A Geodemographic Model for Bus Service Planning and Marketing

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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

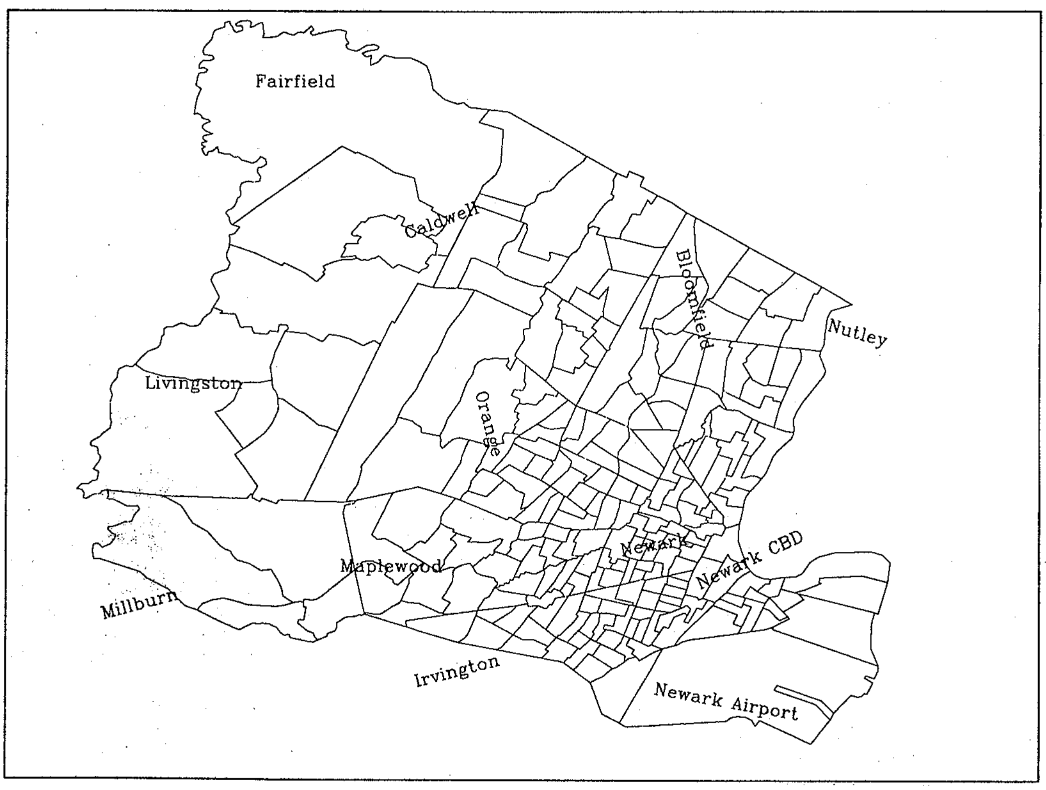

FIGURE 1 Essex County census tracts.

