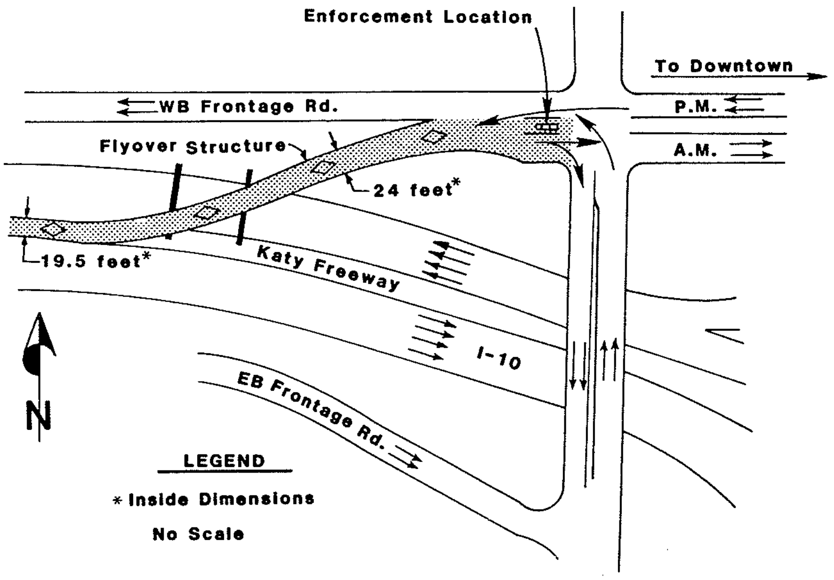


FIGURE 4 Eastern terminus, Katy Freeway Transitway.

passengers) were using the Phase 1 segment of the transitway, which represented average occupancy rates of 37 and 8 persons for buses and vanpools, respectively.

For the initial length of the Katy Transitway from Gessner Drive to near I-610 (a distance of 4.75 mi), a net travel-time savings of 5 to 9 min per trip can be realized during the peak period compared with adjacent freeway mainlane travel times. These travel-time savings are realized despite the 2 min that are lost traveling on the arterial street that connects the transitway's eastern terminus with the Katy Freeway mainlanes inside of I-610.

Current operation of the transitway is manually controlled by an on-site crew that consists of a transit police officer, a wrecker driver, and a traffic control worker. These persons open the inbound transitway by 5:45 a.m. and close the transitway by 9:15 a.m. until reversed operation begins. In the afternoon, the transitway is open for outbound traffic from 3:30 to 7:00 p.m.

The transit police officer is on duty at the eastern terminus to handle emergencies and to warn or ticket any unauthorized patrons using the transitway. The wrecker and driver are situated at the western transitway entrance to handle emergencies and to remove stranded vehicles. In order to improve its maneuverability within the transitway cross-section (in particular, to provide a tighter turning radius), the wrecker was specially designed with a shorter-than-normal wheel base.

A number of signs and lane control signals are used to direct traffic through the transitway. As shown in Figure 5, changeable message signs are used at each end of the transitway to inform vehicles and the public about the facility. Lane control signals that display a red X or a green or yellow arrow verify the direction and conditions of transitway operation. Finally, traffic signs direct vehicles from connecting arterials to the transitway entrance. Currently, all signs and lane control signals within the transitway are manually controlled when the facility opens and closes each day. Within the next 6 months, all transitway signs and signals will be remotely controlled by computer with operator intervention.

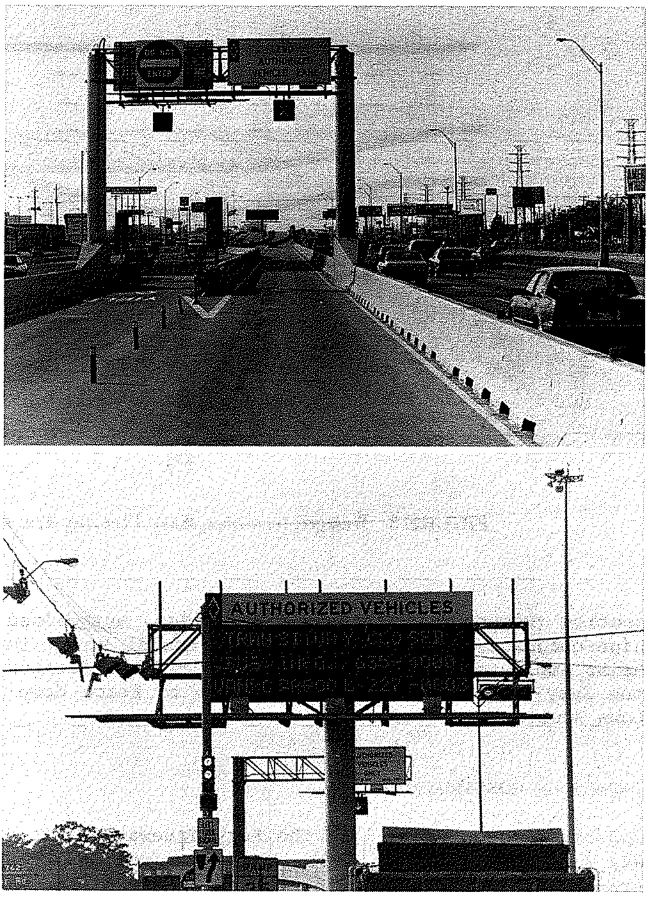


FIGURE 5 Transitway signs.

FIRST-YEAR OPERATIONS

Transitway Buses, Vanpools, and Carpools

The Katy Freeway Transitway was opened on October 29, 1984, as a median, barrier-separated, one-way, reversible, single-lane priority facility to be used by authorized buses and vanpools. Daily vehicle and passenger volumes initially totaled 78 buses and 160 vanpools that carried 2,860 and 1,303 passengers, respectively. Carpools were authorized to use the facility in April of 1985. Monthly transitway vehicle and passenger demand from the time it opened until August 1985 is presented in Tables 1 and 2. The cumulative increases in demand categories are also given. These values are shown in Figures 6 and 7.

As can be seen, the growth in vehicle utilization of the transitway has increased from 238 to 304 vehicle trips per day, and passenger movement has increased from 4,163 to 5,433 passenger trips per day, which represents an approximate 28 percent increase in vehicle volumes, and a 31 percent increase in passenger volumes. Although the number of vehicles currently using the transitway in a peak hour of operation is typically less than 5 percent of the vehicle volume that may be observed on an adjacent freeway mainlane, the number of passengers served by these few vehicles is almost the equivalent of an

TABLE 1 Transitway Vehicle Demand, 1984-1985

	Daily Vehicles				Cumulative Percent
Month	Buses	Vanpools	Carpools	Total	Change
November	78	160	-	238	-
December	81	162	-	243	2
January	90	172	-	262	10
February	97	166	-	263	11
March	101	170	-	271	14
April	104	166	10	280	18
May	106	168	12	286	20
June	121	158	13	292	23
July	116	153	28	297	25
August	122	145	37	304	28

TABLE 2 Transitway Passenger Demand, 1984-1985

	Daily Passengers				Cumulative Percent
Month	Buses	Vanpools	Carpools	Total	Change
November	2,860	1,303	-	4,163	-
December	3,020	1,426	-	4,446	7
January	3,180	1,636	-	4,816	16
February	3,520	1,640	-	5,160	24
March	3,450	1,596	-	5,046	21
April	3,490	1,601	40	5,131	23
May	3,300	1,557	50	4,907	18
June	3,780	1,271	50	5,101	23
July	3,880	1,236	111	5,227	26
August	4,100	1,203	130	5,433	31

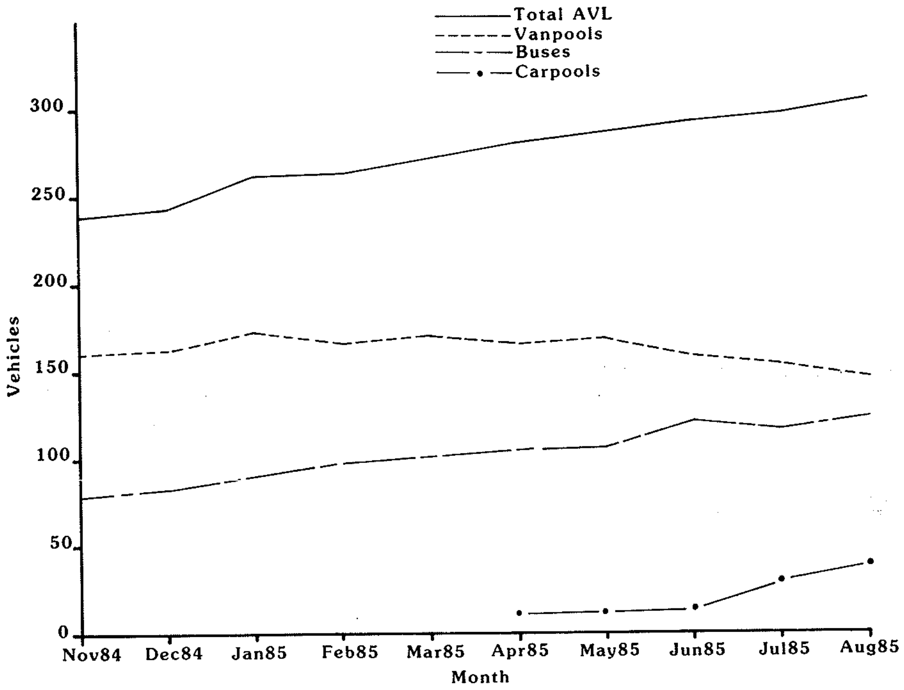


FIGURE 6 Katy Freeway Transitway demand: daily vehicle volumes.

adjacent freeway lane operating at peak capacity with normal automobile occupancies.

There have been corresponding increases in demand for transitway support facilities such as park-and-ride lots and vanpool staging areas. The geographic locations of these facilities within the Katy Freeway corridor and their current capacities are shown in Figure 8. Demand totals for each of these transitway support facilities are given in Table 3. Total corridor demand for park-and-ride facilities has increased by 82 percent over the 9-month period since the transitway began operating.

The typical distribution of vehicle demand during peak periods on the transitway is shown in Figures 9 and 10. Note the substantial and distinctly different peaking characteristics exhibited by buses and vanpools. Approximately 60 percent of total transitway demand is served on the transitway during a typical peak hour of operation.

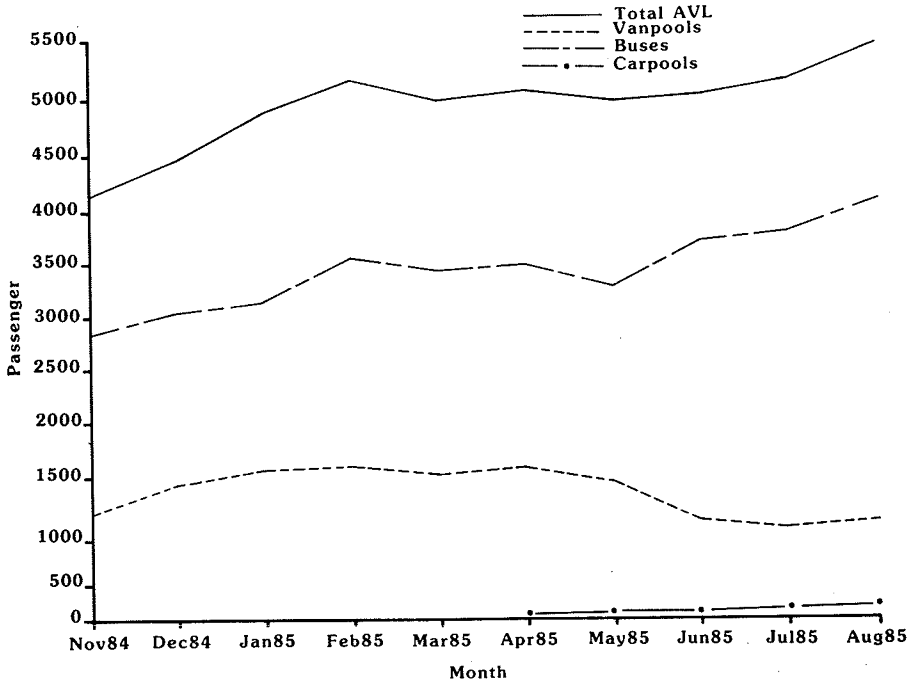
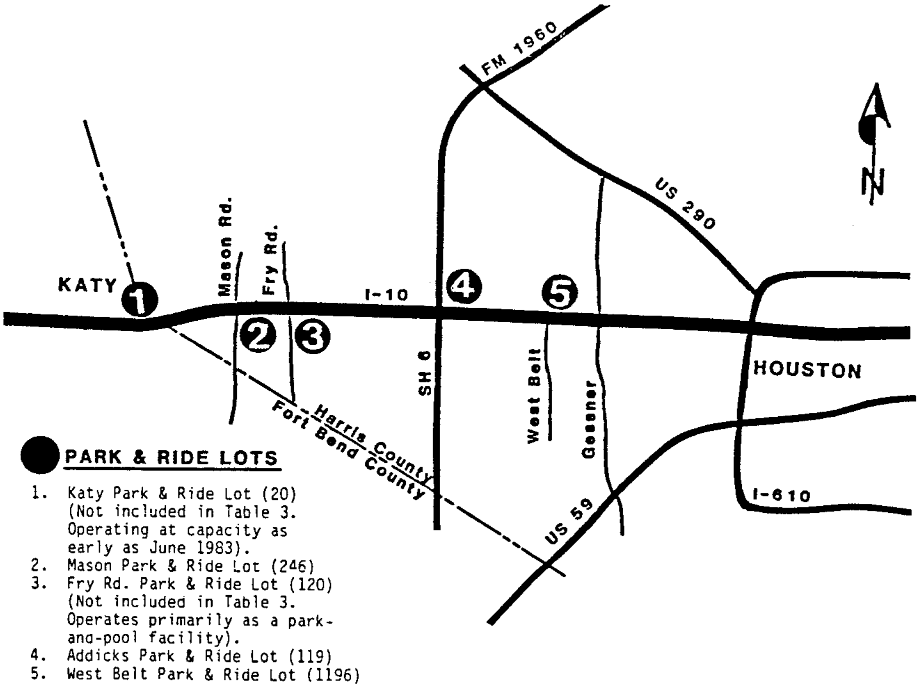


FIGURE 7 Katy Freeway Transitway demand: daily passenger volumes.

KATY FREEWAY (I-10) PARK & RIDE LOCATIONS



● PARK & RIDE LOTS

1. Katy Park & Ride Lot (20) (Not included in Table 3. Operating at capacity as early as June 1983).
2. Mason Park & Ride Lot (246)
3. Fry Rd. Park & Ride Lot (120) (Not included in Table 3. Operates primarily as a park-and-pool facility).
4. Addicks Park & Ride Lot (119)
5. West Belt Park & Ride Lot (1196)

FIGURE 8 Katy Freeway Transitway support facilities.

TABLE 3 Katy Freeway Park-and-Ride Demand Totals, 1984-1985

Month	Demand (parked vehicles) by Park-and-Ride Lot				Percent Change
	Mason[a]	Addicks[a]	W. Belt[a,b]	Total	
November	147	378	-	525	-
December	162	335	-	497	-5
January	173	425	-	598	14
February	171	430	191	792	51
March	170	420	144	734	40
April	167	423	197	787	50
May	165	417	189	771	47
June	175	461	226	862	64
July	180	492	237	909	73
August	203	522	228	953	82

[a] See Figure 8 for location.
[b] Operational Jan. 28, 1985.

Freeway Mainlanes

Because of continued population and economic growth along the Katy Freeway corridor, the impact on traffic congestion has not been apparent. Freeway mainlanes adjacent to the Phase 1 segment of the transitway were operating at depressed levels of service during peak periods before the transitway was built and they continue to be highly congested. The speed profile from Gessner Drive to the I-610 interchange (Phase 1) during peak periods on the Katy Freeway both before and after construction of the transitway is shown in Figure 11. As can be seen, there has been no substantial change in travel time in this section. As shown in Figure 12, there is also no major change in service volumes. Any apparent aberrations in speed and capacity flow conditions are inconsequential and practically insignificant.

Corridor Totals

A quarterly summary of morning peak-period vehicle and passenger movement along the Katy Freeway corridor between Gessner Drive and I-610 is provided in Table 4. Because of the transitway, the corridor serves approximately 1,400 more vehicles (+13 percent) and approximately 3,000 more passengers (+23 percent) (see Figure 13). Although it composes only 1 percent of the corridor's peak-period vehicle volume, the transitway contributes more than 15 percent of the total passenger trips during that peak period.

IMPROVEMENTS AND MODIFICATIONS

West Belt Extension

Phase 1 of the Katy Transitway was originally designed to be operated from I-610 to Gessner Drive. However, since the opening of the transitway in October of 1984, the interim operation of a western extension of the lane became both desirable and feasible. Consequently, a 1.45-mi extension from Gessner Drive to West Belt was implemented on May 2, 1985. Approximately 86 percent of the vanpools, 89 percent of the carpools, and 44 percent of the buses are currently taking advantage of this extension to save an additional 2 to 6 min in travel time over mainlane vehicles.

Carpool Authorization

Based on contraflow experience on the North Freeway, only authorized buses and vanpools were initially permitted to operate on the Katy Freeway Transitway. During the first 5 months of its operation and

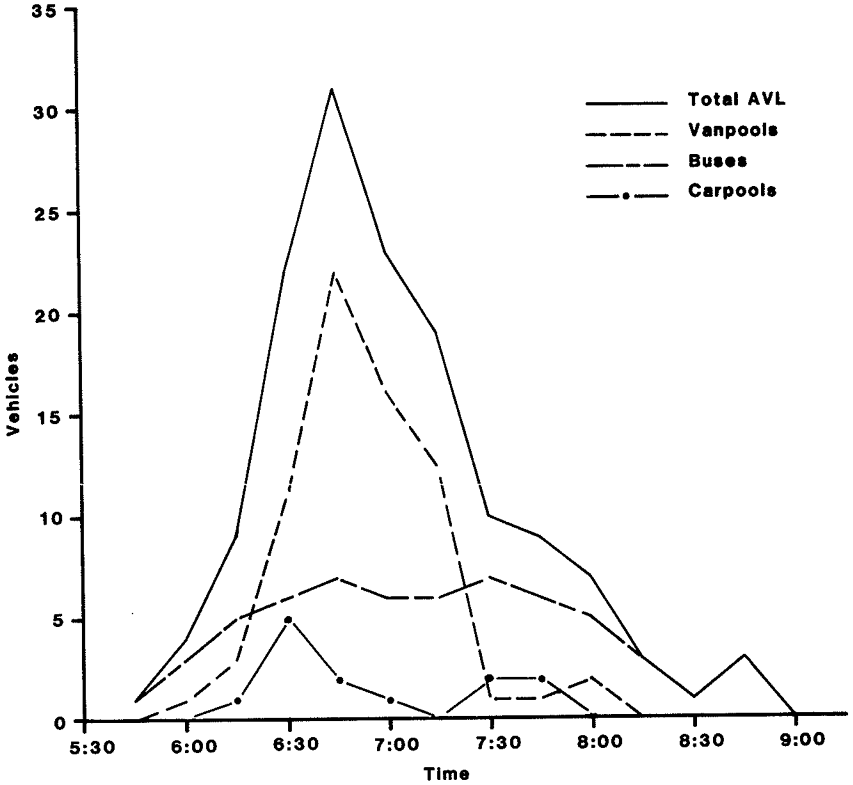


FIGURE 9 Katy Freeway Transitway demand distribution by time: morning, July 1985.