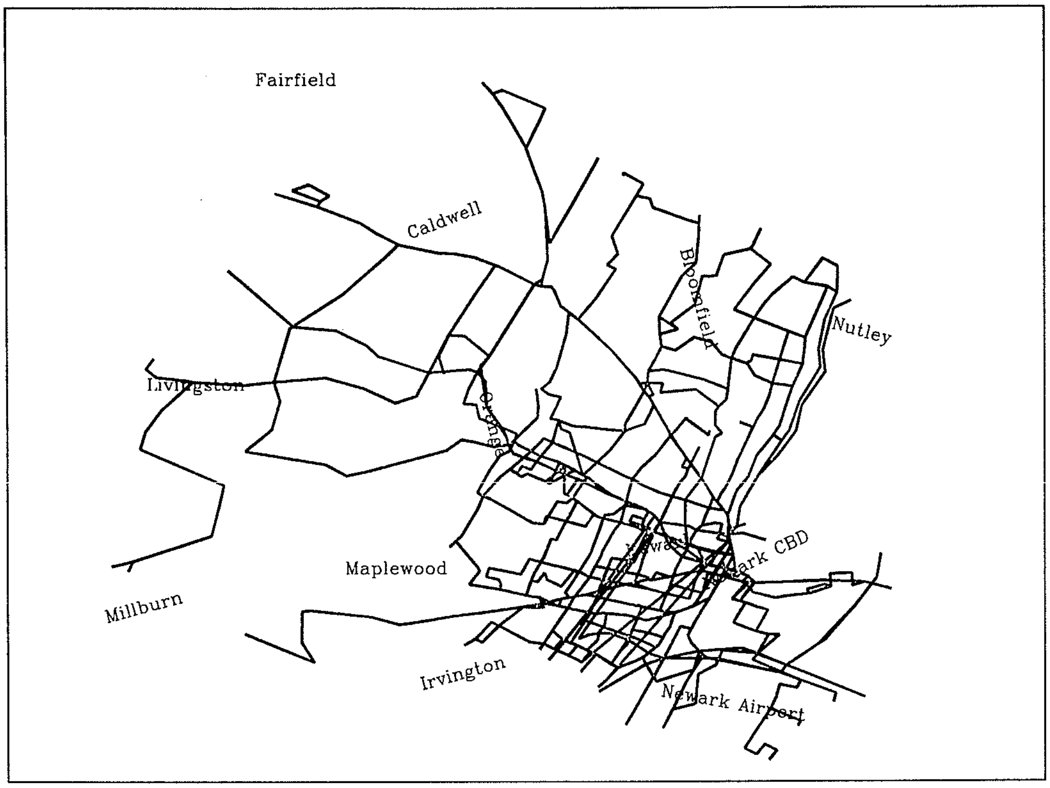

FIGURE 2 Essex County bus routes.

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 non-work 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;

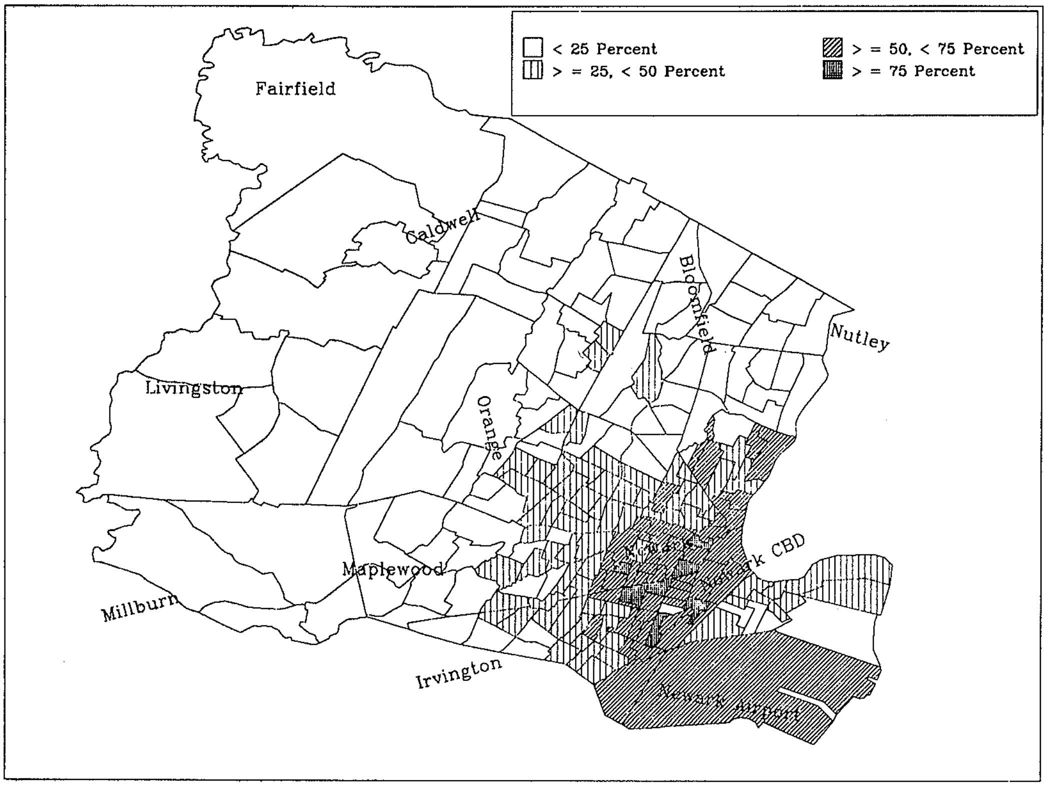

FIGURE 3 Percent of households without automobiles.

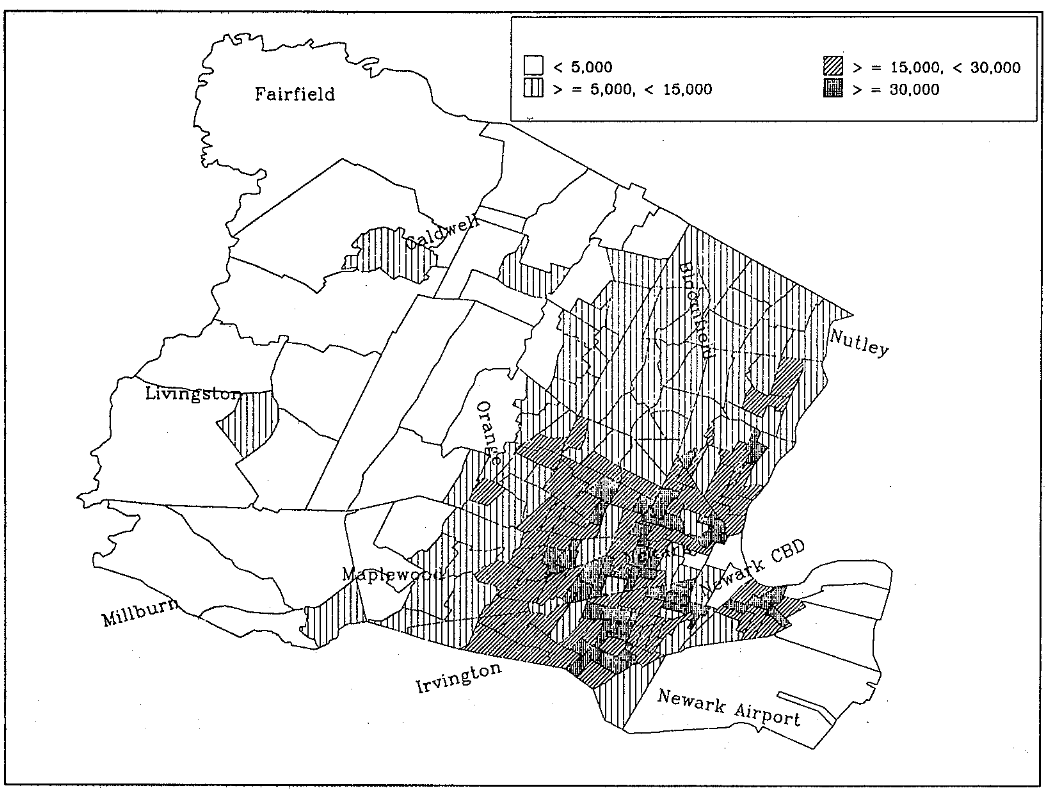

FIGURE 4 Residential density.