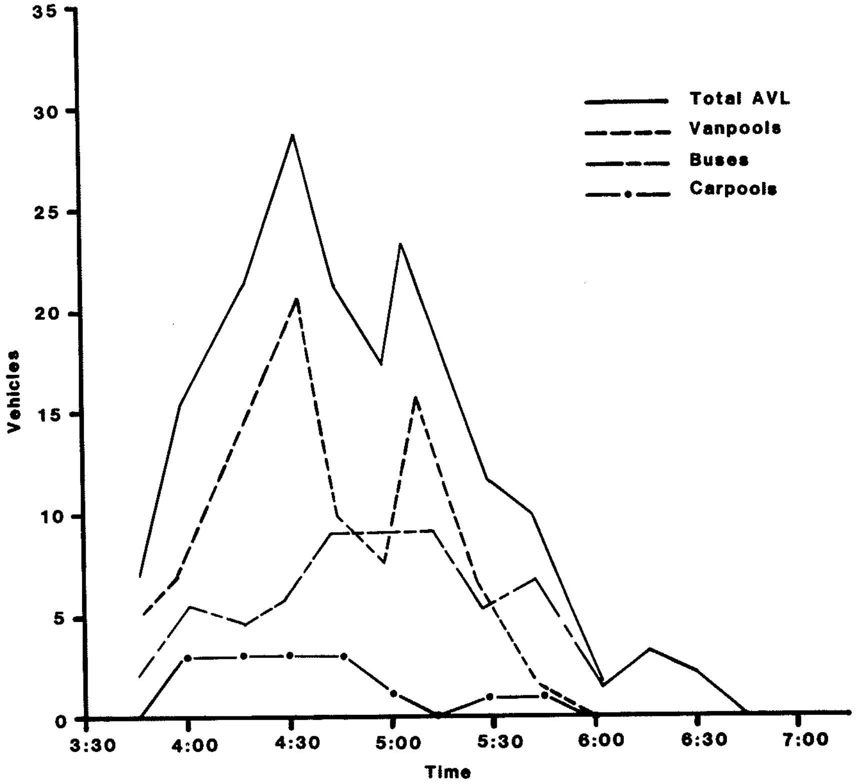


FIGURE 10 Katy Freeway Transitway demand distribution by time: afternoon, July 1985.

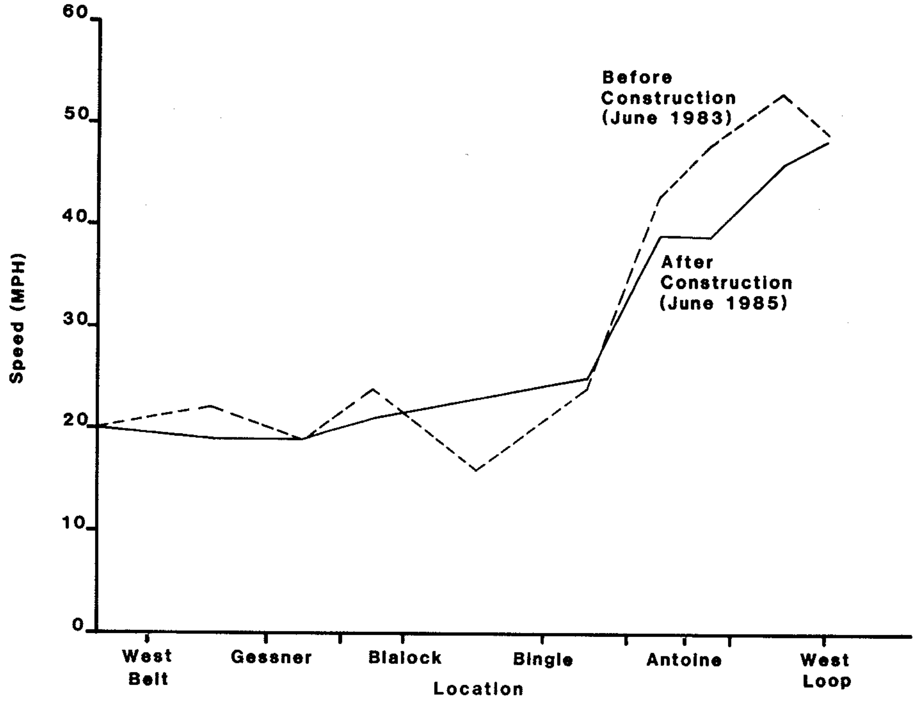


FIGURE 11 Katy Freeway peak-period mainlane speed profile.

despite its sustained growth, combined bus and vanpool volumes on the transitway were relatively low compared with its capacity, which resulted in a perception that the transitway was underutilized (2). As a means of overcoming this perception and following the examples set by most other HOV freeway projects elsewhere in the United States, METRO and SDHPT decided to approve a carpool experiment on the Katy Freeway Transitway beginning April 1, 1985 (3,4).

The use of carpools on the transitway was originally restricted to duly authorized automobiles that carried four or more passengers. If an authorized carpool had fewer than four persons on any day because of a carpool member's work schedule, travel, illness, or vacation, it was not permitted to use the transitway. This carpool designation was structured to ensure maximum passenger occupancy of vehicles traveling within the Katy Transitway and also

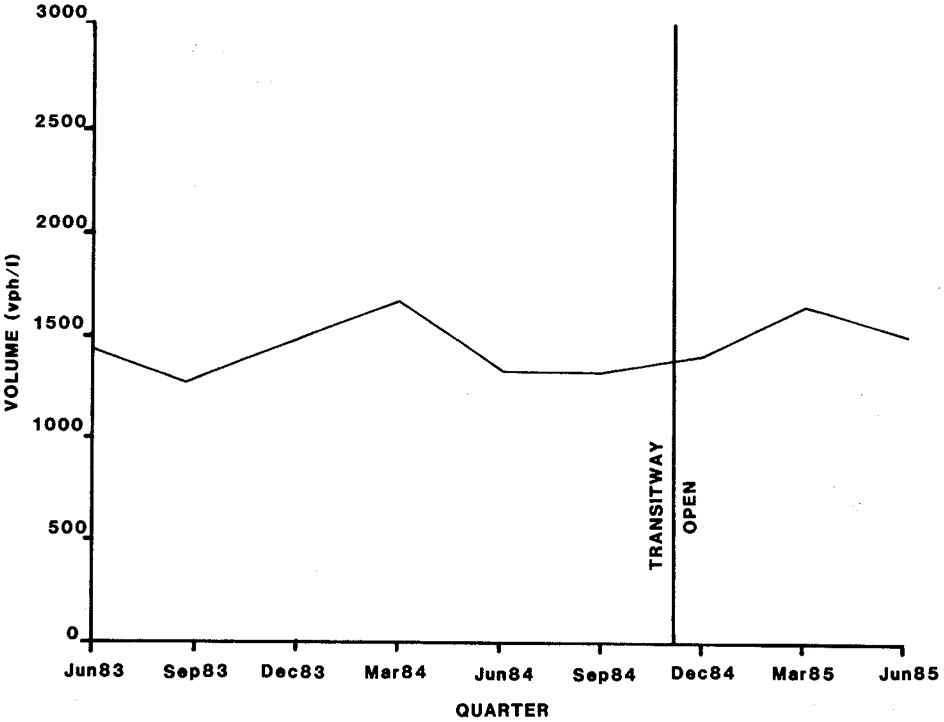


FIGURE 12 Katy Freeway peak-period mainlane service volumes.

TABLE 4 Quarterly Katy Freeway Corridor Volumes, Morning Peak Periods (6:30-9:30 a.m.), 1984-1985

	Freeway		Transitway		Total		Cumulative Percent Change	
Month	Vehicles	Passengers	Vehicles	Passengers	Vehicles	Passengers	Vehicles	Passengers
September	10,729	12,874	-	-	10,729	12,874	-	-
December	11,352	12,884	112	2,093	11,464	14,977	7	16
March	12,012	13,920	131	2,483	12,143	16,403	13	27
June	11,055	13,253	142	2,615	12,097	15,868	13	23

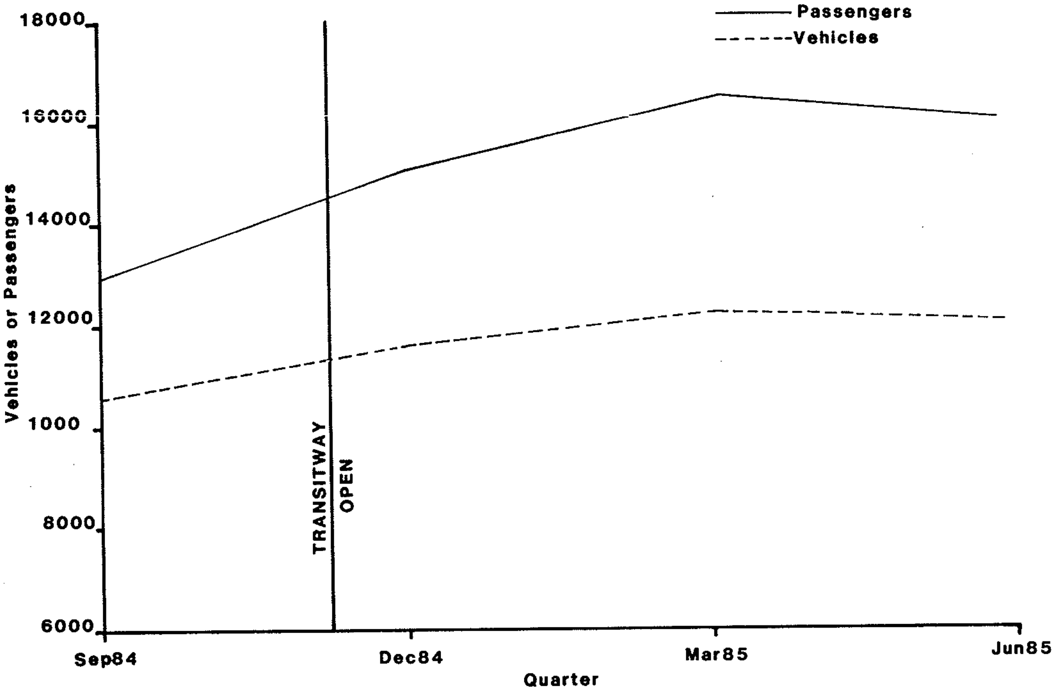


FIGURE 13 Katy Freeway corridor vehicle and passenger volumes.

out of concern that a designation of three or more passengers in a carpool could possibly cause the capacity of the transitway to be exceeded and create unacceptable operating conditions.

Approximately 30 carpools were authorized to use the transitway in April of 1985. However, as shown in Table 5, of these 30 carpools, an average of only 5 carpools actually chose to use the lane during a typical peak period. Since then, the number of carpools observed using the transitway has doubled, but absolute demand levels remain low. Consequently, effective July 29, 1985, carpools were permitted to enter the transitway with at least three passengers, although four or more registered passengers were still required to obtain authorization.

West Belt Park-and-Ride Lot

A major park-and-ride lot was opened by METRO near the West Belt cross street to I-10W in late January of 1985 to support the Katy Transitway. This facility has a capacity of 1,111 parked vehicles. After 7 months of operation, approximately 230 vehicles were using the lot with an average of 12 buses per peak period accessing the transitway. This represents a

TABLE 5 Carpool Demand on Katy Freeway Transitway, 1985

	Morning		Afternoon		Daily	
Month	Vehicles	Passengers	Vehicles	Passengers	Vehicles	Passengers
April	6	24	4	16	10	40
May	6	26	6	24	12	50
June	8	32	5	18	13	50
July	13	52	15	59	28	111
August	20	67	17	63	37	130

growth of approximately 20 percent in the first 7 months of operation.

Benefit-Cost Analysis

Based on August 1985 transitway volumes, persons traveling by authorized bus, vanpool, or carpool on the transitway are realizing a time savings over parallel freeway mainlane travel of approximately 551 person-hours per day. This estimate assumes a conservative travel-time savings of 5 min for each of the 2,478 people using the transitway as far as Gessner Drive (56 percent of bus volumes, 14 percent of vanpool volumes, and 11 percent of carpool volumes) and a savings of 7 min for each of the 2,955 people using the transitway all the way to West Belt (see Table 2). By placing a value of $7.50 on each person-hour of delay saved, the travel-time savings obtained in August 1985 translates into an annual benefit of $1,078,000 (5).

A postimplementation assessment of the benefits and costs of Phase 1 of the Katy Transitway affirms the transitway's long-term cost-effectiveness. By using a 20-year analysis period and a 10 percent discount rate, a benefit-cost ratio of 1.69 is obtained. The major costs and benefits that are included in this analysis are summarized in Table 6.

TABLE 6 Estimated Benefits and Costs, Katy Transitway, Phase 1

Benefit or Cost Component	Present Value ($ 1985 millions)
Benefits	
Travel time savings	22.020
Reduced bus operating cost	3.440
Subtotal	25.460
Costs[a]	
Transitway construction (including associated arterial street improvements)	10.693
Transitway operation	2.986
West Belt park-and-ride lot	1.400
Subtotal	15.079
Benefit-cost ratio	1.69

[a] Source: Metropolitan Transit Authority of Harris County, Texas.

CONCLUSIONS

The Katy Freeway Transitway was completed 4 months ahead of schedule with minimal operational and safety impacts to mainlane traffic during construction of the facility. After 9 months of operation, the transitway is carrying more than 5,400 persons per day. An 82 percent increase in park-and-ride demand has accompanied this rise in transitway utilization. The corridor as a whole is carrying more than 20 percent more people in the peak direction during a 3-hr peak period than it did before the transitway was introduced.

According to annual projections for the first year of operation, the Katy Freeway Transitway should accommodate demand by high-occupancy vehicles for an increase of approximately 39 percent per year for vehicles and 43 percent per year for passengers. If these rates are sustained through 1986, by the end of that year the transitway will serve an average of approximately 4,541 peak-period passenger trips, which is about 30 percent of the daily directional peak-period, mainlane freeway passenger movement.

This overall HOV growth trend is below that experienced on similar facilities nationwide (6) or on the North Freeway (I-45) contraflow lane in Houston (7). The location and short length of the transitway associated with Phase 1 implementation could be responsible for this limited growth in high-occupancy-vehicle volumes. The congestion and depressed level of service on the freeway extends far beyond the transitway terminus of Phase 1. As the Katy Freeway Transitway is extended westward, the reduction in travel time will become more substantial and will therefore offer more of an incentive for modal shifts to occur. It is anticipated that the growth rate of transitway utilization will be markedly greater as succeeding phases of the project become operational.

ACKNOWLEDGMENT

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The contents of this paper reflect the views of the authors, who are responsible for the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official views or policies of the Federal Highway Administration, the Urban Mass Transportation Administration, the Metropolitan Transit Authority of Harris County, or the Texas State Department of Highways and Public Transportation.

Single-Lane Transitway Width Assessment

TIMOTHY J. LOMAX

ABSTRACT

Highway design for transitway (busway) lanes has previously been based on engineering experience and judgment. The results of bus operating tests performed on several simulated transitways at the Texas A&M University Research Annex are presented in this paper. One vehicle was parked in the transitway to simulate a breakdown, and another was driven past the "stalled" vehicle at comfortable speeds. The parked or stalled vehicles included a 40-ft transit bus and a passenger van. The width and alignment of the barriers delineating the transitway were varied to simulate several one-lane transitways with both tangent and curved sections. Bus breakdowns were simulated to determine the percentage of bus breakdowns that might close a transitway of a given width. The findings should allow transitway width in future planning and design efforts to be better determined.

A transitway is defined as a single, barrier-separated, reversible, high-occupancy-vehicle lane. The wide range of transitways design specifications makes the design of transitway difficult in itself; the restricted right-of-way and the need for complementary highway improvements further hinder design flexibility. Engineering judgments must be made as to how transitway and highway configurations can be compromised. The need for clearance envelopes for transit buses must be balanced against the reality that only a small amount of the road can be widened at most locations. In many cases, widening the road may not even be a viable alternative. The Houston region, in which over $400 million is currently committed to transitways, certainly has a need to develop design standards for transitways. Agreement on design standards will also simplify a multiple-agency highway and transit undertaking.

Transitway designers in Houston recognized that transitways must be sufficiently wide to allow vehicles to pass a stalled bus. Less importance was placed on the need to pass a stalled vehicle at a high speed. It was believed that, because passengers on a stalled bus might exit the bus onto the lane, high passing speeds were neither desirable nor safe; also, sufficient space frequently could not be provided to permit a high-speed pass. Potential collision damage to transit buses would also be minimized with slow passing speeds, especially in cases when the disabled bus was unable to park directly against the barrier.

Consequently, the issue became how wide a one-lane, reversible transitway needed to be to allow a stalled bus to be passed. Because each additional foot required for the transitway forced additional compromises in freeway design, this became a critical issue that has not yet been conclusively addressed. Therefore, one of the major objectives of this study was to determine the percentage of controlled vehicle breakdowns (those that do not result in accidents) that might be expected to block a transitway, which depends on how close a bus could come to the barrier during a controlled stop. These tests were conducted by parking a typical transit bus against a New Jersey-type concrete median barrier (CMB) in both tangent and curved roadway sections. Another objective of the study was to test the speed at which one bus could pass a parked or stalled bus within several different transitway width and layout configurations. Measurements of speed and distance were collected for each passing maneuver to determine how widening the transitway affected the potential passing speed.

STATEMENT OF THE PROBLEM

The bus that will typically be used on the Houston transitway system is GMC RTS-04. These buses are 8.5 ft wide with an additional 0.6 to 0.7 ft on each side for mirrors. These mirrors, however, are positioned at different heights (about 5 ft above the ground on the left side and about 7 ft above the ground on the right side), which eliminates a mirror-to-mirror conflict when both buses are facing in the same direction. Therefore, for one bus to pass another on a one-way transitway, the inside clear width of the transitway would have to be between 18.0 and 18.5 ft.

The Metropolitan Transit Authority of Harris County, Texas (METRO), FHWA, and the Texas State Department of Highways and Public Transportation (SDHPT) recognized the problems presented by the possibility that a bus might block a lane and severely reduce the passing speed. It is essential that the transitway provide a reliable level of service. The volume of buses on Houston transitways is expected to generally be in the range of 50 to 100 per peak hour, with the volume of vanpools comprising another 200 to 400 vehicles per hour. Very little documentation could be found for passing speeds on one-lane busways of the type that METRO and SDHPT plan to operate. The plans for a one-way transitway in Houston include a travel lane directly in the center of the transitway (see Figure 1) as opposed to a more typical wider right shoulder, partly because of the reversible nature of the lane. The 50- to 55-mph operating speed planned for these narrow transitways is also somewhat higher than that observed on some one-lane facilities around the country.

A METRO survey of several currently operating priority lane projects (1) indicates that the revenue miles between transit vehicle breakdowns vary from 1,000 to 27,000. Applying a typical Houston priority lane trip of 10 mi results in a forecast of at least one, and perhaps five, bus breakdowns every week on each priority lane project. With breakdown

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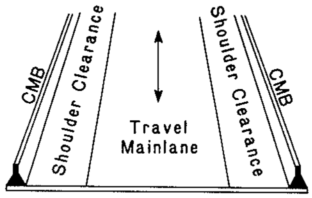

FIGURE 1 Current cross section used for one-way transitways in Houston.

rates approximately equal to that of transit buses and volumes three to eight times as great, vanpools and carpools are also a key component of the breakdown problem. It is possible that at least one breakdown per peak period could become the norm. Safety problems resulting from frequent breakdowns are also a concern in the development of an operating strategy. In addition, the complete blockage of a lane that is totally enclosed with concrete barriers and has infrequent access points (3 to 5 mi apart) would result in severe bus service and traffic handling problems; the intent of providing reliable transitway service would be defeated. Adverse publicity and negative user experiences resulting from congestion on such a frequent basis could lead to diminished ridership or even the loss of public support for priority treatment projects.

TESTING PROCEDURES

The two major objectives of this research effort, as previously discussed, were the stalled-bus parking measurements and the determination of speed profiles of the passing maneuver for various transitway widths. The data collection process for each of these operations is summarized in the following paragraphs. All testing was performed by the Texas Transportation Institute at the Texas A&M Research Annex, which is located west of Bryan, Texas. The tests were conducted during the week of July 23, 1984. The weather was generally clear and hot.

Bus Driver Selection

Two professional bus drivers were provided by METRO for the week of testing. One driver had approximately 3.5 years of experience and the other had 0.5 year of experience. Their driving skills were, according to an assessment by METRO supervisors, near the average for expected transitway drivers. Although two drivers do not qualify as a statistically valid sample of a fleet of 1,000 drivers, the cost of providing a statistically significant number of drivers would have been prohibitive. Several passes were made for each test, and several different transitway widths were measured. Time constraints precluded other drivers from participating in the study. Several shifts of drivers would have been required to discount the inevitable learning process that results from doing the same type of test over a period of a week. No available record of comparison of driving skills was available in advance of the tests. Although two drivers are not an optimum sample, they were assumed to be adequate for the conduct of this research study.

Bus Parking During Breakdown Situations

Perhaps the most important phase of the study was the initial determination of the bus-to-barrier relationship that results when a bus is parked in the transitway. A 600-ft length of New Jersey-type barrier formed of precast concrete sections was supplied by SDHPT for the tangent and curved section parking tests. The sloping shape of the sides of this type of barrier not only assist in redirecting vehicles upon impact, but also provide a warning (tire scrubbing) to drivers before the vehicle itself hits the barrier.

The drivers were instructed to accelerate their buses to 35 to 40 mph and approach the line of barriers in the center of the transitway. They were to then move to the left side of the lane and position their buses as close to the barrier as was comfortable. This parking maneuver was performed both with the bus engine on and while coasting with the engine off. The power steering was not deactivated when the power was switched off but the maneuverability of the bus was hampered by the lack of power. Parking the bus on the left side of the transitway allowed the driver to have a clearer view of the distance between bus and barrier and also facilitated the possible exit of passengers through the doors on the right side of the bus. The distance between the toe of the barrier and the edge of the far side of the bus was measured at the front and back of the bus. Four to eight attempts, with and without engine power, were made for both curved and tangent transitway sections. The difference between the transitway width and this parking distance is hereby referred to as the clear width.

Passing Maneuver Simulation

The one-lane transitway test site consisted of barrels, W-beam guardrail sections, and concrete barriers that were arranged as shown in Figure 2. The short (100-ft) section of concrete barrier and barrels on the left side of the lane was moved to pro-

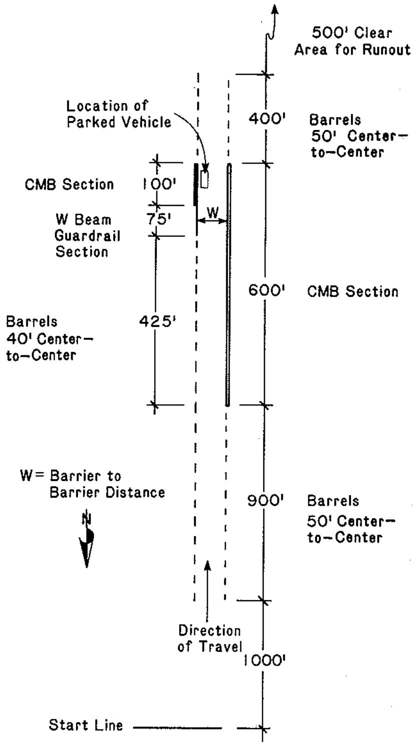

FIGURE 2 One-lane tangent and curved section passing test site configurations.

vide the appropriate transitway width for the test, whereas the long section remained stationary. Single-lane transitway widths of 19.5, 20.5, and 22.0 ft were used. Nighttime operation, without luminaire lighting, was tested for 19.5- and 20.5-ft transitways.

The bus was parked (stalled) on the left side of the simulated transitway, as will be the policy in the Houston system. The curved section was curved 3 degrees and the buses approached from the northeast and exited to the southeast. METRO advisors determined that the configuration with a bus parked inside, rather than outside, the curve represented the most difficult passing maneuver. Neither of these layouts had lane markings for the passing test; this provided less guidance to the driver than would actually be present during normal transitway operation.

The speed versus distance data were collected by attaching an instrumented fifth wheel to a bus and a van (the two types of passing vehicles). The 2,400-ft length of roadway (Figure 2) was provided in advance of the test site so the drivers could accelerate from 0 to 50 mph and then decelerate to a speed they felt was comfortable to pass the "stalled" vehicle (bus or passenger automobile). A distance of more than 500 ft was provided after the test site to allow the driver to accelerate back to at least 30 mph.

The bus drivers were instructed to pass the stalled vehicle at speeds that were comfortable for them, assuming they had a full load of passengers. They were to ignore the possibility, which is present during actual operation, that people might step out of the stalled vehicle into the path of the passing bus. This possibility would have lowered the passing speeds to less than 10 mph, for safety reasons, at any one-lane transitway width of less than 25 to 30 ft. Ignoring the possibility that passengers might exit therefore allowed the passing speed to vary strictly according to the width of the transitway.

BUS AND VAN BREAKDOWN SIMULATION

The unadjusted data that were obtained from the several bus parking tests are shown in Figure 3. The distance from the concrete barrier to the far side of the bus was measured at both the front and back of the parked bus. Because of the relationship of the shape of the bus to the shape of the concrete barrier, it is possible for the measured parking distance to be less than the 8.5-ft width of the bus. The barrier layouts and approximate parking locations for the simulated tangent section are shown in Figure 2.

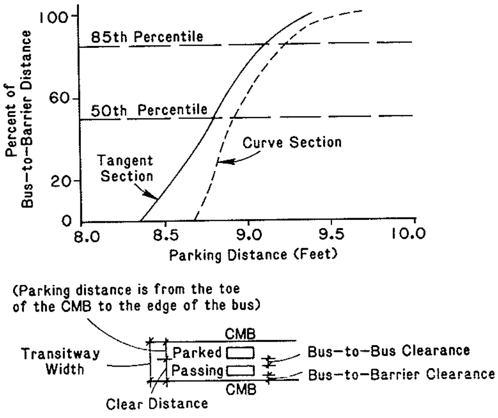

FIGURE 3 Transit bus breakdown parking test data.

The 85th percentile distance used in positioning the buses for the passing speed tests was 9.1 ft for a tangent section and 9.2 ft for a curved section. The clear widths (Figure 3) used in the estimation of passing speeds were obtained by subtracting the parking distances of 9.1 and 9.2 ft for tangent and curve layouts, respectively, from the distance between concrete barriers. This clear width could be expected for at least 85 percent of the controlled breakdowns. The impact of the variation in clear width on passing speed and the cost of transit operation during a vehicle breakdown is examined in the "Delay in the Bus Passing Maneuver" section of this paper. In that section, the costs of breakdowns that close the lane and those that only slow passing speed are estimated and conclusions are made as to minimum and optimum transitway widths.

Tests were conducted with the engine on and off. A 0.1- to 0.3-ft increase in parking distance was observed with the engine off. A decrease of a similar distance was noted between the first and last set (three to four parks per set) of tests with the engine on. A difference in performance according to level of experience was also observed in the passing tests.

Values for passenger van parking maneuvers were obtained by using an experienced van driver and show less variation than those of the bus drivers, possibly because of the relative ease of parking a van. The values also indicate that a stalled bus occupies nearly 2 more ft of lane space than a van, which led to the conclusion that during controlled (nonaccident) breakdowns, transit buses will constrict the clear width much more than vans.

BUS BREAKDOWN PASSING TESTS

Most of the study concentrated on obtaining speed versus distance data for several different transitway configurations. The learning experience of the bus operators over the week of testing previously referred to required several adjustments to be made in the actual data before expected speed-distance curves could be developed.

Adjustments to actual data were made to estimate the passing characteristics of novice and experienced transitway bus operators. The term "novice" refers to the average of the results of the two professional bus drivers at the beginning of the week of testing. The term applies to those bus drivers who have general experience, but little transitway experience. The term "experienced" is applied to those drivers who made approximately 45 test runs (passing maneuvers) in this study. Speed versus distance curves for both categories of transit driver are used in the evaluation of transitway designs in the final section of this paper.

Actual Data Points: Passing Tests

The test number in Table 1 indicates how experienced each driver was during that set of tests. Three to

TABLE 1 Actual Data Points of Bus Passing Tests

Transitway Width (ft) and Alignment	Test No.	Mean Passing Speed (mph)	Standard Deviation (mph)	Standard Deviation as a Percent of Mean
19.5, tangent	2	9	5	63
20.5, tangent	5	21	4	19
22.0, tangent	6	42	10	24
19.5 curve	13	16	8	50
20.5 curve	15	32	6	19
22.0, curve	17	38	5	13

five runs per test were conducted; therefore, each driver made about 60 passing maneuvers (17 tests) over the week of testing. The standard deviation of the average passing speed quantifies the distribution in speeds in the actual speed tests. These values could be combined with the recommended curves presented later in this paper to obtain an estimate of the range of passing speeds to be expected. The range of speeds appears to be related more to the width of the transitway than to the driver's level of experience. The narrow lane standard deviations represent a high percentage of the mean speeds; the other deviations represent half of that percentage. Driver perception of the clear width is particularly crucial at narrow clear widths; more variability will therefore be seen in the passing speeds of narrow lanes. It is also shown in Table 1 that both driver familiarity and slight changes in transitway width can result in dramatic improvements in passing speeds. This information is expanded in the following section.

The passing speed of a novice van driver, even in the narrow transitway simulation, was significantly higher than that of professional bus drivers. The relationship of van passing speeds to bus passing speeds remained constant throughout the testing period. A 50-mph van passing speed was attained in all but the narrowest transitway clearances. Therefore, the situation in which a van passes a stalled bus will not affect the operation of a transitway under breakdown conditions.

Passing Speed Adjusted for Driver Experience

Passing tests were conducted at the beginning and near the end of the week for a simulated transitway width of 20.0 ft. The difference resulting from experience gained during about 45 test runs, as shown in Figure 4, resulted in a doubling of passing speeds on a tangent alignment. The relationship shown in Figure 4 applies to the graphs that follow it in order to adjust the data actually collected to the two conditions defined in this test. For the sake of clarity, only that portion of the graph plotted below 45 mph is shown. The plot between 45 and 50 mph is long and almost identical among all the various transitway widths. However, significant differences in the amount of delay occur below 45 mph; therefore, 45 mph is used as the base line for the bus passing speed curves in a later section. The speed curve from 0 to 1,500 ft has likewise been deleted because it was insignificant.

Because operational safety is an important factor in the design of a narrow transitway, the recommendations made in this paper are derived from novice driver behavior. This should be remembered when analyzing the figures. The descriptions of curves that follow attempt to show all relevant comparisons between driver experience, transitway width, transitway alignment (curved versus tangent), and lighting conditions (day versus night) without recommending any particular widths. These curves only describe the operating behavior that could be expected under several different conditions. Not all comparisons are available due to the short testing period, but major design features and operational expectations can be ascertained.

Tangent Versus Curved Layouts

The adjusted comparisons for tangent and curved layouts are shown in Figures 5 and 6. The expected passing speeds for 19.5-ft lanes are below 10 mph for both layouts and are not significantly different. The medium-width transitway (20.5 ft) passing speeds increased to 20 mph for tangent sections and 15 mph for the 3-degree curve. The increasing speed differential culminated in speeds of 38 mph and 25 mph for tangent and curved layouts, respectively, in the wide transitway (22.0 ft).

Passing speeds of 5 to 10 mph, as observed in the tests, are possible in narrow clearances with relatively inexperienced drivers. Because of the driver's ability to perceive the clear space, the speed differential between tangent and curved layouts grows as the transitway widens. A driver must slow down to comfortably pass through a narrow gap; as the gap on

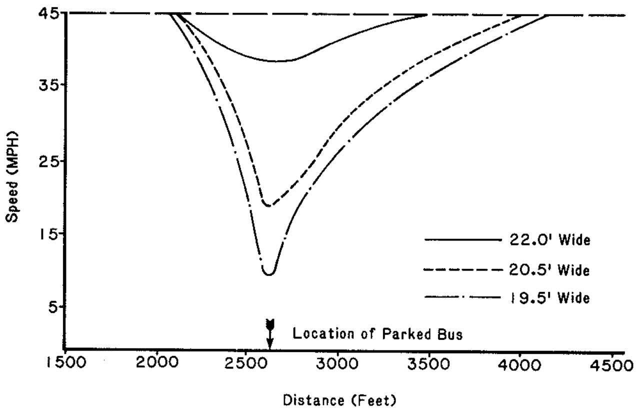

FIGURE 5 Novice driver speed profiles on tangent transitway sections.

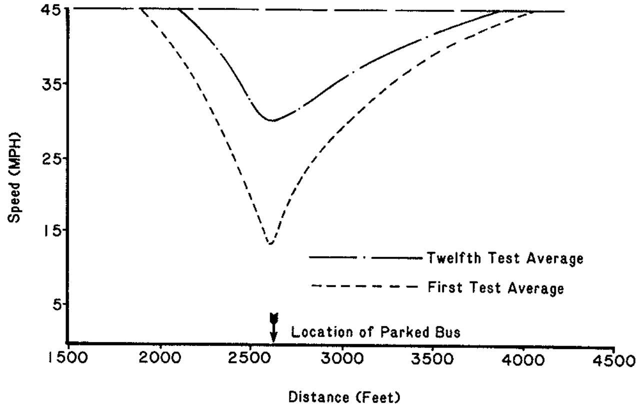

FIGURE 4 Impact of approximately 45 test passes on speed profile of transit bus on 20.0-ft tangent transitway.

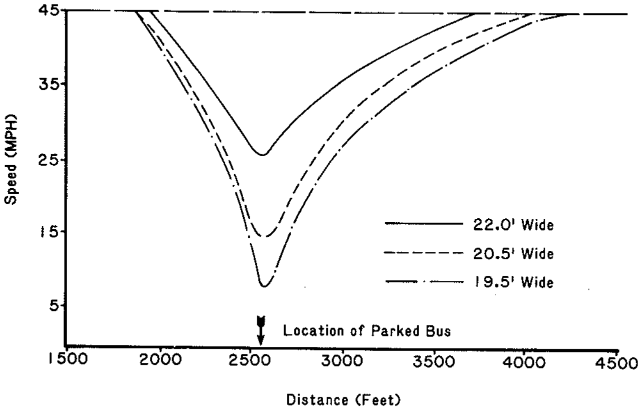

FIGURE 6 Novice driver speed profiles on transitway sections with 3-degree curves.

a tangent layout widens, the bus operator can adjust his speed accordingly. The passing maneuver on a curve, however, does not allow for such an immediate judgment to be made. The passing speeds on a 19.5-ft lane are almost identical, but the driver decelerates more gradually on the curved layout.

Day Versus Night Conditions

Two different transitway widths were tested at night. The conditions during the night test consisted of no moon, no illumination other than passing vehicle headlights and parked vehicle flashers, and no reflectors on the barriers. These are, with the exception of rain or fog, probably the worst visibility conditions that would actually be experienced. An approximate 5-mph decrease in passing speed was observed for both 19.5- and 20.5-ft tests. The more gradual deceleration observed on the curved layout was also evident in the night passing maneuver.

Novice Versus Experienced Drivers

The estimated improvements in passing speed that could be expected as a result of increased driver familiarity with transitway operations are presented in Figures 7 and 8. The novice driver curves for the tangent and curved layouts are presented in Figures 5 and 6 and the experienced driver curves were estimated by using the relationship presented in Figure 4.

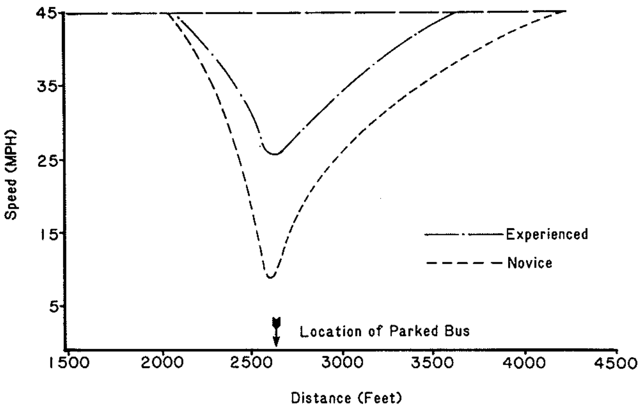

FIGURE 7 Speed profile comparison on 19.5-ft tangent transitway: novice versus experienced driver.

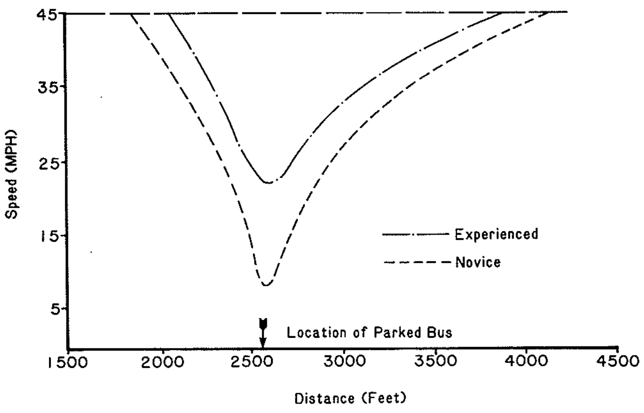

FIGURE 8 Speed profile comparison on 19.5-ft transitway with 3-degree curves: novice versus experienced driver.

Passing operations in all three transitway widths, for both tangent and curved layouts, are estimated to significantly improve according to driver experience. The narrow transitway speeds more than double for experienced drivers. Passing speeds of experienced drivers on 19.5- and 20.5-ft transitways improve by 15 mph, and the passing speed on wide transitways is estimated to be 40 mph or more.

Delay in the Bus Passing Maneuver

Although the passing speed during a breakdown situation is important, an economic estimate of the impact that lower passing speeds have on transit operation can be obtained through the use of delay estimates. The delay in passing time may be defined for transitway traffic as the difference in travel time between unconstrained operation and a situation in which a stalled vehicle is in the transitway. The additional time required to make a trip on the transitway may be estimated by measuring the area between the passing speed curve and a horizontal line at 50 mph. As was previously discussed, the 45-mph value was used in the graphs because all curves between 45 mph and 50 mph were relatively consistent. All transitway widths tested would incur approximately 20 sec of delay between a speed of 45 mph and the normal operating speed of 50 mph.

The values shown in Table 2 indicate that a breakdown on the narrow transitway would result in more than 3 min of delay for every bus driven by a novice driver. The use of experienced drivers would reduce the delay by approximately one-half and increase the passing speed by a factor of 3. Similar reductions are exhibited in medium-wide to wide transitways from the categories of novice driver to experienced driver. The delay also decreases as the lane widens. Passing a stalled vehicle on a tangent section of 22.0-ft transitway is not estimated to result in any more delay than the 20 sec between 45 mph and 50 mph. Novice drivers on a wide (22.0-ft) curved layout, however, may still experience a delay of 2 min.

TABLE 2 Estimated Bus Passing Speed and Delay

	Novice Driver		Experienced Driver	
One-Way Transitway Width (ft) and Alignment	Passing Speed (mph)	Delay (sec)	Passing Speed (mph)	Delay (sec)
19.5, tangent	9	200	26	110
20.5, tangent	20	155	35	80
22.0, tangent	38	55	45+	20
19.5 curve	7	215	23	135
20.5, curve	15	180	32	95
22.0, curve	25	120	38	50

Note: "Novice" refers to professional bus driver at the beginning of the test. "Experienced" refers to professional bus driver with approximately 45 test runs. "Delay" is the difference between a constant 50-mph speed and each estimated speed profile.