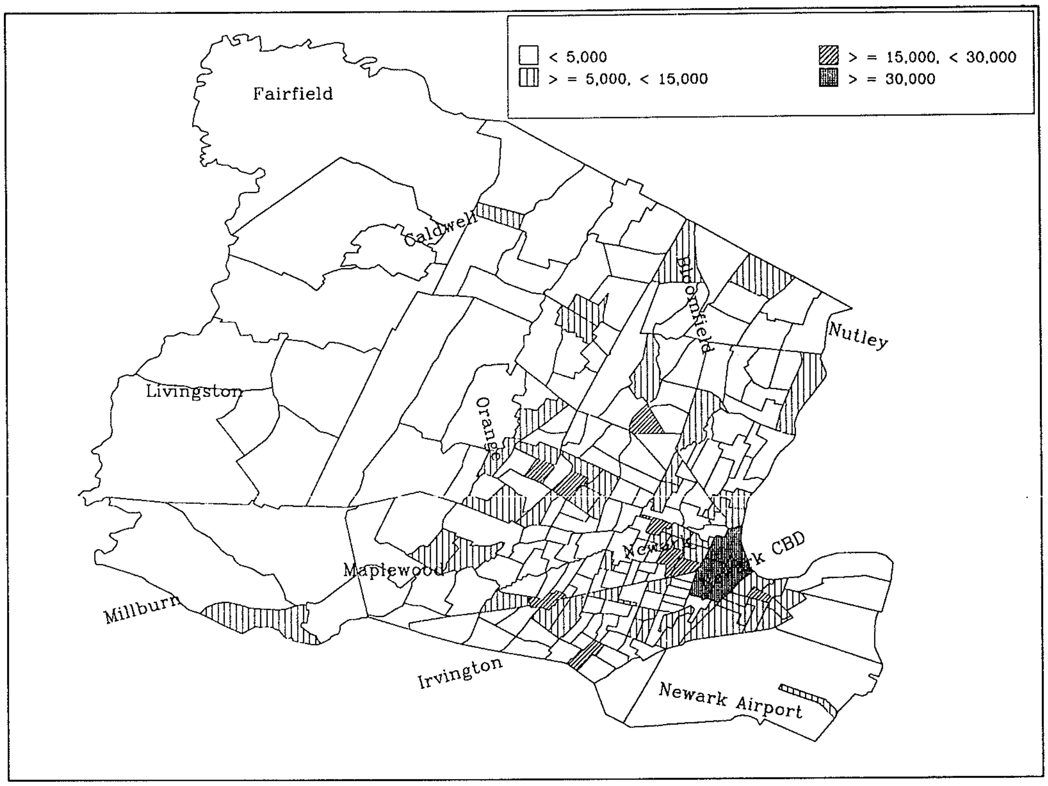

FIGURE 5 Worker density.

• 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:

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

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:

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

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 $route_k$.