The parking distances on tangent layouts shown in Figure 3 are used in Figure 9 to estimate the percentage of controlled bus breakdowns that could block narrow transitways. According to the collected data, any transitway wider than 19.0 ft would never be blocked because of a nonaccident bus breakdown, but a 1-ft decrease in barrier-to-barrier width would increase the blockage rate above 80 percent. In addition, the use of a required clear width of 9.5 ft results in extremely slow passing speeds because an 8.5-ft bus with a 0.7-ft wide driver's side mirror

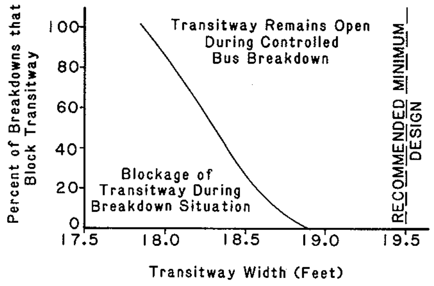

FIGURE 9 Percentage of controlled bus breakdowns that block transitway.

leaves only 0.3 ft of total clear space. The percentage of blockage would decrease somewhat over time as drivers became more familiar with the parking maneuver, but any width of less than 18.5 ft would almost certainly result in transitway closure if buses broke down.

Estimates of the cost of delay to transitway users per peak-hour breakdown can be obtained by using the data on Figure 9 and the values for delay in Table 2 to generate the delay cost estimates in Figure 10. If typical breakdown rates are assumed, 15 bus breakdowns and 75 van breakdowns can be expected each year. The delay cost is calculated by multiplying the probability of the event (lane closed or open) to the value associated with that event. Peak-hour volumes of 50 buses and 300 vanpools were combined with an incident time of 30 min. Values of $50 per bus operating hour and $7 per passenger hour were used to assess the cost of delay.

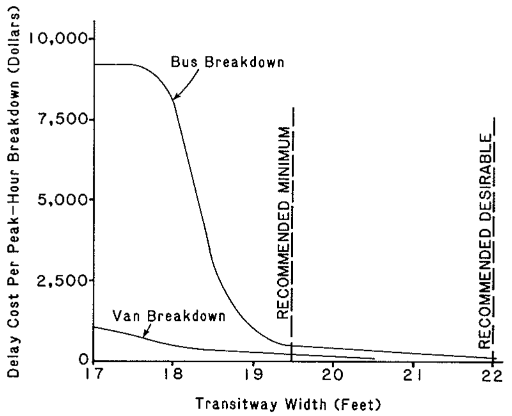

FIGURE 10 Cost of delay of a peak-hour breakdown on tangent transitway.

The stalled vehicle, whether it blocked the lane or not, was estimated to be parked for 30 min, which accounts for the time to detect the stalled bus, dispatch a tow truck, transfer passengers, and tow the disabled bus. A curve similar to that in Figure 9 was used to develop the van breakdown curve.

The sharp curve at 19.0 ft in the line representing the cost of a bus breakdown in Figure 10 reflects the increasing probability that the transitway will be blocked as the width of the lane decreases. The simulation of a lane blockage accounted for an estimated 70 vehicle-hours of delay and a queue in excess of 1 mi for each transitway closure. The probability of this occurrence was multiplied by the value of that delay ($9,250) and added to the remaining probability and an estimated passing delay if the lane was not blocked. The estimated increase in the cost of delay from less than $500 per incident on a 19.5-ft lane to $3,000 for an 18.5-ft lane and to more than $7,500 on an 18.0-ft transitway illustrates the importance of maintaining sufficient width on all sections of the transitway for stalled-bus parking. This curve can be used to determine minimum and optimum transitway widths.

MAJOR FINDINGS CONCERNING THE DESIGN AND OPERATION OF TRANSITWAYS

Data that can be used to develop guidelines for the design and operation of a transitway facility enclosed by barrier walls have been presented. Safety considerations, as well as passing speed and delay times, can also be used to develop the suggested guidelines.

Design Guidelines

Bus drivers and METRO supervisory personnel both had a strong preference for the standard New Jersey-type concrete barrier with flared bottoms. This is important because barriers with vertical walls were being considered in order to increase space in the transitway. Experience with the parking tests and passing maneuvers in tight clearance sections also suggests that the drivers used the wide bottom of the barrier as a guide to position their vehicle. As they became confident that the tire could be rubbed on the bottom of the barrier without damaging the body of the bus, the drivers were able to park the bus much closer to the barrier.

The travel speed and delay values summarized in Table 2 and the delay cost curve shown in Figure 10 were used to develop both minimum and optimum widths for reversible transitways. A minimum width of 19.5 ft allows one bus to park on the left side of the transitway and another bus to pass on the right. Parking test data indicate that, under controlled breakdown (nonaccident) situations, the clearance between the right side of the parked bus and the barrier will allow other drivers to slowly pass a parked vehicle. Increasing the width by 2.5 ft, which is desirable, would allow the passing speed to increase to almost 40 mph, which would result in little delay to passing vehicles. The optimum width also provides additional flexibility in the parking location for disabled vehicles and, thus, greater assurance that the transitway will remain open when a vehicle breaks down in it.

Sections that are curved more than 2 degrees should be widened a minimum of 0.5 ft and an optimum of 1.0 ft. The increases in width of curved sections would allow passing speeds to remain consistent with those of tangent sections.

Pavement markings for the reversible transitway should delineate a 12-ft lane in the center of the transitway. A solid white, 4-in. stripe of paint should be used to delineate the lane. A disabled bus would use the left side of the transitway for parking. Striping the lane in a manner that would provide a single, wide shoulder on one side of the transitway, thereby forcing the bus operators to drive near one barrier, could lower operating speeds relative to a center lane operation. Also, because the lane is reversible, a stalled or parked vehicle would have to park on the left side of the transitway; if the bus was parked on the right side, the door would be next to the concrete barrier and passengers would not be able to exit.

Operation Guidelines

This paper dealt primarily with the case of a bus passing another bus, because this maneuver had the greatest impact on passing speed. Other passing tests indicated that little deceleration (less than 15 mph) could be expected when a van passes a bus. In all cases, a stalled van would not narrow the width of the lane as much as a stalled bus would, thereby allowing higher passing speeds.

The two bus drivers in these tests were told to ignore the possibility that passengers might disembark from the stalled vehicle into the path of the passing vehicle, thus allowing the passing speed to vary according to the clear width only. In actual operation, the concern for passenger safety would lead to slow (less than 10 mph) passing speeds for clear widths up to 25 to 30 ft. These safety considerations must be resolved before operating speeds can reach the levels obtained by experienced drivers indicated in this paper. The driver of a stalled vehicle could be instructed to keep all passengers inside until another vehicle (relief bus or van) arrives on the scene and keeps other vehicles from passing. Passengers from the stalled vehicle would then transfer to the "blocking" vehicle and resume their trip.

One of the most important results of this study is the realization of how vital previous driver training is to the successful operation of a transitway. Curves were derived to show the improvement in passing speed from the novice to the experienced driver. This increase in speed reduces delays, but, more importantly, it reduces the potential for accidents by allowing a more constant speed to be maintained. Training drivers in the parking maneuver also provides greater assurance that breakdowns will not result in a total blockage of the transitway. The cost of a lane closure is shown in Figure 10.

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Improved Service Strategies for Small-City Transit

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ABSTRACT

At a time when transit operating subsidies are threatened with drastic reductions, finding the most efficient way to provide adequate service has become extremely important. Models that have recently been developed to optimize or rationalize transit operations do not appear well suited to those small transit properties that form the majority of transit systems and are the most vulnerable to reduced subsidies. The Multiple-Route Transit Optimization Method (MRTOM) model introduced in this paper finds a set of solutions to minimize deficits in small-city transit systems. In the model, the transit system is considered a coordinated set of routes, not a series of individual routes that must be optimized separately. Solutions are presented as a list of the 20 best alternatives to consider, not a single, "optimal" solution that must be accepted or rejected. Each solution in the list includes integer-valued management variables (the number of routes and vehicles in each route) where appropriate, not continuous variables that must be rounded off at the user's risk. As with other models that have comparable objectives, several simplifying assumptions have been made. Tests conducted to date indicate that MRTOM provides useful answers that expand the perspective of the transit manager and the flexibility of the decision-making process.

The job of managing a public transit authority has never been easy. Public transit operations typically arose from the ashes of debt-ridden private transit firms whose rolling stocks and physical plants reflected the ravages of deferred maintenance and inadequate cash flow. In the days of public takeovers, public sentiment and public funding supported the newly established transit operations, but expectations were greater than the resources that were provided. A service region large enough to satisfy the public and its representatives was usually not conducive to economically viable transit operations. Operating costs, especially fuel and labor, rose to threaten transit's self-appointed role as a public utility. Instead of managing a firm, the transit manager was forced to concentrate on developing grantsmanship skills to accumulate every available federal subsidy dollar of the $31.5 billion that UMTA has distributed since FY 1965 (1). Since 1981, the UMTA operating assistance program has been threatened with being phased out by the Reagan Administration. Although Congress has resisted this proposal, the mounting federal deficit and a growing constituency calling for user fees and local responsibility make this threat ominous for transit properties.

In any case, the transit manager would be wise to seek ways to reduce operating deficits. Ideally, this should be done with minimal disruption to the existing system and the region served. Any proposed changes must be well supported by easily understood analyses that offer flexibility to all the actors in the decision-making process. A method is introduced and demonstrated in this paper that allows a transit manager to regain the ability to explore a range of options that preserve a desired level of service while enhancing the financial condition of the operation. The method had its origins in a transit performance evaluation model that has been accepted in the field and that has modest data requirements. Some of the model's distinguishing characteristics are presented in this paper, including an application to a representative small-city transit system.

OPTIMIZATION OF TRANSIT SERVICE

There is a growing body of literature devoted to finding the best way to provide transit service. The objective is normally to reduce operating costs and deficits. The constraints are minimum levels of service (defined in such terms as headway, walking distances, and population served) and upper limits on fares and expenditures. The management choices available to the operator include the number of routes, route lengths, vehicles per route, service frequency, and fare.

The first efforts made toward optimizing transit service probably involved performance evaluation models that provided a computerized means of predicting and evaluating the outcome of proposed transit service changes. Single-route and transit corridor level demand forecasting and optimization models followed (2-9). More recently, systemwide optimization procedures have been attempted (10, Ch.1). The problem is complex and each approach to a solution to date has been based on certain simplifying assumptions. A typical simplification is that all routes will exhibit the same demand characteristics (11,12). In fact, the solution may specify a certain number of identical routes. Another practice that is becoming common is to solve the mathematical programming formulation as a linear program, which assumes that decision variables may take on noninteger variables (10,13). This assumption becomes risky in a problem in which the key variables (number of routes and number of vehicles per route) must be integer-valued; the smaller the transit system examined, the riskier this assumption becomes. A solution that specifies, for instance, 8.60 identical routes with 2.35 vehicles per route is not likely to be well received by the operator of a small transit system. A noninteger service frequency (buses per

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hour) is possible, but it complicates the provision of consistent schedules or timed transfers, especially in smaller cities.

The method described in this paper also makes certain simplifying assumptions, but they are quite distinct from those just mentioned. Because 25 of Indiana's 30 publicly supported transit properties have peak-hour fleets of 26 vehicles or less (14), a special interest is taken in small transit systems, which are the systems that will be most severely threatened by reductions in operating subsidies. The assumptions in this paper were made with respect to the integer nature of the small transit operator's decision variables and to the preservation of the distinction nature of each existing route. The dominant form of transit service in small systems--the pulse system--is also exploited in order to define a reduced set of options to consider in the model. This model was not designed for large systems, but it is a more appropriate tool for managers of small transit systems to use than the continuous models that appear in the literature.

PROVIDING MORE EFFICIENT SERVICE

For a number of reasons, transit system managers are interested in determining what the most efficient route configurations would be if they were free of the fare, route length, and service area requirements or incentives imposed by various levels of government. The findings might inform the manager of

- Clues to revising the system to better operate within the current environment of regulation and subsidies,
- Which subsidy allocation schemes to support and oppose as they are reviewed at the state level, and
- What form service might have to take if current subsidy levels are drastically reduced.

A logical problem formulation might proceed as follows:

1. Objective: minimize system operating deficit;
2. Requirement: carry at least as many riders as are currently carried;
3. Operational variables: fare, route length, and frequency of service; and
4. Data: current values and historical records.

The general manager might first choose to examine individual route corridors to determine the effects of service changes. In each corridor, the intent would be to find which combination of fare, route length, and service frequency would both minimize the operating deficit and maintain current corridor ridership levels. Initially, there would appear to be a large number of combinations to try, but the manager would be wise to first consider those service frequencies that most easily fit within the pulse system concept: one, two, or four buses per hour. The corresponding route lengths can be approximated for each frequency given the average operating speed, the number of vehicles per route, the maximum round-trip time, and a specified layover time (see Table 1). Of course, other options are possible (including noninteger frequencies), but even the pulse system concept can lead to a large number of combinations.

Three ways of providing a service frequency of four buses per hour (i.e., with one, two, or four buses) are shown in Table 1. Longer routes are possible with more buses, but operating costs will also increase. Will the greater ridership levels of the longer routes offset the additional expense? A reliable forecast of ridership is needed to answer that question. Once the number of buses on a route is determined, it must be decided whether longer routes or greater service frequency is desired. A demand forecasting technique is again needed to compare response to different service configurations. The manager knows what each corridor's current operating values are (fare, route length, and service frequency), and what the current ridership level is. The manager will also typically have a good idea of which demand elasticities will be useful in a demand forecasting technique.

TABLE 1 Definitions of Standard Route Options (BxFy)

Option	No. of Buses	Frequency	Route Length (mi)	Round-Trip Time (min)
B1F4	1	4	2	10
B1F2	1	2	5	25
B2F4	2	4	5	25
B1F1	1	1	11	55
B2F2	2	2	11	55
B4F4	4	4	11	55

Note: Route length and round-trip time values are approximations based on an average operating speed of 12 mph, a CBD layover duration of 5 min, and a maximum round-trip time of 55 min.

DEVELOPING A DEMAND FUNCTION

The responsiveness of ridership levels to changes in fare, in-vehicle travel time (IVTT), out-of-vehicle travel time (OVTT), or other variables is usually described in terms of elasticity. Because the method by which elasticity is incorporated into a demand model can have a significant impact on the model's behavior, various methods of measuring demand response to changes in service variables were examined (15) and the following demand function was adopted:

$$Q = K\ (\mathrm{IVTT})^{\alpha}\ (\mathrm{OVTT})^{\beta}\ (\mathrm{FARE})^{\gamma} \tag{1}$$

This equation is a product form of the demand function. Because the usual objective is to predict the level of ridership (Q) that will result from new values of FARE, IVTT, and OVTT, based on existing values Q_O, FARE_O, IVTT_O, OVTT_O, and calculated or assumed elasticity values, Equation 1 is more useful when expressed as the following:

$$Q = Q_O\ (\mathrm{IVTT}/\mathrm{IVTT}_O)^{\alpha}\ (\mathrm{OVTT}/\mathrm{OVTT}_O)^{\beta} \times (\mathrm{FARE}/\mathrm{FARE}_O)^{\gamma} \tag{2}$$

Equations 1 and 2 make use of point elasticities, which are different from the shrinkage ratio, arc elasticity, and pivot point methods of quantifying ridership changes in response to changes in service variable values. Point elasticities possess the mathematical consistency, convenience, and precision required in the iterative equilibrium-seeking components of the model (15,16).

THE MANUAL ANALYSIS CONTINUED

Even with such a mathematically convenient and consistent demand model, the manager would still have much work to do to implement a manual corridor analysis. For each service combination in Table 1, the manager must seek a fare that generates enough revenue to minimize the operating deficit and still meet a prescribed ridership target, for example, the status quo. The service combination that leads to the lowest deficit solution is the preferred strategy in the corridor under study.

If this manual method appears tedious, it is only part of the story. Another dimension must be added to these calculations. If patronage levels increase, so will the time to board and discharge passengers, which would result in a reduction of the overall operating speed and the route length possible to cover during a specified round-trip time. As the length of the route is reduced, so is the ridership level, until a route length equilibrium is reached for a given combination of Q_0 and FARE. Of course, each time FARE is changed in a search for a minimum-deficit condition, the equilibrium is disturbed and must be reestablished.

Models are available on which to base this process of searching for an equilibrium. One of these models is the Transit Performance Evaluation Model (TPEM), which can be modified to take inputs of the sort involved in the manual analysis and convert them to ridership and deficit values (17). Although TPEM can ease the computational burden associated with a corridor analysis, the user must still provide one set of input values after another in a trial-and-error search for a minimum-deficit solution that maintains existing ridership levels. TPEM was the stepping-stone to the method introduced in the following section.

AN AUTOMATED METHOD

The type of corridor analysis described earlier is clearly awkward and tedious. Furthermore, the results of an analysis of a single corridor would be of limited practical value in an analysis of the complete transit system. It is quite likely that each corridor's separate equilibrium solution would lead to a different FARE value, but route-specific fare structures are inequitable and unacceptable. A proper systemwide solution with a common fare structure that maintains total system ridership and clearly specifies the best service configuration for each individual corridor is certainly beyond the capability of any manual or intuitive procedure. A computerized Multiple-Route Transit Optimization Method (MRTOM) was developed to generate systemwide solutions for the transit manager to consider (16). The following list summarizes the major steps in MRTOM:

1. Read basic input for system and each route (see input list that follows this list);
2. Convert basic input into characteristics for each route that are suitable for processing by MRTOM;
3. For each option (BxFy, where B is bus, F is frequency, and x and y are their respective numbers) on each route find the route length and ridership level that correspond to the minimum deficit at the current average fare; these are known as the initial equilibrium solutions;
4. For each system service combination, adjust the system fare and each route's length to minimize the deficit and achieve the target ridership level; and
5. Output: rank system combinations with the lowest deficits; list the best 20. Rank system combinations that have the lowest deficits and fares within a prescribed range; list the best 10 (see the output list).

The basic inputs for MRTOM are as follows:

Required input:

- Operating cost per vehicle hour ($);
- Operating cost per vehicle mile ($);
- Average fare ($); and
- For each existing route: route identifier, round-trip length (mi), round-trip travel time (min), number of buses in service, frequency (buses/hr), stops per mile, ridership per hour, and service options to consider.

Optional (input defaults available):

- Average boarding or alighting time (sec/passenger);
- Stopping/starting delay (sec/stop);
- Minimum and maximum acceptable fares;
- Elasticities (FARE, IVTT, and OVTT);
- Assumption regarding relationship between ridership level and route length; and
- Definition of each route service option to consider: frequency (buses/hr), round-trip time (min), number of buses on route, and average out-of-vehicle travel time (min).

MRTOM provides the following output:

- Echo of input data;
- Route characteristics derived from input data: vehicle speed, average OVTT, boarding and alighting passengers per stop, and operating deficit;
- Preliminary equilibrium solution for each option selected on each route at current average fare;
- Twenty system combinations with the lowest operating deficits, consisting of a specified option (BxFy, route length) for each route; route-by-route estimates of ridership and speed, and system fare, ridership, and operating deficit; and
- The 10 lowest-deficit system combinations within the prescribed range of fares (with same details as top 20 combinations).

APPLICATION TO AN ACTUAL SYSTEM

With a peak-period fleet of 17 buses, the Greater Lafayette Public Transportation Corporation (GLPTC) is representative of most transit systems in Indiana and many small-city transit systems in the United States. GLPTC operates 13 routes on a timed transfer basis, with a transit center in downtown Lafayette. During the average peak hour, the ridership level is 248 and the operating deficit is about $285. The current peak service is summarized in the second column of Table 2. When selecting options for each route from among the seven options available, the following rules of thumb should be applied:

- If a route has a cost recovery ratio (reve-

TABLE 2 GLPTC Peak-Period Analysis

Route No.	Current Service Combination[a]	MRTOM Lowest Deficit Solution[b]
1	B1F2	B1F1
2	B1F2	B1F1
3	B1F2	B1F1
4	B4F4	B1F1
5	B1F2	B0F0
6	B1F2	B0F0
7	B1F2	B1F1
8	B1F2	B0F0
9	B2F4	B1F2
10	B1F1	B1F1
12	B1F2	B1F1
13	B1F2	B1F1
15	B1F2	B0F0

[a] Avg fare, $0.346; system deficit, $285/hr; peak fleet, 17 buses.
[b] Avg fare, $0.367; system deficit, $105.24/hr; peak fleet, 9 buses.

nues divided by operating cost) below the system average, include the B0F0 (discontinue route) option.

- Do not select options BxFy for which hourly $Q_o > y * V$ in peak periods or for which hourly $Q_o > y * 2V$ in the off-peak period, where y is frequency and V is the maximum acceptable number of passengers to be carried on a bus. This screens out most of the relatively infrequent capacity-violating cases before the solution process begins.
- Because option B1F2 is generally a weak option, try a longer route with the same (B2F2) or minimal (B1F1) service, if capacity constraints will allow it.
- To make up for ridership lost elsewhere, especially where the B0F0 option is used, try to increase service on routes with better-than-average values of ridership, cost recovery, and deficit per passenger.

The first test of MRTOM is its ability to reproduce existing conditions. Using cost data and an allocation formula provided by GLPTC, the average peak-hour deficit was estimated to be $285. MRTOM's route-by-route deficit calculations, which were derived from the input data, sum to a deficit of $286 per peak hour. Because both values are estimates, the almost exact match of the two cannot be taken too seriously, but at least MRTOM's solution process has a sound starting point.

MRTOM's lowest deficit solution is shown in the third column of Table 2. Besides reducing the peak-hour operating deficit by 63 percent, the solution requires only nine peak-hour buses. Thus, possible capital savings are also identified.

The full output displays the 20 distinct service combinations that have the lowest deficits, from $105.24 to $115.41 per peak hour. In each of these 20 best solutions, four or five of the six routes with the lowest current cost recovery values are abandoned. The ridership lost on these routes is recovered by making most surviving routes longer and, presumably, more circuitous. The conversion of the B1F2 option to the B1F1 option is a common example in Table 2 in which a 25-min route that is operated twice an hour is converted into a single 55-min round-trip. The 20 combinations provide the decision makers with a basis for comparison to evaluate which routes to abandon, and a financial analysis with which to balance political arguments. For example, Route 15 is always assigned the B0F0 option in the 20 best solutions, while Routes 5, 6, and 8 are slated for abandonment (or partial coverage by expanded adjacent routes) at least 17 times each. Routes 3 and 7 get the B0F0 option 4 and 10 times in the top 20 solutions, respectively, but never in the same solution. MRTOM's list of 20 solutions illustrates various trade-offs and informs the decision-making process; it does not attempt to replace that process.

The list of solutions can also indicate trends that call for more careful analysis. The conversion of many B1F2 routes to the B1F1 option is based largely on the presumption of relatively inelastic peak-hour demand with respect to IVTT ($\alpha = -0.35$) and OVTT ($\beta = -0.70$) (17). These elasticities are often based on outdated or borrowed data. A special survey or a single-route trial service change may be needed to update these values before systemwide service changes are inaugurated.

Sometimes none of the 20 best system combinations is totally acceptable to the decision makers. For example, a policy of one-hour headways and acceptance of route abandonment in more than one or two corridors may not be politically desirable. Running MRTOM again with a correspondingly revised set of route service options will produce a new list of 20 system solutions with deficits and service values that can be compared against the original, less politically constrained list. Both solution lists will be optimal within the constraints reflected in the route options selected. MRTOM allows a more explicit analysis of the cost (increased subsidy) of adding or retaining service above the basic level needed to meet a specified ridership.

TESTING MRTOM FOR FLEXIBILITY AND FEASIBILITY

Several sets of analyses were performed to test the model and learn more about the pattern of solutions it provided. Besides the deficit reductions possible in each case studied, several interesting, logical results can be observed. Some of the findings are listed as follows (16):

1. The B0F0 strategy (discontinue route) occurs more often for lower system Q_o's. This strategy may be politically infeasible, but the presence of alternative combinations without B0F0 strategies in the solutions list allows the cost of such political considerations to be assessed.
2. Discontinuing service on the least-patronized routes leads to lower fares on the remaining routes. It is more economical to attract more passengers on the remaining routes by lowering fares than to maintain service on routes with low ridership levels. Of course, these economic considerations may be overruled, but the list of solutions includes many alternatives that can be checked against other criteria.
3. The MRTOM solutions list repeatedly demonstrates the trade-off between better service and lower fares. A higher service frequency is compensated for in the MRTOM equilibration phase by a higher fare.
4. The flexibility in choosing among alternative service combinations is demonstrated by the fact that drastically different solutions can appear near each other in a list. In one list, the sixth best combination consisted of no service to Route 2 and low fares (15 cents) with minimal service (B1F1) on the remaining routes. The next best combination in the list offered a relatively high level of service (B4F4/B2F2/B1F1) with an average fare of $1.76. If neither a loss in service nor an increase in fares is acceptable, a compromise combination usually appears nearby in the list.
5. The B2F4 option seldom appears in any solutions list. If two buses are to be used on a route, the B2F2 option is a superior solution as long as serving a longer route attracts more new passengers than serving a shorter route twice as often. If a frequency of four buses per hour is desired, the B4F4 option likewise permits a longer route length than the B2F4 option and, in most of our examples, either a higher ridership level or a lower deficit for a given fare, or both. In the tests conducted, the B1F4 option was not competitive for a system with an average route ridership level greater than 25 per hour, but it consistently outperformed the B2F4 option until the high small-city ridership level of 100 per hour per route was reached.

The relative frequency of a combination's appearance in a solutions list largely depends on its elasticity values. If service elasticities (IVTT and OVTT) are more sensitive than fare elasticity, then MRTOM can be expected to favor combinations with higher service frequencies and some limitations on route length based on the number of buses in use. After this proposition is tested, long-route low-frequency combinations could be manually excluded from the input (i.e., not requested) to reduce computation time.

SUMMARY

Recent attempts at optimizing the operations of transit systems (10,11,16) reflect both the increasingly difficult financial environment of transit systems and the trend toward applying more sophisticated analytical tools to systemwide (rather than route-by-route) analysis. These tools will be more quickly accepted if they are not unrealistically "data-hungry" and if the results are truly useful. The objectives of the MRTOM model described in this paper are to (a) provide a decision aid to the small-city transit manager, (b) take a large step toward true optimization of transit systems, (c) make the best use of data currently collected, and (d) provide a variety of useful solutions to enlarge managers' decision-making perspective instead of confining them to a single, "optimal" solution. In order to accomplish those objectives, MRTOM is based on certain simplifying assumptions that differ from those in other models. The assumptions in MRTOM appear to be reasonable in the context of small-city operations, based on the quality of results of a variety of hypothetical cases and on tests run on actual transit systems.

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A Comparison of Privately and Publicly Owned Bus Companies and a Public Bus Transit Agency

ANTTI TALVITIE and ARI HEINILÄ

ABSTRACT

An examination is made of the level of service provided to patrons, the cost structure, the productivity, and the profitability of the companies that offer regularly scheduled bus service in the Metropolitan area of Helsinki, Finland, which includes the cities of Espoo and Vantaa. Data are given on the following types of bus companies: city-owned, private, and a public bus transit agency, Helsingin Kaupungin Liikennelaitos, in Helsinki. The data are averages, and they conceal a variance that is often substantial. It is believed that this variance is due more to management and managerial skills than to economies of scale or operating environment. Unit costs of bus transportation in the Helsinki region and the composition of these unit costs are presented. A discussion of productivity concludes the paper.

The Helsinki metropolitan area is composed of three cities--Helsinki, Espoo, and Vantaa (Figure 1). Both the population and employment are centered in Helsinki, as shown in Table 1. Three types of companies offer regularly scheduled bus service in the Helsinki area. Within the city of Helsinki, service is offered by the city's transit agency, Helsingin Kaupungin Liikennelaitos (HKL). A small part of HKL routes is operated by private bus companies for which HKL acts as service sponsor. In and from Espoo service is offered by several private bus companies and by a bus company owned by the city. The city is a sponsor for some normally unprofitable bus routes. The same arrangement prevails in Vantaa, where the number of sponsored routes is larger than that in Espoo.

The sponsored routes are awarded in negotiations with the operators. The principle of the historically owned traffic market plays a dominant role in these complex negotiations, which deserve a study of their own. Suffice it to say that because bus routes, schedules, and (maximum) tariffs are regulated, the private operators' last line of defense is to hang on to the market that they captured when regulation was less intrusive to private initiative.

The purpose of the study on which this paper was based (1) was to examine the level of service provided to the patrons, the cost structure, the productivity, and the profitability of the companies operating in the Helsinki area. The data pertaining to individual companies are confidential at their request. By permission the data to be reported are averages, weighted in the following ways: (a) the two city-owned companies (in Espoo and Vantaa); (b) all the private bus companies; (c) the Espoo-based companies, including the city-owned company; (d) the Vantaa-based companies; and (e) HKL, Helsinki's transit agency.

The averages conceal a variance that is often substantial. Without quantitative analysis, the authors believe that the variance is due more to management and managerial skills than to economies of scale or operating environment.

The paper is organized as follows: discussion of the data source and the operating environment, routes and patronage, level of service, tariffs, and the current financial situation of the bus companies; presentation of the unit costs of bus transportation in the Helsinki region and the composition of these unit costs; and discussion of productivity.

DATA SOURCE

The private bus companies provided their data generously. Ambiguities and matters of interpretation were clarified in confidential discussions. These data are considered accurate and reliable.

City-owned companies were reluctant to provide access to data and even to discuss them. Their data were obtained from the annual reports, schedules, and an annual legally mandated vehicle inventory. These data are not as good as those from the private companies, but every effort is made to ensure their accuracy and reliability.

HKL cooperated fully in the study; the agency did not provide access to bookkeeping but produced the data specified by the authors. Some data were subject to interpretation, because HKL also operates trams and a subway link. Nevertheless, every effort was made by both HKL and the authors to ascertain that only HKL's bus operations were covered by the data.

The data given in the paper are comparable and permit reliable cross-comparisons. Not all the data the authors wanted were available.

ROUTES AND PATRONAGE

In the Helsinki region some 320 bus routes are operated daily. Of these, 230 (70 percent) are covered by the study. The remainder are operated by small companies that did not wish to participate in the study, were in the process of merging or had just recently merged with another company, had an abnormally short or long accounting period as permitted by Finnish law, or operated on only a few routes.

The bus routes, schedules, and tariffs for intracity operations are regulated by the city itself. Intercity routes and schedules are chartered by a regional, politically appointed policy-making body

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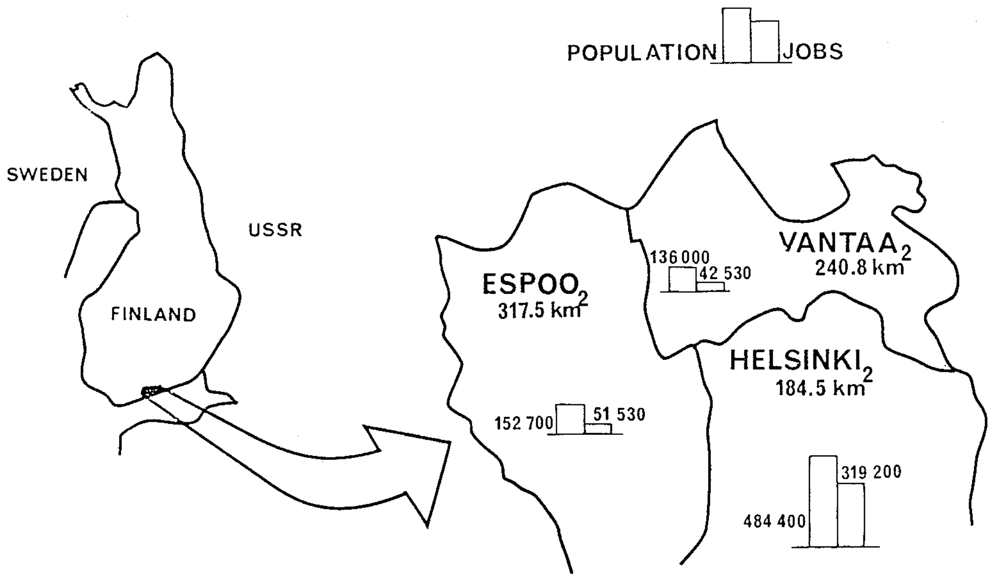

FIGURE 1 Study area.

TABLE 1 Bus System Attributes in Helsinki Region, 1982

	HKL[a]	Espoo	Vantaa	Total
Bus kilometers per population	43	94	99	63
Bus kilometers per square kilometer	117,720	45,120	56,425	65,490
Avg bus speed (km/hr)	20	30	33	
One-way route length (km)	10	19	26	
Patronage (passengers/yr)				
Peak	190,000	33,000	32,000	255,000
Off peak	175,000	31,000	26,000	232,000
Bus trips per population	0.77	0.48	0.47	0.66
Passengers per bus kilometer	4.4	1.3	1.2	

[a] Helsingin Kaupungin Liikennelaitos, Helsinki's transit agency.

similar to a regional transit authority, but the fare tariff is decided by the Ministry of Transport.

Of the bus route kilometers studied, the private operators provide 41 percent; the city companies, 19 percent; and HKL, 40 percent (Figure 2). The distribution of total bus mileage among the three types of operators is 46, 23, and 31 percent, respectively. Figure 2 also shows the distribution and volume of passengers. Private operators serve 21 percent; city companies, 8 percent; and HKL, 71 percent of the total transit demand carried by bus.

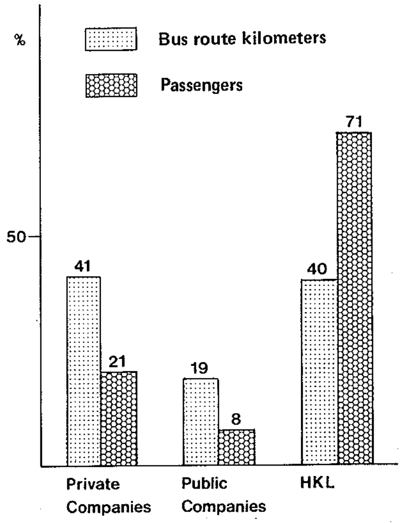

FIGURE 2 Distribution of bus kilometers and passengers in Helsinki region, 1982.

LEVEL OF SERVICE

Bus service coverage and selected route and patronage information are given in Table 1. Service is the most dense in Helsinki, where there are short walk distances, headways, and route and trip lengths. Headways are 3 to 7 min during the peak period and 4 to 16 min during the off peak. An unspoken objective is to eliminate the need to remember the timetable. HKL's service is directed to the central business district (CBD).

In Espoo and Vantaa the trip attributes are longer. However, because the bus routes overlap after the residential collection area has been passed, headways may be markedly reduced by walking further to reach the buses when they are operating on the main line. The private operators offer a very good level of service from Espoo and Vantaa toward the Helsinki CBD from early morning well past midnight, weekends included. During the peak, headways vary between 5 and 30 min depending on demand; off-peak headways are twice as long. Schedule adherence is good.

The average bus speed is 20 km/hr in Helsinki and 30 km/hr or more in Espoo and Vantaa. There is an express bus service from Espoo and Vantaa to the Helsinki CBD with an average bus speed of 50 km/hr. Thus in the city HKL looses in speed what it gains with lower headways and shorter walk distances.

Besides walk distance, headway, and route coverage, load factor is an important service attribute. Substantial differences exist among the companies. Measured at the peak-load point during the peak hour, HKL's load factor was 0.74. In Vantaa and Espoo the corresponding factor was 0.47. During the highest off-peak hour the load factors for Helsinki and Espoo-Vantaa were 0.48 and 0.20, respectively.

HKL's overall load factor is not much greater than that of the other bus operators because the average trip length in Espoo and Vantaa is 2 to 3 times longer. Low monthly and yearly passes encourage the Helsinki citizens to use public transport over

TABLE 2 Bus Size and Load Factors for Helsinki Region, 1982

	Private Company	Public Company	HKL	Espoo	Vantaa
Bus capacity (no. of passengers)	56	59	69	59	54
Seats	44-56	–	37	44-58	44-50
Standees	0-10	–	32	0-10	0-10
Load factors					
Peak	NA	NA	0.74	0.47	0.47
Off peak high	NA	NA	0.48	0.20	0.20
Overall	0.27	0.25	0.30	0.23	0.31
Passengers per bus kilometer	1.3	1.2	4.4	1.3	1.2

short distances. As shown in Table 2, the number of passengers per bus kilometer in Helsinki is 3.5 times that in Espoo-Vantaa.

A better measure to examine the load factor would be passenger kilometers per seat kilometer, but such data were not available. In general, several bus companies knew surprisingly little about their demand patterns, demonstrated by the range in load factors between 0.20 and 0.40 for private operators.

The percentage of seats in the total passenger capacity is 0.54 in an HKL bus and 0.70 in an Espoo-Vantaa bus. For this reason, even during the off peak the likelihood of standing in an HKL bus is rather great. The operators from Espoo and Vantaa make an attempt to offer a seat for each passenger. HKL, on the contrary, attempts to fill the buses. This is also clearly shown by the buses that the companies use. On the average the private companies have the smallest and the largest buses. Table 2 shows both the load factors and bus sizes.

Routes, headways, operating speed, and load factors can be summarized by looking at the vehicle fleet requirements at various times of operation, as shown in Table 3. Designation of the operating hours in Table 3 is flexible because they differ by line. The data show that private companies have more vehicles in off-peak service than do public companies and that the public companies and HKL have too large a vehicle fleet. HKL acknowledges this, but wants to keep the reserve buses in case the subway breaks down.

TABLE 3 Fleet Size by Time of Day in Helsinki Region, 1982

	Percentage of Total Fleet				
Period	Private Company	Public Company	HKL	Espoo	Vantaa
A.M. peak	95	78	77	90	83
P.M. peak	86	76	77	85	83
Base	45	–	27	56	30
Evening	30	–	22	33	23
Night	17	–	8	19	13
Saturday	36	–	30	41	26
Sunday	32	–	23	39	23

Many bus operators, private ones included, were interested in the peak-period data only because they determined the fleet size. Subjective methods and rule-of-thumb procedures were used to make optimal or even effective use of resources. This was seen from the methods used to plan bus routes and to construct timetables and run schedules, and from the lack of knowledge of demand. All this was reflected in the productivity and profitability indices. Immediately, of course, it could also be seen from the bottom line.

TARIFF STRUCTURE

The tariff structure in the Helsinki region was complicated at the time of the study. Three different tariffs existed: the tariff approved by the Ministry of Transport, which applied in intercity traffic and also within Espoo; the city of Helsinki tariff with its low monthly and seasonal passes; and the flat-fare tariff for sponsored traffic in Vantaa. The principal fares and tariffs in 1982 are shown in Table 4. It should be mentioned that only the Ministry's fare schedule depends on distance. HKL's flat fare is expensive for short trips and Vantaa's flat fare very cheap for long trips. (The tariff structure has changed since 1982, and also Espoo and Vantaa now have seasonal and monthly passes.)

CURRENT FINANCIAL SITUATION

The annual bus operations turnover for HKL was approximately \$85 million (\$1 U.S. = 5.4 Finnish marks). For the other bus companies the annual sales ranged from \$1.5 million to \$7 million. The average for the city-owned companies was \$4.8 million and for the private ones \$3 million. Excluding HKL, the bus companies studied were small, with fleet sizes from 23 to 117.

Bus companies engage in economic activity like any firm in the market. The income consists of farebox revenue from the regularly scheduled and charter traffic. There is also minor income from selling old buses.

TABLE 4 Principal Fares in Helsinki Region, 1982

Type of Fare	HKL	Espoo	Vantaa
Single	Adult, \$0.70 Child, \$0.25	\$0.60 up to 6 km + \$0.10 per 2 km	Adult, \$0.60 Child, \$0.30
Multiple	10 trips (10) Aged or handicapped (80) Year pass,[a] \$120 30-day pass, \$12 30-day pass for students and children, \$4	50 trips (30) 25 trips (15) 10 trips (10) Children (50)	30-day pass, \$12

Note: Fares are given in U.S. dollars. Percentage of discount is given in parentheses.

[a] Passes sold only to Helsinki residents.