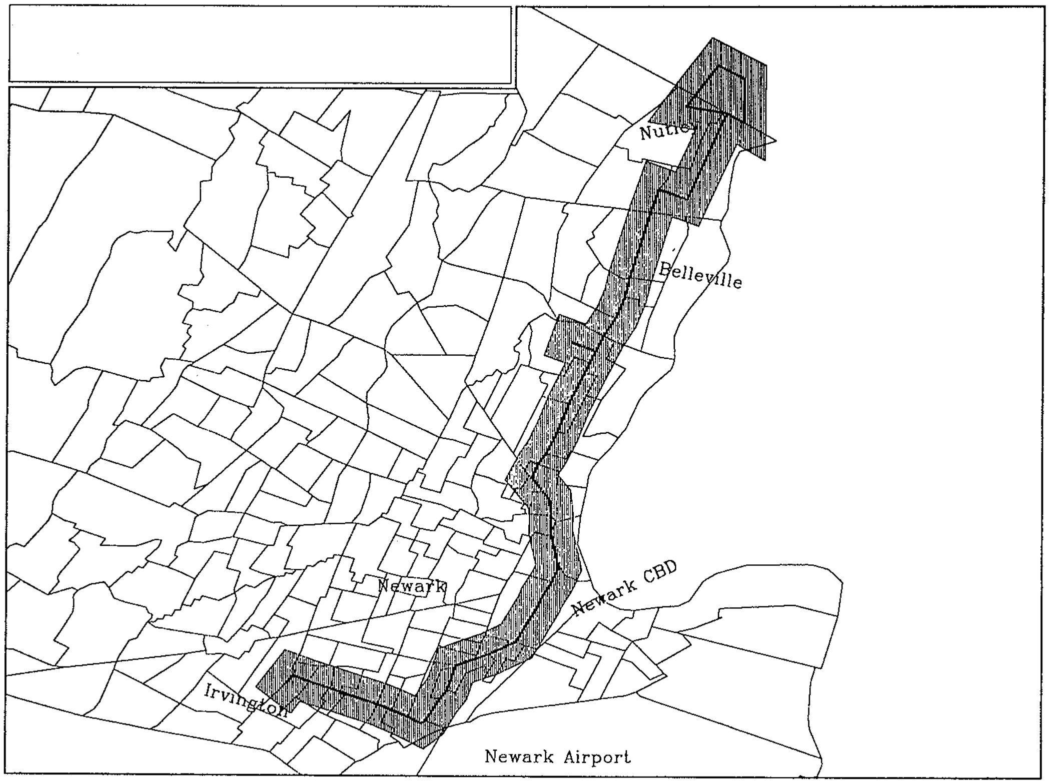

FIGURE 6 One-quarter-mile service area for Route 27.

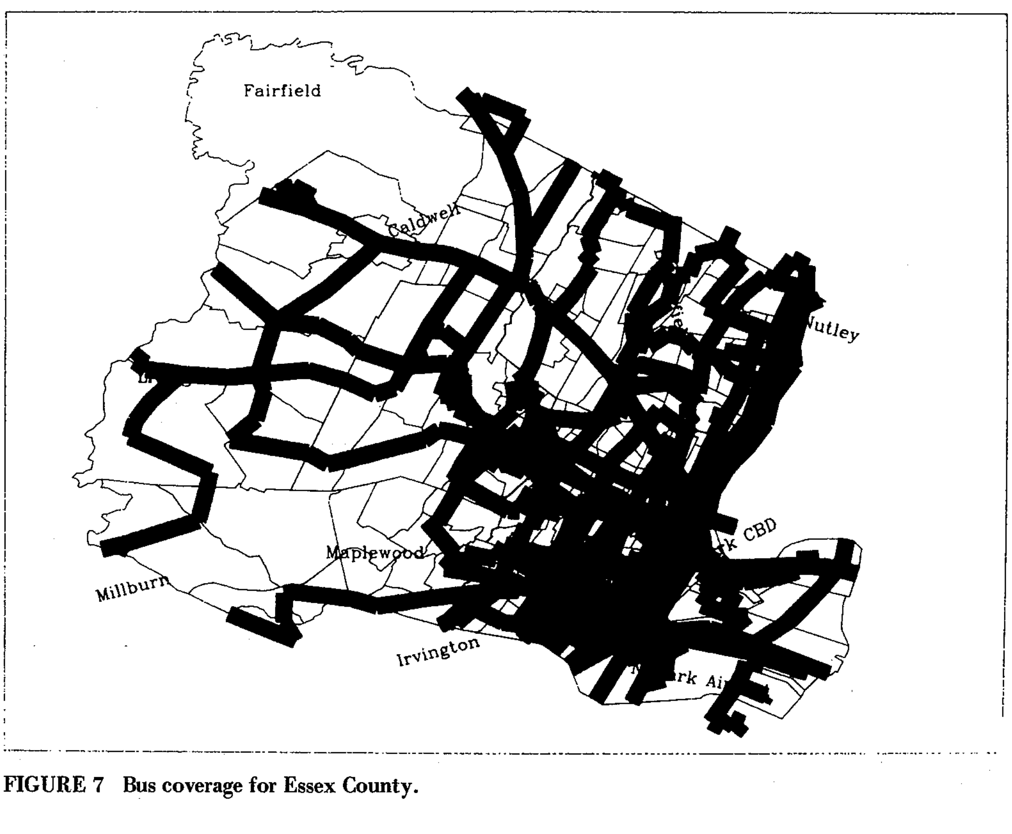

FIGURE 7 Bus coverage for Essex County.