For the city-owned companies the provision of capital stock monies is also a type of income. The capital stock is provided by the city with zero interest and there is no requirement to pay it back. Private companies borrow their operating capital and pay it back with interest; there is, naturally, a return-on-investment requirement on the invested capital. On a per-bus basis the capital stock is 20 times larger in the city-owned companies than in the private ones.

The city-owned bus companies must accept the operation of sponsored routes, some of which may entail substantial deadheading. The city also plays a role in personnel policy and politics, and the company president has a more limited authority than in the privately owned bus companies.

HKL is similar to the city-owned companies, but in addition to farebox revenue it receives a direct subsidy to cover the deficit. For bus operations this subsidy is about 45 percent of the budget.

In any sustained economic activity, income must be greater than expense. Because Finnish laws permit flexibility in depreciation, taxes, and investment funds, the accounting procedures can yield a deceptive picture about income and costs. Therefore the data chosen to depict profitability of the bus operations include not only the accounting costs and income but also the cash-flow balance (per bus kilometer) and share of income financing. Cash-flow balance differs from the accounting profit in that it excludes depreciation, changes in investment reserve fund, and tax refunds, which may cover several years.

Data in Table 5 show that on the basis of accounting costs and income the city-owned bus companies are as economical as the private ones. However, the net cash-flow balance is 35 percent better for the private companies than for the city-owned companies. Helsinki's transit agency operates at a substantial loss.

There is a large difference between companies based at Espoo and those at Vantaa. Part of this difference is explained by the much newer equipment of the Espoo-based companies. This advantage and the rest of the difference between the two cities are rooted in managerial skills. Again, the (weighted) average conceals large differences among the private companies.

The profit margin of the city-owned companies is unlikely to be as large as that shown in Table 5. Nonetheless, they do quite well. One reason, besides good management, for this profitability is the sponsored routes, whose net yield is greater than that of the "market" routes.

In Espoo the sponsored routes pay $1.10/km and in Vantaa $1.17/km. When these incomes are compared with the costs in Table 5, it is seen that the net yield from the operation of sponsored routes is about $0.20 per dollar in Espoo and $0.35 per dollar in Vantaa. Private bus operators have calculated that the operation of sponsored routes costs roughly 20 percent more than the operation of market routes because buses and personnel are underutilized and there is additional administrative expense. If this rough calculation is even approximately correct, it helps explain why the Espoo-based companies are reluctant to operate sponsored routes and why there is competition for them in Vantaa. The city-owned company in Vantaa operates the majority of the sponsored routes.

Economic assessment of bus operations cannot be based on the average per-bus kilometer cost because this does not in sufficient measure consider the costs of the resources: the buses and the drivers. Bus transportation requires the purchase of buses, hiring of drivers, and operation of buses over a route. In a simplified way, the costs of bus transportation also vary with buses, driver hours, and bus kilometers driven (2). The passengers pay for these costs, in part or totally, as fares. The subsidy provided by the city or the state is paid by citizens as taxes. The greater the costs of bus traffic and the less the farebox revenue, the greater the taxpayer expense.

Because of heightened interest in profitable bus transportation, the emphasis on its costs and productivity is important and the focus of the remainder of the paper.

UNIT COSTS OF BUS TRANSPORTATION IN HELSINKI REGION

Costs of bus transportation are classified into three groups: those that vary with the number of buses, with the driver hours, and with bus miles driven. The composition of these groups is the following:

1. Costs that vary with the number of buses:
    a. Vehicle taxes and mandatory and voluntary insurance payments
    b. Income taxes
    c. Depreciation of buses, other vehicles, buildings, and equipment; changes in investment reserve fund
    d. Interest payments
    e. General overhead expenses such as rental payments, marketing, public relations, vehicle inspections, and taxes
2. Costs that vary with driver hours: wages and benefits
3. Costs that vary with bus kilometers driven:
    a. Fuel, oil, and coolants
    b. Tires, spare parts, and other garage expenses
    c. Work done outside the company (this includes maintenance and repairs done by a private vendor and costs of rented spare buses)
    d. Wages, salaries, and benefits in the garage

There are other factors that affect costs, but the foregoing classification into three groups is illuminating, and bus operators with whom it was discussed agreed with it.

The unit costs classified into these three groups

TABLE 5 Selected Profitability Indices of Bus Companies in Helsinki Region, 1982

	Private Company	Public Company	HKL	Espoo	Vantaa
Income	92	94	109	97	89
Costs	91	91	184	96	87
Cash flow[a]	22	16	−62	24	17
Share of income financing[b]	0.23	0.17	−0.57	0.25	0.18

Note: Indices given in cents per bus kilometer.

[a] Income minus (costs - depreciation - tax refunds - change in investment reserve).

[b] Cash flow gross income.

TABLE 6 Unit Costs of Bus Transport in Helsinki Region, 1982

Cost	Private Company	Public Company	HKL	Espoo	Vantaa
Bus [\$/(bus) (yr)]	21,914	22,328	24,637	25,704	18,684
Driver hours (\$/hr)	6.33	7.57	7.91	6.39	7.00
Bus kilometers (\$/km)	0.22	0.22	0.53	0.22	0.22

are shown in Table 6. Two things stand out: the significant difference in driver pay between the private and public companies and the large bus kilometer costs of HKL. In the following three sections these unit costs are discussed in detail.

Per-Bus Costs

The cost disaggregation in Table 7 is a weighted average of the bus fleet costs of the companies in a given group. Depreciation is the largest expense. The private companies have the greatest depreciation costs, which are close to the legally permitted amounts. HKL's depreciation costs are low, partly because in the past 4 years no new buses have been acquired and there are no plans to purchase any in the next 2 years. All capital funds are currently committed to the subway.

Excluding depreciation and investment reserves, the expenses of the private companies are over \$3,000 per bus lower than those of the city-owned companies and \$9,000 per bus lower than those of HKL. Why is this? The biggest contributor to the difference is seen to be the administrative salaries, benefits, and other general overhead expenses. These are nearly two times higher in the city-owned companies and three times higher in HKL than in the privately owned firms.

Large expenses for salaries and overhead in the city-managed operations are simply the result of excessive bureaucratization. Their service or marketing activities are not so extensive as to affect personnel size. A good point of reference for these expenses is the number of administrative employees per bus: in private companies, 0.16; in the city-owned companies 0.31; and in HKL, 0.40. This is directly related to administrative costs.

There are differences, of course, among the companies in terms of the cost of salaries. Their percentage share of the per-bus costs varies from 6 to 26 percent, the largest percentage belonging to a private company. Thus, there are opportunities for cost reductions in private and public operations alike.

There are also differences between cities. Excluding depreciation, yearly bus costs of Espoo-based companies are about \$2,000 per bus greater than those in Vantaa. The difference is due to interest payments, taxes, and a newer fleet. The range in the interest payments in the sample firms was from 3 to 15 percent of the total bus costs.

Per-bus costs are often expressed only as equal annual payments consisting of depreciation and interest using the capital recovery factor (CRF). This is approximate at best because allocation of lump sum interest payments and depreciation costs to buses is artificial when the fleets have a varied age distribution. The age distribution in turn depends on the market for used buses, the mutually interdependent conditioning and reconditioning of the current fleet, and the need for depreciation to hold taxes down.

Nonetheless, it is interesting to calculate the annual capital expenses by using the CRF, as shown in Table 8. The average age and the salvage values are group specific and based on data. To make a fair comparison, the same interest rate of 14 percent is used. This rate was determined after discussions with the operators and includes the cost of money and the desired rate of return on investment. For example, the accounting interest rate of 6 percent used by HKL does not include such a rate of return; money cannot even be bought at that rate in Finland.

The reader is asked to draw his own conclusions from the data in Tables 7 and 8. Suffice it to say

TABLE 7 Bus Transport Costs That Vary with the Number of Buses, Helsinki Region, 1982

Item	Private Company	Public Company	HKL	Espoo	Vantaa
Depreciation	11,968	9,211	5,723	14,029	8,603
Administrative salaries and benefits	2,840	5,137	9,630[a]	3,221	3,731
Interest, taxes, and insurance	4,742	3,714	4,273[b]	5,167	3,802
General overhead	2,364	4,266	5,011	3,286	2,548
Total	21,914	22,328	24,637	25,704	18,684

Note: Costs are given in dollars per bus per year.

[a] Approximate.

[b] HKL pays no taxes.

TABLE 8 Bus Capital Costs, Helsinki Region, 1982

	Private Company	Public Company	HKL	Espoo	Vantaa
Purchase price (\$)	104,600	105,550	120,350	104,650	104,650
Salvage value (\$)	7,400	4,600	12,150	9,250	3,700
Life (yr)	8	10	15	6	10
Annual cost (\$)	20,960	19,350	17,600	24,500	19,350

Note: $r = 0.14$.

that the data reinforce the conclusions drawn earlier about bureaucratization in city-managed operations and low or no required rate of return. Again, large intercompany and intracompany variances exist in salvage and resale values and in bus age. Some private firms use up their buses and sell them for scrap, whereas others sell their buses when still new at a good price. Large capital expenses are not necessarily bad: new buses mean riding comfort (which may be reflected in demand), low repair and maintenance costs, and high depreciation and low taxes.

Driver Hour Costs

Driver hour costs are dependent solely on driver hours. The private firms do not explicitly count driver hours and only one company was able to give accurate information. The city-owned companies refused to give this information; HKL kept the best records and made them available.

Driver hours are therefore calculated for each company by using certain rules. When compared with actual costs of one private firm and of HKL, the calculated costs were within 3 percent. Consequently, the method was pronounced good and accurate. The results are given in Table 9. The city-managed operations pay 20 to 25 percent higher than the private firms. HKL is known to have generous retirement benefits, as shown in Table 9.

Related to driver pay and affected by peaking and deadheading is the proportion of effective hours (i.e., hours spent on a bus route) to the total bus hours. For the private companies this share was 0.60 and for HKL, 0.48.

TABLE 9 Driver Salaries, Helsinki Region, 1982

	Private Company	City-Owned Company	HKL	Espoo	Vantaa
Wages	5.13	6.09	5.77	5.15	5.69
Benefits	1.20	1.48	2.14	1.24	1.31
Total	6.33	7.57	7.91	6.39	7.00

Note: Salaries are given in dollars per hour.

The total driver wage bill is determined by the number of drivers as well as the pay itself. Opportunities to improve efficiency exist: the number of drivers per bus is 1.37 in private companies, 1.56 for the city-owned companies, and 2.10 for HKL. There also exists a variance in pay scales. The difference between maximum and minimum hourly wages was $2.25/hr in Vantaa and $1.25/hr in Espoo.

Per-Kilometer Costs

Table 10 shows the disaggregation of costs that vary with bus kilometers driven. The costs of private and city-owned firms are roughly equal; HKL's costs are 2.5 times greater, which is due in part to the operating conditions in Helsinki--short intervals between bus stops, heavier bus loads, and older buses.

The differences in shop personnel wages and salaries are substantial and not explained by the operating conditions alone. HKL's shop personnel costs are six times those of the private firms. Private firms have the equivalent of 0.16 person per bus in the shop; the city-owned companies have 0.21 and HKL, 0.69.

There is substantial variance in cost items among the companies. For example, in repair and garage costs the difference between maximum and minimum was $0.054/km, and it was a private firm that had the highest shop personnel costs. In fuel costs the maximum difference was $0.021/km. Again, the opportunities to make economy improvements range from driving skills to good repair and garage management.

Summary

Table 11 shows the cost structure of the bus companies and agencies as a percentage of the total costs. The account for driver wages and benefits is by far the biggest. If depreciation is ignored, the share of driver wages is comparable for all types of operations.

TABLE 10 Bus Transport Costs, Helsinki Region, 1982

	Private Company	City-Owned Company	HKL	Espoo	Vantaa
Fuel and oil	12.4	11.9	19.1	12.4	12.0
Tires, parts, and private vendor work	5.7	5.4	11.5	5.6	5.7
Wages and benefits of shop personnel	3.7	4.3	22.2	3.7	4.1
Total	21.8	21.6	52.8	21.7	21.8

Note: Costs are given in cents per bus kilometer.

TABLE 11 Summary of Unit Cost Structure, Helsinki Region, 1982

	Private Company	City-Owned Company	HKL	Espoo	Vantaa
Fuel and oil	13.6	13.0	10.4	12.9	13.9
Tires, spares, and related work	6.3	5.9	6.2	5.7	6.6
Driver wages and benefits	34.4	40.0	42.2	33.1	39.1
Shop wages and benefits	4.1	4.7	12.1	3.9	4.8
Administrative salaries and benefits	5.4	7.4	11.4	5.6	7.2
Depreciation	22.7	15.0	6.7	24.2	16.3
Interest and taxes	6.5	3.6	2.8	6.7	4.5
Vehicle insurance, taxes, and general overhead	7.0	9.4	8.2	7.9	7.6

Note: Values given are percentages.

TABLE 12 Worker Productivity, Helsinki Region, 1982

	Private Company		City-Owned Company		HKL		Espoo		Vantaa	
	Bus Kilometers per Worker Hour	Employees per Bus	Bus Kilometers per Worker Hour	Employees per Bus	Bus Kilometers per Worker Hour	Employees per Bus	Bus Kilometers per Worker Hour	Employees per Bus	Bus Kilometers per Worker Hour	Employees per Bus
Drivers	18.7	1.37	17.9	1.56	9.5	2.10	18.7	1.44	18.3	1.41
Shop personnel	158.0	0.16	134.5	0.21	30.0	0.69	179.9	0.15	129.7	0.19
Administration	160.8	0.16	90.6	0.31	52.9	0.40	135.8	0.20	125.7	0.21
Total	15.2	1.69	13.5	2.08	6.2	3.19	15.1	1.79	14.2	1.81

It may also be seen from Table 11 that the principal costs are bus depreciation, driver wages, and fuel. This lends further credence to the division of costs into the three groups cited earlier--per bus, per driver, and per kilometer.

PRODUCTIVITY

The unit costs reveal one aspect of bus operations. Worker productivity, demand, and profitability are equally important. In this section some indices of worker productivity are presented. Perhaps the best measure of productivity would be the en-route driver hours divided by total work hours. Such precise data were not available, but rough calculations showed that the average for private companies was 40 percent higher than that for the city-managed operations.

Table 12 shows bus kilometers en route divided by hours worked for three employee groups: drivers, repair and maintenance personnel, and administrative workers (including dispatchers). The data show that the private firms have the highest productivity, but the difference to the city-owned companies is marked only in administration. HKL's productivity is very low in all worker categories, especially those in repair work.

A second production-factor-based measure of productivity, the size of the labor force per bus, is also given in Table 12. These data parallel bus kilometers per hour worked and any differences can be explained by the speed of the buses.

Another angle to productivity, an output measure, is related to demand. The objective of bus transit is to transport people, not to produce bus kilometers. Table 13 shows passenger kilometers per hour worked for various personnel categories and firm types. It is seen that the differences in productivity between the private and city-owned companies is the same as that measured with bus kilometers as a yardstick.

However, HKL is closing the gap. Private firms drive 145 percent more bus kilometers per worker hour than HKL; the difference in terms of passenger kilometers per worker hour is only 68 percent. This could have been surmised from the load factors and bus speeds. HKL's load factor and passenger volumes are greater and bus speeds are lower than those of the other companies.

Yet a third angle to productivity is the profitability of bus operations, because it is a good indicator of efficiency in the use of resources. Table 14 shows the costs and income per passenger kilometer. The data in parentheses exclude depreciation, taxes, and changes in the investment reserve fund on the cost side; on the income side only farebox revenue is included. The data in parentheses tell the most about profitability because depreciation does not reflect the cost of buses sufficiently accurately and these data cannot be changed with creative accounting.

The bottom line of productivity indicators is that the private firms are the most productive and the city-owned companies are much more productive than a city transit agency. The same conclusion applies to profitability.

CONCLUSIONS

The cost structure, level of service, and productivity of three types of bus operations have been

TABLE 13 Worker Productivity, Helsinki Region, 1982

	Private Company	City-Owned Company	HKL	Espoo	Vantaa
Drivers	268	257	199	239	288
Shop personnel	2,257	1,927	628	2,299	2,042
Administration	2,297	1,298	1,104	1,735	1,980
Total	217	193	129	192	224

Note: Productivity given as passenger kilometers per worker hour.

TABLE 14 Profitability of Bus Operations, Helsinki Region, 1982

	Private Company	City-Owned Company	HKL	Espoo	Vantaa
Income	7.0 (6.5)[b]	7.6 (7.0)[b]	9.4[a] (5.6)[b]	8.1 (7.6)[b]	6.3 (5.9)[b]
Expenses	6.8 (5.2)[c]	7.4 (6.3)[c]	9.4 (8.7)[c]	8.1 (5.9)[c]	6.3 (5.2)[c]

[a] Includes subsidy.
[b] Farebox income only.
[c] Excludes depreciation, taxes, and changes in investment reserve fund.

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

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

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

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

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

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Passenger Service Times for a No-Fare Bus System

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ABSTRACT

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

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

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

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

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

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

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

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

ANALYSIS

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

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

TABLE 1 Frequency of Observed Boarding Groups by Size

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

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

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

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

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

$$t_p = 1.94 + 0.03\ r_p \tag{1}$$

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

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

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

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

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

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

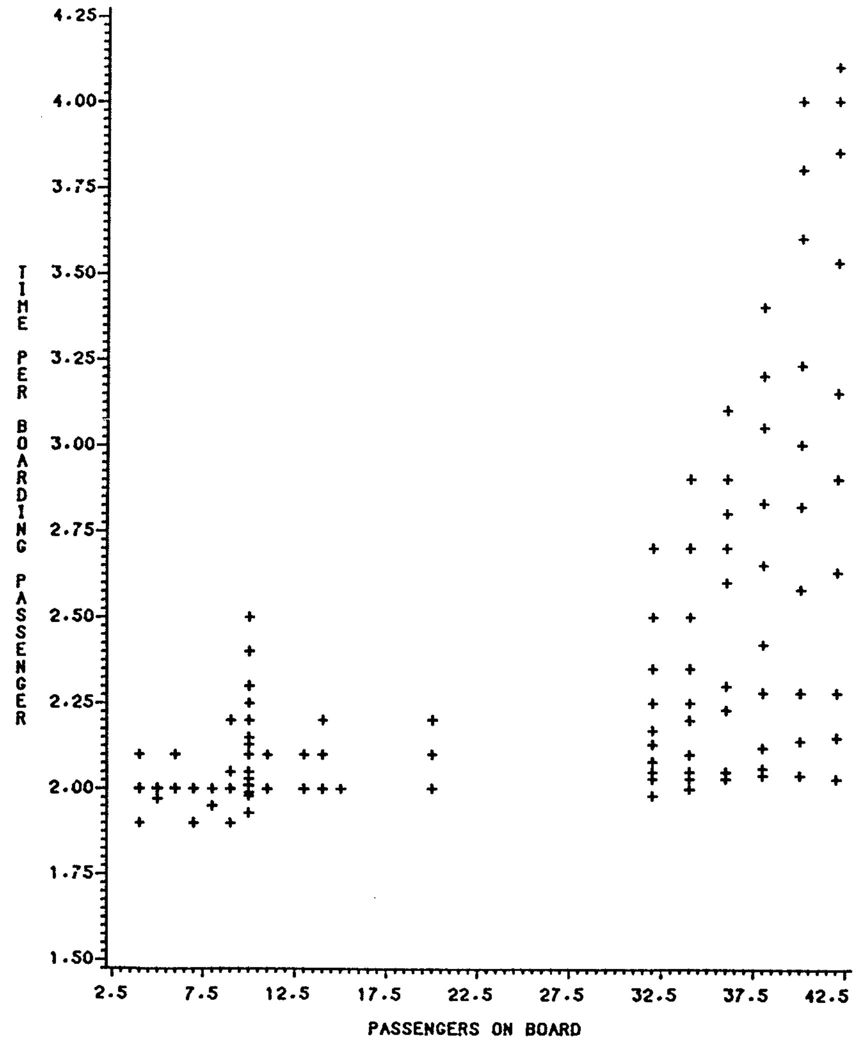

FIGURE 1 Time per boarding passenger (in seconds) versus number of passengers on board.

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

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

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

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

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

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

$$t_p = -1.56 + 0.16\ r_p + 0.09\ n_p \tag{2}$$

where

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

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

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

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

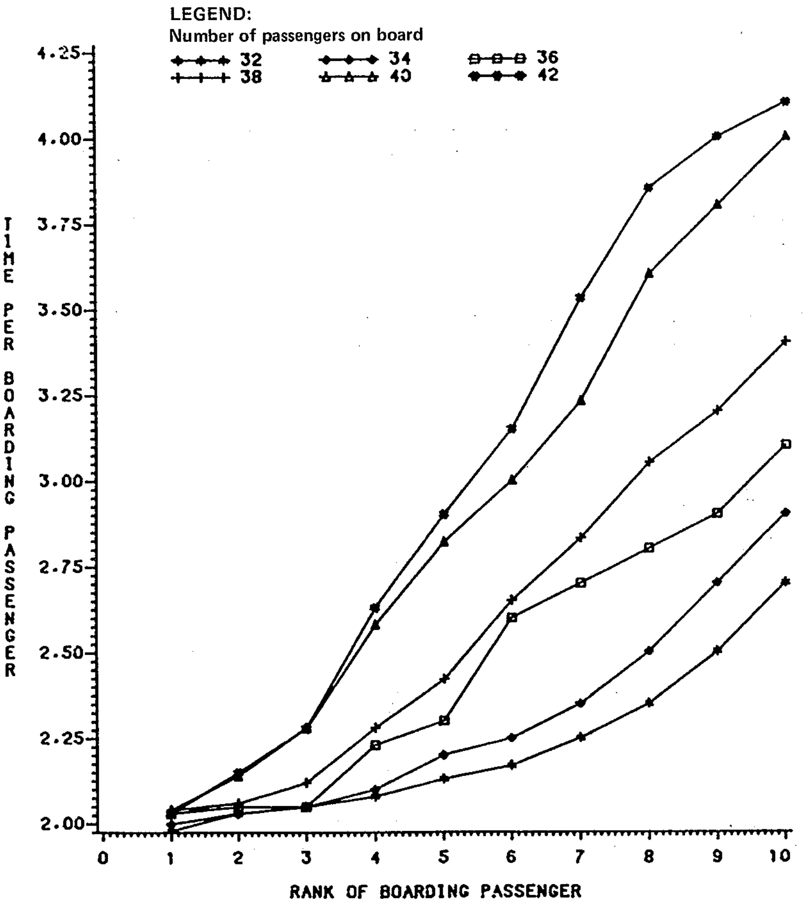

FIGURE 2 Time per boarding passenger (in seconds) versus passenger rank.

TABLE 6 Determination of the Area of Applicability for Equation 2

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

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

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

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

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

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

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

CONCLUSIONS AND APPLICATIONS

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

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

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

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

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

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Developing a Cost Model for Privately Contracted Commuter Bus Service

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ABSTRACT

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

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

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

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

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for cost estimation can easily lead to misleading and nontransferable results. The use of bid quotations for a specific service with particular operating parameters is no substitute for a structural cost model if the objective is to estimate private-sector costs in a variety of service settings under different operating scenarios.

In order to better understand private operator costs, an approach is presented to model the costs of privately contracted commuter express bus service. Only peak-period express bus services were chosen as the subject of the model, for several reasons. Such services have been identified as being unusually expensive to provide by public transit agencies because they utilize labor poorly; consequently, they are often cited as prime candidates for private-sector contracting. In addition, peak-period services cannot be adequately costed in either the private or public sector by using average cost methods. An all-day service with little or no peak period is perhaps appropriately costed with an average cost approach. However, for an operation that consists of only peak-period service, labor conventions, duration of the peak, and amount of service provided can all affect cost in a nonlinear fashion. Furthermore, even among peak-period services, differences in route length, deadhead miles, and type of equipment required can all affect costs in ways not adequately described through a simple cost-per-mile or cost-per-hour approach. Finally, because peak-period services are the most difficult services for which to develop cost models, there is virtually no information available on what reasonable unit costs are for contract services.

WHY DEVELOP PRIVATE-SECTOR SERVICE COST MODELS?

There are three important reasons why private-sector service cost models are needed, particularly for peak-period-only services. First, an agency that is able to use models to estimate the cost of private-service provision before putting a service out to bid can establish where contracting has the greatest potential for saving money before the fact. Most public agencies prefer not to solicit private-sector bids unless they are reasonably confident that significant cost savings will accrue. It is politically embarrassing to discover after the bids are received that no savings will accompany a shift to private-sector service. Moreover, the very specter of service contracting is almost certain to create labor complications, and an agency should be reasonably confident that contracting will yield significant financial benefits before it creates labor problems for itself.

Second, cost models enable an agency to verify, in a rough fashion, the plausibility of private operator bids. Private operators have been known to bid below cost in an effort to secure a contract that they believe will be in their long-term interest. In the short term, however, the contract may become so financially onerous that the operator will seek a rate adjustment or be forced to terminate its involvement, which would result in service disruptions and political embarrassment for the agency. In addition, a financially strapped operator is likely to cut corners, to the probable detriment of service quality. Public agencies can avoid these problems in advance if they can determine whether bid quotations are suspiciously low, and if they require detailed cost estimates from bidders to justify their proposed rates.

Third, private operator cost models can identify which factors most significantly influence service costs. With this knowledge, the public agency may be able to modify certain service parameters, or the bid requirements, to reduce costs. For example, if capital costs are a major portion of total service costs, then allowing a private operator to use less expensive (i.e., older) buses may reduce the costs to the public agency.

CURRENT USES OF PRIVATE OPERATORS FOR COMMUTER BUS CONTRACT SERVICES

Several public agencies in the United States are currently contracting with private bus companies for commuter express service. The largest such use of the private sector is in Houston, Texas, where the Metropolitan Transit Authority contracts for service for 75 buses on 6 routes. The regional transit agency of Dallas has recently begun contracting with a consortium of private companies (including Continental Trailways) for a 60-bus peak-period express service, and plans to expand service in the near future. Other notable examples of peak-period service contracting include the services sponsored by Golden Gate Transit (a subscription bus operation) and the counties of Los Angeles and San Diego. In addition, the city of Los Angeles will shortly begin contracting for express bus services that were previously provided by the regional transit agency. In addition to these competitively contracted services, franchised private operators in Boston, northern New Jersey, and San Mateo County, California, are subsidized by public agencies to continue operating commuter services that might otherwise be absorbed by regional transit operators.

Contract commuter bus operations tend to have a number of similar, distinctive features. The service is usually a park-and-ride type of operation, in which the bus picks up riders at one or two locations and then travels nonstop to its destination, which is generally a central business district (CBD). Service is typically provided only during peak periods, with a limited number of runs on each route (sometimes as few as two per peak period). Contractors are predominantly charter bus operators, who are almost always required to furnish the vehicles used for the service.

As a means of illustrating the characteristics of these privately contracted services in order to understand the operating environment that affects their economics, more detailed information on the Houston and Golden Gate operations is presented in the following sections of this paper. Another reason for describing these operations is that the participating private operators provided data that were used to estimate the parameters of the cost model, and the cost model itself was applied to routes in the two systems.

Houston Metro Contract Bus Program

The Metropolitan Transit Authority of Harris County, otherwise known as Houston Metro, has contracted with private bus companies in the Houston region since 1981 to provide a substantial portion of its express bus service into downtown Houston. The service is of a park-and-ride nature from suburban regions, mostly in northern Houston, that are accessible to the I-45 high-occupancy-vehicle (HOV) lane.

Houston Metro turned to the private sector because of its inability to expand its own operation rapidly enough to meet demand in its fast-growing and increasingly congested service region. The services were implemented in a short time with the aim of meeting the political demands for more commuter buses. The contract operation initially involved 120 buses on 12 routes with 430 bus runs daily. Five private operators were involved in providing service. The transit agency has recently absorbed some of the contracted services, and now only 75 buses operated by two service providers are involved. Routes vary in length from 15 to 25 mi, and essentially all service is provided during the two peak periods. Operating statistics for the contract operation as of 1982, when it was at its height, are summarized in Table 1.

At its height, the commuter bus program included most of the charter bus companies in the Houston region. The transit agency had a policy of awarding routes to all of the bidders because none was large enough to provide all of the service on its own; consequently, competitive pressures were minimized.

Three aspects of the Houston contract operation directly affect its costs, which, as can be seen in Table 1, are relatively high on a per-hour basis. The first aspect is the requirement that contractors supply their own vehicles. This means that Metro must pay the capital costs, which can amount to as much as 30 percent of total contract costs. Few of the buses acquired for contract services can be put to alternative uses during the day. Consequently, operators charge most or all of the capital costs of most of the vehicles to the contract operation. Moreover, the contracts are only for 2 years, so the capital costs must be written off quickly, which in turn adds to the contract cost.

TABLE 1 Total Daily Operating Statistics for Houston Metro Park-and-Ride Contract Services

Route	Operator	No. of Buses	Revenue Miles	Deadhead Miles	Cost/Revenue Vehicle Hour ($)
224	KV	8	777	148	67.02
112	KV	6	643	119	72.08
142	TEI	10	1078	199	83.50
263	7K	7	438	106	87.50
201	NL	13	1078	130	75.00
132	7K	8	642	159	87.50
204	TEI	10	1268	213	88.00
202	KV	13	2315	231	77.81
107	TEI	8	808	165	88.00
221	KV	4	532	100	99.02
270	KV	7	514	89	61.16
205	KV	13	1296	344	96.79

Note: KV = Kerville Bus, TEI = Transport Enterprises, Inc., NL = Northline, 7K = 7-K Bus Company.
Source: Houston Metro Contract Service Reports, May-Dec. 1982.

The second aspect is that Metro requires the use of over-the-road coaches or vehicles with a similar ride quality, and has a strong preference for relatively new vehicles. The result is that the vehicles are relatively expensive ($75,000 to $150,000 if they are new compared with at least $40,000 if they are used). The average vehicle age is about 7 years and the average vehicle value is in excess of $75,000.

The third aspect of the Houston contract operation is that the cost per hour is high because, although the contractors operate only during the peak period, they charge rates approaching those for all-day charter service. Metro saves little more than mileage charges over daily charter rates. Even though there are only about 4 hr of revenue service per bus per day, this time is spread over two peak periods, and there is not enough midday charter work for the drivers to schedule them for more than one piece of work per dispatch. The contractors therefore pay 8 hr of driver labor per bus per day, which is the equivalent of two driver dispatches. (Drivers receive a minimum of 4 hr of pay per dispatch.) Therefore, as is the case in public agency operations, driver labor is used inefficiently, although drivers often perform other tasks when they are not driving.

Golden Gate Transit Subscription Bus Service

The Golden Gate Transit District has been subsidizing privately contracted subscription bus service since 1971. Golden Gate Transit serves Marin and Sonoma counties to the north of San Francisco, and operates what is probably the most heavily peaked large transit operation in the United States. A 5-to-1 peak-to-base ratio reflects both the virtual absence of transit use by the area's affluent residents during off-peak periods and the heavy patronage of the transit system as a means of commuting to downtown San Francisco during peak periods. The severely limited highway capacity of San Francisco has made transit a strong commuting mode for the past 20 years.

A subscription bus service, organized by residents working in San Francisco, has been in place for many years. These commuter clubs have contracted with private bus operators to provide service since they were formed. The transit agency began subsidizing subscription services in 1971; in recent years, private operations have been absorbed into the agency's family of services, although the commuter clubs retain a role in service organization and financing. At its peak, the subscription bus program consisted of 27 daily round-trip bus runs that served 15 routes. Because of program cutbacks and the dissolution of some clubs as a result of work-site relocations, the program now consists of 18 daily subscription buses provided by two bus companies.

Subscription service is currently provided from 12 separate suburban locations, with from one to five bus runs per location; service is park-and-ride in nature. Routes vary in length from 20 to 60 mi, and most of the destinations are employment sites outside downtown San Francisco that are served poorly or not at all by the regular Golden Gate Transit commuter services. Service statistics for 1984 are summarized in Table 2.

Golden Gate Transit has devised rather elaborate bidding procedures for private service in an attempt to minimize costs and maximize the number of potential bidders. Companies bid on a minimum number of routes from a set of zones that are based on a series of 10-mi radii from downtown San Francisco. Adjustments to bid prices are based on actual route mileage and the size of the vehicle specified in the bid. In the past, the transit agency discouraged the use of vehicles more than 10 years old, but now older vehicles are allowed, although they are subject to a preservice inspection and periodic inspections once they are in service. The average fleet age is now more than 12 years; one contractor uses vehicles that are all at least 14 years old. Consequently, the average bus used in the service has a value of only about $50,000.

As is the case in Houston, the two contractors pay their drivers a minimum of 4 hr for any piece of work. One contractor in San Francisco found an opportunity to use excess driver hours in midday charter work, but this is an uncommon occurrence. Both contractors have attempted to locate drivers near the beginning of a subscription route; many of the drivers on these routes were hired because they live in Marin or Sonoma county. This practice minimizes deadhead time and distance, because the drivers park the vehicles near their residences overnight.

TABLE 2 Operating Statistics for Golden Gate Transit Contract Subscription Bus Service

Route	Operator	Origin	Round-Trip Miles	Round-Trip Cost/Day ($)	Cost/Revenue Vehicle Mile ($)
A-1	TransCal	Ignacio	54	190	3.52
A-2	K-G	Santa Rosa	119	262	2.29
A-3	TransCal	Greenbrae	40	151	3.77
A-4	TransCal	Fairfax	42	170	4.04
A-5	TransCal	Tiburon	42	180	4.26
A-6	K-G	Petaluma	87	266	2.60
A-7	TransCal	San Rafael	40	168	4.17
B-1	TransCal	Terra Linda	56	167	2.98
C-1-4	TransCal	Sonoma	100	218	2.18
D-1	TransCal	Peacock	49	177	3.59
F-1-5	K-G	Glenwood	49	225	3.59
H-1,2	K-G	Rohnert Park	106	246	2.28

Note: TransCal = TransCal Tours, K-G = K-G Bus Company.
Source: Golden Gate Bridge Highway and Transportation District.

COMPONENTS OF PRIVATELY OPERATED COMMUTER BUS COST

The cost of privately operated commuter bus services is a function of seven major component costs: (a) vehicle capital, (b) drivers, (c) maintenance, (d) direct operation (fuel and oil), (e) insurance, (f) administration and overhead, and (g) miscellaneous. The factors that affect these costs, and the range over which they vary, are discussed in the following paragraphs.

Vehicle Capital

Four types of equipment are used to describe the range of vehicle capital costs: the MC7 through MC9 over-the-road coaches built by Motor Coach Industries, Inc., (MCI) from 1968 through 1985; the General Motors Corporation (GMC) Suburban, built from 1963 through 1977; new transit-type coaches (Blue Bird City Bird); and new school-bus-type vehicles with air ride suspension (Blue Bird All American). MCI coaches represent the more recent over-the-road coaches, which are designed with charter operations in mind. The GMC Suburban is an example of an older, less expensive bus that is nonetheless suitable for contract operations. The Blue Bird buses represent two less expensive new vehicle options.

In general, the cost of a used bus varies with

- The condition of the bus;
- The availability of new buses;
- The general economic outlook, specifically the interest rate and the overall demand for buses; and
- The type of bus.

The cost range of the different types of vehicles is as follows:

Bus Type	Cost ($000s)
GMC Suburban	10-40
MC7 68-72	35-60
MC8 73-79	55-90
MC9 79-83	95-160 (new)
Blue Bird All American 80-83	48-85 (new)
Blue Bird City Bird 80-83	78-130 (new)

It should be noted that these are values for buses that are purchased new from dealers. Vehicles that have been owned and maintained by the operator since they were new will have greater value. GMC Suburbans are likely to have been rebuilt or refurbished, or both. If so, their value will be closer to the upper rather than the lower end of the indicated price range. Costs for Blue Bird coaches include the cost of charter-type reclining seats.

Drivers

There is a perception that private bus operators have substantially more flexibility than their counterparts in public transit agencies in scheduling and compensating their bus drivers. This is only partly correct. Although drivers for private operators do not enjoy the same generous work rules and benefits as do public transit drivers, there are definite restrictions on how flexibly they can be used, and particularly on the minimum amount of pay they are guaranteed. Work rules are more flexible in private companies and drivers routinely perform minor work tasks other than driving. In most charter bus companies, however, drivers are not compensated solely for actual hours worked in driving, but, as in public transit agencies, are usually guaranteed a minimum level of compensation that often exceeds actual working time.

Eight private companies in San Francisco and Houston that provided contract service were surveyed for their labor practices. All had a guaranteed minimum pay of 4 hr of work per dispatch, which applied to the transit agency routes as well as to other types of operations. (Private charter bus operators generally price their services to the public on a minimum rate per dispatch.) The wage rates vary, but in all cases a minimum compensation applies. Peak-hour express service almost always requires two dispatches; therefore, in most cases a full day's driver's wage must be paid (although two different persons may drive the route).

Hourly wages for bus drivers of contract carriers in Houston and San Francisco are as follows:

Operator	Avg Wage ($/hr)
Kerville Bus	8.50
Transport Enterprises	8.00
7K	7.00
Northline Bus	7.00
TransCal Tours	7.00
Western	6.75
Petersen	6.00
Average	7.18

Wages vary from $6.00 to $8.50/hr, with most operators paying $7/hr or more. Driver cost for the typical 8 hr pay, including benefits, averages about $75/day.

It is possible, but difficult, to bring driver costs below these levels. Some companies engage in buspool-type operations, in which the driver has a job at the trip destination and is therefore only paid for actual driving time. Because time constraints prevent many commuter express buses from making two round trips per peak period, this is often a practical option from a driver-scheduling viewpoint. However, service sponsors may be reluctant to approve such labor arrangements. Companies may also attempt to pay their drivers only for actual working time, but if they cannot find work outside the transit contract, this practice sharply reduces the pool of qualified drivers. Many potential drivers are unwilling to receive only 2 to 3 hr of pay per day, or to work an extreme split shift to obtain 5 to 6 hr of pay. Other types of part-time work are often more attractive. Most established companies have found that the minimum-pay guarantees attract better-quality drivers.

Another possibility for reducing driver costs is for the company to use the drivers on other work between the peak periods. In practice, however, it is difficult to generate charter business that requires the buses only during the time between contract runs. Moreover, even if such work can be generated, the driver will have to be paid for three dispatches, or 12 hr, because the a.m. and p.m. peaks and an intervening dispatch would encompass an 11- to 12-hr working day. Consequently, the contract services will still be allocated most (if not all) of two dispatches' worth of driver cost.

Maintenance

Maintenance costs show a definite relationship to the age of the vehicle fleet. Recent data for both large intercity carriers and small, predominantly charter bus operators indicate an average maintenance cost of $0.21/mi, but this will vary depending on fleet age. An instructive comparison is between two operators with large differences in fleet age. Commuter Bus Lines is a buspool operator based in Los Angeles whose fleet consists primarily of older GMCs with an average age of approximately 25 years. Maintenance expense is relatively high at $0.32/mi. This is probably an upper bound on maintenance costs for express service using intercity-type buses, because this company was going through major fleet rehabilitation during the period for which the data were collected. In comparison, Kerville Bus is a Houston charter operator with an average fleet age of approximately 8 years. Their maintenance expense is listed at $0.213/mi. This figure is comparable with the average for large private carriers.