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:

$$R_i = p_i \ r_i \qquad (3)$$

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:

$$p_i = p(s_i, f_i) \qquad (4)$$

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:

$$W_i = q_i \ w_i \qquad (5)$$

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:

$$q_i = q(s_i, f_i) \qquad (6)$$

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:

$$T_i = R_i + W_i \qquad (7)$$

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:

$$N_i = T_i \ \bar{x} \qquad (8)$$

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:

$$M_i = T_i + N_i \qquad (9)$$

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:

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

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

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; $R^2 = .41$.

tend to account for the diminishing returns of additional service applied to a given tract.

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

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

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.

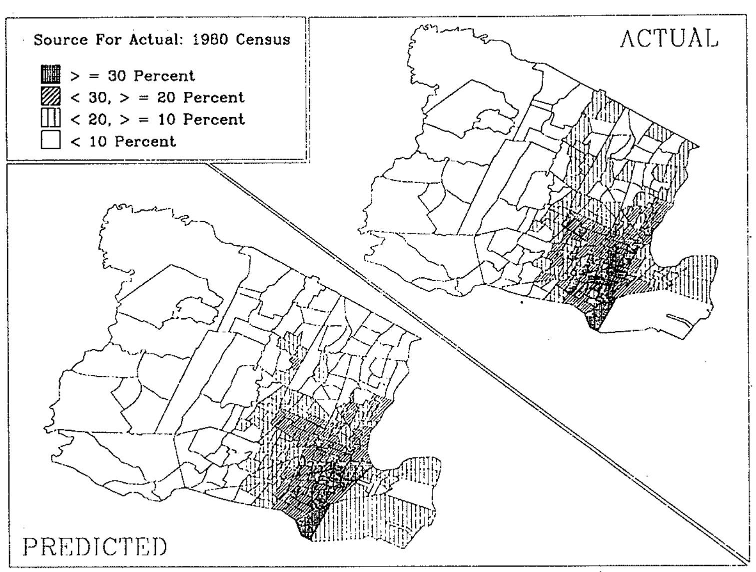

FIGURE 8 Actual versus predicted percentage of bus riders.

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.

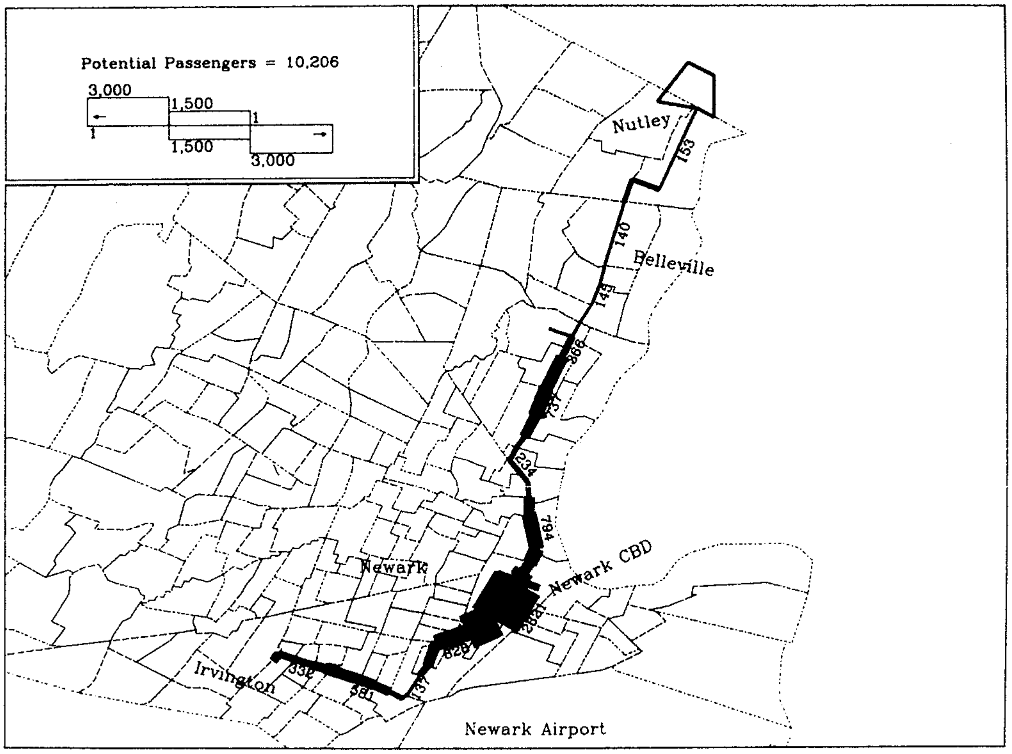

FIGURE 9 Potential daily boardings on Route 27.

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

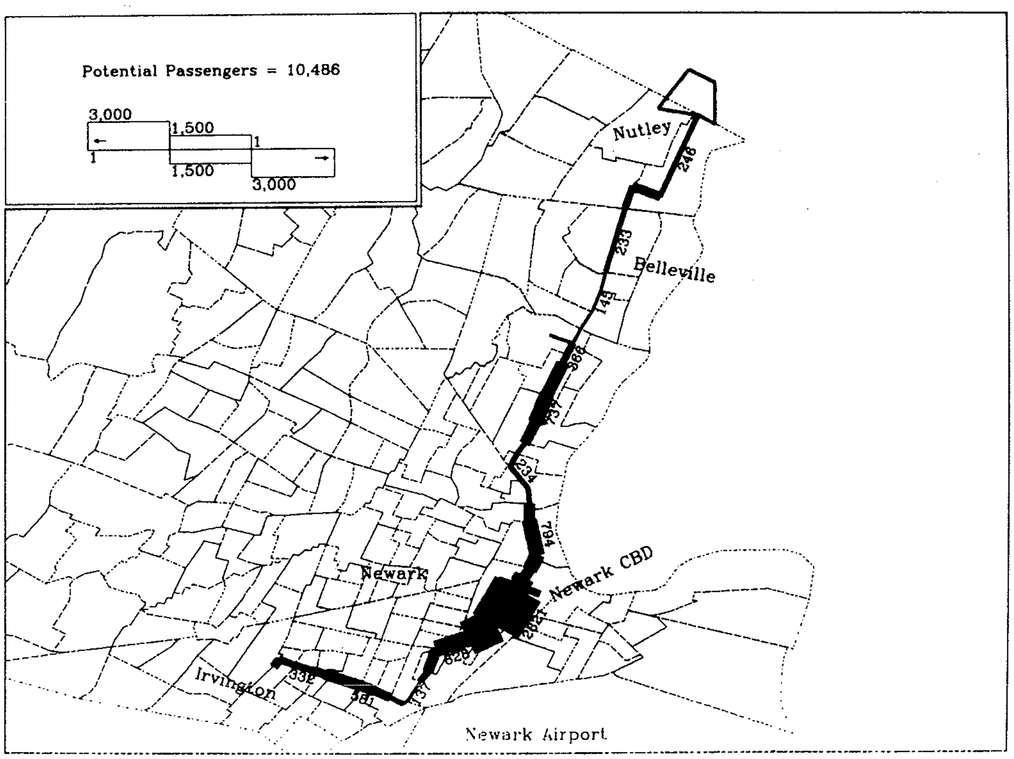

FIGURE 10 Potential daily boardings after employment center is added to Nutley.

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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