Maintenance costs for three operators who were surveyed by the authors in the course of an UMTA-sponsored study regarding contract transit operations and the results of a United Bus Owners of America (UBOA) survey of 40 of its members are as follows (UBOA members own an average of 30 vehicles, with an average fleet age of 8 years):

Operator	Cost per Mile ($)
Kerville Bus	0.213
Northline Bus	0.20
TransCal Tours	0.21
UBOA	0.21

Insurance

In recent years, insurance costs for bus operators have fluctuated substantially. Insurance costs depend on the value of the vehicle, the condition of the bus, the size and age of the bus company, and the loss experience of the operator. In addition, insurance costs are sensitive to the amount of excess coverage, self-insurance limits, and deductibles. Currently, liability costs are approximately $2,000 to $3,000 per year per bus, assuming a relatively high level of self-insurance. Coverage for vehicle damage is $3,000 to $4,000 per year per bus for a medium-value bus. Premiums for small operators are on the high end of the scale, and all costs depend on the ability of the insurance broker to obtain the best possible deal from underwriters.

On the basis of survey data and information from Southern California bus fleet insurance brokers, the following costs were used for insurance: high vehicle cost, $4,000 per bus per year; medium vehicle cost, $3,000 per bus per year; low vehicle cost, $2,000 per bus per year. The differences represent the variance in collision insurance rates for vehicles with different monetary values. These insurance costs represent 1983-1984 conditions, because the other cost components were estimated from data for this period of time. Current insurance rates are typically at least 50 percent greater.

Direct Operation

Direct operating costs consist of fuel and oil. These costs depend on the fuel efficiency of the bus, but most buses have relatively similar fuel consumption rates. On the basis of data from several sources, direct operating cost is estimated at $0.20/mi.

Administration and Overhead

Facilities rental, clerical assistance, project management, supplies, contract services (e.g., custodial), and general overhead combine to form administrative and overhead costs. Data from San Francisco and Houston operators and from the survey of UBOA members were used to estimate this cost component at $9,800 per year per bus; these costs do not vary with the amount of service produced. A summary of these costs for two Houston contract operators and the UBOA survey respondents is as follows:

Operator	Cost per Bus per Year ($)
Kerville Bus	9,700
Northline Bus	10,300
UBOA members	9,800

Certain administrative and overhead expenses depend on amount of service (e.g., supervision expense, taxes, and licenses) and these are included with the miscellaneous costs.

Miscellaneous

Miscellaneous expenses are composed of three major cost items: supervision, operating taxes and licenses, and other miscellaneous costs.

Supervision costs are assumed to be mileage-related because the number and the length of the trips required are directly related to the need for supervision. The costs for supervision are based on data procured from three operators (TransCal Tours, Northline Bus, and Kerville Bus). Their estimates of this cost item ranged from $0.043/mi to $0.051/mi. The average was $0.047/mi.

Operating taxes and licenses are assumed to vary with mileage, because in many states annual license fees vary with bus mileage, and fuel taxes depend on miles driven. Based on the UBOA membership survey and figures provided Kerville Bus and Northline Bus, these costs are estimated at $0.085/mi.

The category of other-miscellaneous costs consists principally of contract maintenance labor and is based on data from the same sources as the foregoing data. These costs vary from approximately $0.05 to $0.03/mi with an average of $0.013/mi.

BUS OPERATIONS MODELING CONVENTIONS

Private- and public-sector bus companies employ relatively similar modeling conventions to estimate operating costs. In general the models use the following components, either alone or in combination:

Public Sector	Private Sector
Mileage costs	Wheel costs
Hourly costs	Hourly costs
Pullouts	Dispatch costs
Peak vehicles	

In both the public and private sectors, mileage-related methodologies are generally used to estimate costs that vary with the distance the vehicle travels, notably maintenance, fuel, oil, tires, and certain miscellaneous costs. In the private sector, mileage costs are referred to as wheel costs. In the public sector, hourly cost factors typically model labor costs, especially driver labor, and pullouts and peak vehicles reflect the costs related to operating a highly peaked service. This aspect of a model is used to load costs associated with the administrative and labor burden of peak-only services. In general, in public-sector cost models, hourly, mileage, pullout, and peak-vehicle components are combined.

Private bus operators use the dispatch cost convention to quote prices in blocks of time. Dispatch costs are usually for a minimum of 4 to 5 hr of service, even if the actual required work time is less. In addition, a customer may have to pay mileage charges, at least for any miles beyond a predetermined limit (typically 100). Thus private operators also often combine components to cost out services.

PREVIOUS PRIVATE COMMUTER BUS COST MODELING EXERCISES

Two earlier efforts to explicitly model private operator costs for peak-period commuter services have been published. The first model is a one-variable mileage cost model developed by the Southern California Association of Governments (SCAG) in a study of potential cost savings of peak-period service contracting (2). SCAG requested private operators in the Los Angeles region to provide cost quotations for a number of routes in Los Angeles and Orange counties that could be contracted out to the private sector. The survey requested operators to supply only a total cost for each route, not a breakdown of costs. On the basis of operator responses, it was determined that it would cost an average of $2.79 per revenue vehicle mile to provide the peak-period service in question. This model is obviously not sensitive to the fixed-variable nature of private operator service costs or to the influence of type of bus on cost, nor does it explicitly include deadheading considerations.

The second private-operator model is a marginal cost model developed by Herzenberg in a master's thesis at Massachusetts Institute of Technology (4). Herzenberg compared the costs of 12 bus routes operated by the regional transit agency in Boston with the costs of operating the same routes in the private sector. Two Boston-area private bus companies, Hub Bus Company and Gray Line of Boston, were used to model private-sector costs.

Herzenberg developed private-operator cost models from data she obtained from the two companies. She assumed that only the marginal or incremental cost of operating the routes was relevant. As a result, the routes were assigned no administrative costs. The models developed are as follows:

$$OCG_R = 10.96\ PH_R + .321\ VM_R + 2V_R$$

$$OCH_R = 5.20\ PH_R + .506\ VM_R$$

where

OCG_R = operating cost for Gray Line to operate route R ($/day),
OCH_R = operating cost for Hub Bus Company to operate route R ($/day),
PH_R = platform hours associated with route R (hr/day),
VM_R = vehicle miles associated with route R (mi/day), and
V_R = total number of vehicles needed to operate route R.

These costs do not include vehicle capital costs or insurance; Herzenberg used lease costs for buses to estimate capital costs. When the results of this model were compared with those of others, Herzenberg's maximum cost for vehicles ($97.50/day) for capital and insurance was assumed. This was the figure cited for new buses that can be leased. However, the term of such leases is usually 7 years, and this figure is therefore questionable for a contract with a 2- or 3-year term.

DEVELOPING AN ORIGINAL COST MODEL

In the development of a private-sector cost model, care should be taken to explicitly include all major sources of cost difference inherent in the operating parameters of contract commuter bus operations. In particular, capital cost differences based on equipment specifications, the length of the contract, and the use of the vehicle outside the contract should be included. The model should also treat cost components as variable with hours or miles or both only if they are truly variable and not relatively fixed for an operating day.

These considerations are best incorporated within the framework of a utilization-adjusted fixed-variable cost model. This model is similar to conventional transit agency cost-allocation models in that a mileage category--wheel cost--as well as a dispatch-cost category, which is similar to the public-sector pullout or peak-vehicle category, are used. In this model the following assignments of cost components will be made to the dispatch-cost or the mileage category:

Dispatch Cost	Mileage Cost
Equipment	Maintenance
Administrative	Fuel and oil
Driver labor	Miscellaneous
Insurance	

The dispatch component of this private-sector cost model is attractive also because it provides for the allocation of fixed costs on the basis of vehicle use. The level of charter demand relative to contract demand is the basis for making estimates of vehicle use. As the level of charter demand increases, the proportion of the daily fixed costs that must be allocated to the contract is reduced. In allocating such costs, a simple assumption is made: If the proportion of contract revenues to total revenues is less than 50 percent, then a high-use situation is in effect and fixed costs will be allocated 50 percent to the transit contract and 50 percent to other dispatches. That is, as the percentage of contract revenues relative to total revenues increases, there is a decreased likelihood of other uses for vehicles for contract service, and vice versa. Therefore, a distinction between high and low use will be made within the dispatch-cost category. This will apply to all fixed costs except driver labor, which does not vary on this basis because drivers will generally be paid a full day's (8 hr) rate for working commuter services.

In the model, vehicle capital costs depend on the age of the equipment, which is represented by three different cost levels derived from the information presented previously on the price of buses from dealers:

Level	Vehicle Cost ($000s)
High	95-160
Medium	55-90
Low	10-60

The model differentiates among capital costs for 2-, 3-, and 5-year contracts; the 5-year contract is assumed to apply only in situations where the contractor supplies high-cost vehicles.

The following method was used to determine daily vehicle capital costs:

1. On the basis of discussions with Borg Warner Acceptance--a company that has leased vehicles to commuter bus transit operators--a residual value of 67 percent of the original cost was used for a lease period of 2 years, 60 percent for a 3-year lease period, and 50 percent for a 5-year lease period.
2. An interest rate of 15 percent was used because the Houston and San Francisco contracts had been awarded during the period when interest was at this level or higher.
3. The cost of vehicles used is the mid-range of the foregoing cost levels, namely, high cost, $127,500; medium cost, $72,500; low cost, $35,000.
4. The capital recovery method is used and the duration of the contract determines how much of the cost will be allocated to each year.

The results are summarized in Table 3; 255 operating days per year are used.

TABLE 3 Daily Capital Costs for Different Vehicle Costs and Contract Lengths

Initial Vehicle Cost ($)	Contract Length (yr)	Salvage Value ($)	Cost/Day ($)
127,500	2	85,170	152
127,500	3	76,500	132
127,500	5	63,750	121
72,500	2	48,430	86
72,500	3	43,500	75
35,000	2	23,380	41
35,000	3	21,000	37

The dispatch-cost portion of the model uses a cost per bus per day to reflect the fixed charges of supplying commuter bus service. Thus insurance and administrative and overhead costs are converted from an annual cost per bus to a daily bus cost. The insurance costs range from $8 to $16 per bus per day, depending on the value of the bus, and the administrative and overhead charge is $38 per day per bus. Only 50 percent of these costs is charged to the contract service in high-use situations. In Table 4 the dispatch-cost (fixed-cost) component of the cost model is summarized for different capital cost, utilization, and contract-length assumptions. Obviously the fixed daily cost values in Table 4 can be recalculated to reflect different ones for vehicle capital, contract length, insurance, driver wages, and interest rate.

Finally, the wheel-cost component of the model must be estimated. To represent the total mileage involved in providing service to a route, revenue miles will be combined with deadhead miles to reflect the mileage-related cost more accurately. The mileage-related costs (wheel costs) are summarized as follows:

Expense Item	Cost ($/mi)
Maintenance	0.21
Fuel and oil	0.20
Supervision	0.047
Operating taxes and license	0.085
Other miscellaneous	0.013
Subtotal	0.555
Plus profit of 10 percent	0.055
Total	0.610

The final form of the model is thus

$$TDBC_R = DFC\ (k,\ u,\ l) + .61\ TVM_R$$

where

$TDBC_R$ = total daily cost per bus for route R;
DFC = value from Table 4 for an operator's particular combination of vehicle capital cost, utilization, and contract length; and
TVM_R = total vehicle miles per day to provide service for route R.

RESULTS OF APPLYING THE COST MODEL

The private-operator cost model was applied to three situations: to estimate the cost of the contract subscription bus service provided to Golden Gate Transit and the Houston Metro commuter bus program and to estimate the cost of providing peak-hour service on several park-and-ride bus routes in Los

TABLE 4 Daily Fixed Costs for Different Assumptions of Commuter Transit Capital Cost, Vehicle Utilization, and Contract Length

	Capital-Cost and Use Combination and Contract Length (yr)													
	HL			HH			ML		MH		LL		LH	
Cost	2	3	5	2	3	5	2	3	2	3	2	3	2	3
Capital	152	132	121	76	66	60	86	75	43	38	41	37	21	19
Administration	38	38	38	19	19	19	38	38	19	19	38	38	19	19
Driver	75	75	75	75	75	75	75	75	75	75	75	75	75	75
Insurance	16	16	16	8	8	8	12	12	6	6	8	8	4	4
Profit[a]	28	26	25	18	17	17	21	20	14	14	16	16	12	12
Total	309	287	275	196	185	179	232	220	157	152	178	174	131	129

Note: HL = high capital cost, low utilization; HH = high capital cost, high utilization; ML = medium capital cost, low utilization; MH = medium capital cost, high utilization; LL = low capital cost, low utilization; LH = low capital cost, high utilization. All costs are in dollars per bus per day.

[a] At 10 percent.

Angeles that are now being bid on by private operators. The contracts will be for 5 years.

In all three cases, the estimates generated by the model were compared with the actual price being charged the public agency by the contractor or, in the case of Los Angeles, the bid price of a major private operator. In addition, the estimates of this model were compared with the cost estimates derived from Herzenberg's model and the SCAG vehicle-mile model.

The results of these comparisons are shown in Tables 5, 6, and 7. For Tables 5 and 6 the capital cost and vehicle utilization are noted by route, because different contractors use different vehicles and there are different bid prices by the major operator. In all three applications, the predictions of the model were always within 27 percent of actual costs and in over 80 percent of all routes within 10 percent of actual route costs. In Los Angeles, the fit was amazingly close, and Los Angeles data were not used to develop the model. The model appears to provide an acceptable level of accuracy for the purposes for which it would be used.

In contrast, the Herzenberg marginal cost model and the SCAG mileage cost model produced much less acceptable estimates. The Herzenberg model suffers from its marginal-cost approach--it is apparent that in the programs evaluated, the contract bus operators charge public agencies costs that are closer to fully allocated ones than marginal ones. As a result, the Herzenberg model produces cost estimates that are consistently 30 to 50 percent below actual contract prices. The problem appears to be severe underestimates of driver costs and administrative costs, as well as some dubious assumptions about capital costs. The SCAG model performs reasonably well in Houston but poorly elsewhere. This reflects the absence of a fixed-cost component in the model, which makes it underpredict for shorter routes. That is, for short routes, the actual cost is much greater than $2.79/mi because the fixed charges (for drivers and equipment) are spread over relatively few miles. The mileage cost approach to cost modeling appears to be particularly inappropriate for these types of contract operations.

CONCLUSIONS AND POLICY IMPLICATIONS

The results of applying the private-sector bus cost model developed here indicate that it is relatively accurate and that the cost considerations that the model includes are valid. These considerations are (a) that fixed costs, especially capital costs, are the largest cost component and therefore the primary factor in the expense of contract commuter bus operations; (b) that the level of utilization outside the contract is relevant; and (c) that the length of

TABLE 5 Houston Cost Comparison

Route No.	Capital-Cost and Use Combination	Actual Cost	Comparison with Actual Cost					
			Private-Sector Bus Cost Model	Percent Difference	Herzenberg Model	Percent Difference	SCAG Model	Percent Difference
107	HH/HL^{a}	331	270/383^{b}	−18/+16^{b}	155	−53	282	−14
112	ML	305	310	+1.6	161	−47	278	−8.8
142	HH/HL^{a}	346	274/387^{b}	−21/+12^{b}	161	−53	301	−13
201	ML	309	299	−3.2	151	−52	232	−25
202	ML	295	310	+5.1	158	−46	307	+4.1
204	HH/HL^{a}	348	287/400^{b}	−18/+15^{b}	166	−52	354	+1.7
205	ML	332	311	−6.3	150	−55	279	−16
221	ML	372	276	−26	157	−58	296	−21
224	ML	302	304	+0.7	161	−40	271	−10
270	ML	220 (262)^{c}	280	+27 (6.4)^{d}	114	−36 (−56)^{d}	179	−19 (−32)^{d}
				11.3–12.7 (9.2–10.6)		49.0 (51.0)		13.3 (14.6)

Note: HL = high capital cost, low utilization; HH = high capital cost, high utilization; ML = medium capital cost, low utilization. All costs are in dollars per bus per day.

[a] Both use assumptions employed because operator's contract accounts for about 50 percent of revenues.

[b] Cost and percent differences for both use assumptions.

[c] Current contract rate; all other current route contract rates are similar to values shown.

[d] Percent difference using current contract for Route 270.

TABLE 6 Golden Gate Cost Comparisons

Route No.	Capital-Cost and Use Combination	Actual Cost	Comparison with Actual Cost					
			Private-Sector Bus Cost Model	Percent Difference	Herzenberg Model	Percent Difference	SCAG Model	Percent Difference
A-1	MH	190	189	−0.5	122	−35	151	21
A-2	LL	262	260	−0.7	155	−41	332	27
A-3	MH	151	178	+18	114	−25	112	26
A-4	MH	170	181	+6	115	−32	117	31
A-5	MH	180	181	+0.5	115	−36	117	35
A-6	LL	226	236	+4	138	−40	243	08
A-7	ML	168	180	+7	110	−35	112	33
B-1	MH	167	191	+13	128	−23	156	7
C1-4	MH	218	225	+3	143	−34	279	28
D-1	MH	177	185	+5	117	−34	137	23
F1-5	LL	225	212	−6	113	−50	240	7
H1-2	LL	246	248	+0.8	139	−45	310	26
Mean				5.4		42		24.8

Note: MH = medium capital cost, high utilization; LL = low capital cost, low utilization; ML = medium capital cost, low utilization. All costs are in dollars per bus per day.

TABLE 7 Los Angeles Cost Comparison

		Private-Sector Bus Cost Model		Herzenberg Model		SCAG Model	
Route	Bid[a]	Cost	Percent Difference	Cost	Percent Difference	Cost	Percent Difference
413	296	304	+2.7	181	-36	132	-52
418	340	339	-0.3	228	-31	240	-27
419	338	336	-0.6	224	-31	194	-40
423	357	349	-2.2	237	-31	237	-31
427	333	327	-1.8	222	-31	203	36
429	335	322	-3.9	229	-29	202	-37
430	327	324	-0.9	218	-31	141	-53
431	320	318	-0.6	213	-31	167	-94
436	352	336	-4.5	237	-30	195	-42
437	355	343	-3.4	237	-31	225	-34
438	337	332	-1.5	223	-31	219	-32
445	337	333	-1.2	224	-31	225	-30
Mean			2.0		31.2		42.3

Note: All costs are in dollars per bus per day.

[a] Actual bid adjusted downward by 5.7 percent to reflect lower profit margin in cost model; high capital cost and low utilization assumed for all vehicles.

the contract is important, especially when new equipment is specified. Each of these points has important policy implications.

The contribution of capital costs to the total cost of privately provided commuter services is very large, whereas capital costs do not even enter into the calculation of the operating cost of publicly provided transit services. This disparity, of course, strongly biases cost comparisons, because capital costs can make up as much as 25 to 40 percent of the total cost of privately provided commuter services and typically represent 20 to 30 percent of total cost. This percentage is the greatest when sponsors require new or recent equipment and the contract is of short duration, for example, 2 years. The obvious strategy for reducing costs is for the public agency to acquire the vehicles with its capital funds and contract only for their operation. If this is not feasible because of labor contract provisions or other constraints, the sponsor can still minimize the capital costs for which it must compensate the operator by allowing older vehicles to be used and award contracts for up to 5 years. Allowing older vehicles to be used also maximizes the number of potential providers, and competition is a powerful mechanism for holding bid prices to the minimum possible level. The sponsor may also wish to guarantee to the contractor that it will buy back, at prevailing market prices, any buses that the operator does not need once the contract has been terminated. Any or all of these actions can result in considerable cost savings.

The utilization findings also suggest certain policy actions. Costs are obviously greater when vehicles cannot be utilized outside the contract. Limited vehicle utilization is a fact of life for commuter services, but utilization can be maximized by spreading the contract business among multiple providers. If one or two operators each provide 30 or 40 vehicles, only a small fraction of the contract vehicles will achieve additional utilization. In addition, it is a wise policy not to become dependent on one or two private operators, because if other potential providers become discouraged from ever participating and do not bid on services, contract prices are likely to be excessively high.

Privately operated commuter bus services are not inexpensive, as this cost modeling exercise demonstrates. Nonetheless, they can often be less costly than comparable public agency services. The model presented here provides a method of estimating private operator costs and also indicates strategies that public agency sponsors can pursue to keep these costs to the minimum level possible.

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