end. Unguarded growth now would assure major service withdrawals in 1985 and the loss of the goodwill of district patrons.

ACKNOWLEDGMENT

Special thanks to Don Dravis for preparing the manuscript and to Susan Chapman for composing the charts.

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Using the 1980 Census to Evaluate the Equity of Transit Service in Northern New Jersey

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ABSTRACT

A computer-based method is developed to evaluate the compliance of New Jersey Transit with Title VI of the 1964 Civil Rights Act regarding a fair and adequate distribution of transit service to all persons. The method involves a combining of transit-service and census data so minority areas and the level of service to these areas can be identified. One county (Union County) was selected as a test case to examine the four main problems encountered. The first involved geographical matching of transit routes and census tracts. Second, transit service had to be measured and apportioned to the tracts. Third, minority classifications were defined and assigned to the tracts. Finally, a means was necessary to present the results in an easily interpreted format.

At the request of New Jersey Transit (NJ Transit), the newly formed state organization responsible for owning and operating most of the public transportation services in New Jersey, a procedure was developed at Princeton University for evaluating the equity of transit service to the various minority groups residing in northern New Jersey's urbanized areas. This was prompted by NJ Transit's need to report to UMTA the compliance or noncompliance with Title VI of the 1964 Civil Rights Act regarding a fair and adequate distribution of federally assisted transit service among all persons.

The two main data requirements for this study were the transit operations and the census information. The route locations and frequencies for approximately 150 bus routes, 9 commuter rail lines, and 1 subway (Newark) were provided by NJ Transit. Also provided were similar data for privately owned, state-subsidized bus services. The census data concerning the various minority groups were obtained from the 1980 census at the tract level. The study region in northern New Jersey contained 1,280 tracts in the following 10 counties: Bergen, Essex, Hudson, Middlesex, Monmouth, Morris, Ocean, Passaic, Sommerset, and Union (see Figure 1).

Union County was used as a test case to focus on the four main problems that had to be resolved in order to permit a rational, rapid, and objective display of the facts. The first problem concerned the geographical matching of transit routes and census tracts. Second, transit service had to be measured and apportioned to each tract. The third problem involved defining the minority classifications and assigning those properties to the tracts. Finally, a method was needed to present the results so that all pertinent information could be displayed for easy interpretation and assessment by UMTA's evaluators.

GEOGRAPHIC MATCHING OF ROUTES AND TRACTS

The transit routes were provided by NJ Transit as a series of bold lines traced over streets on Hagstrom maps. A digitizer was used to code these routes for computer storage as a series of line plots with X-Y coordinates. [Digitizing routes involves tracing the route on a sensitive table with a special pen that automatically records the location of a point (node) when it is depressed.] From the X-Y coordinates of the nodes, routes were pieced together as a series, or chain, of links (see Figure 2).

The tract boundaries were available in a digitized form from the Princeton University Computer Center. This file, as with the route file, consisted of a set of X-Y coordinates, but these coordinates were in latitude and longitude (Figure 3). Therefore, a method to combine the two data sets into a

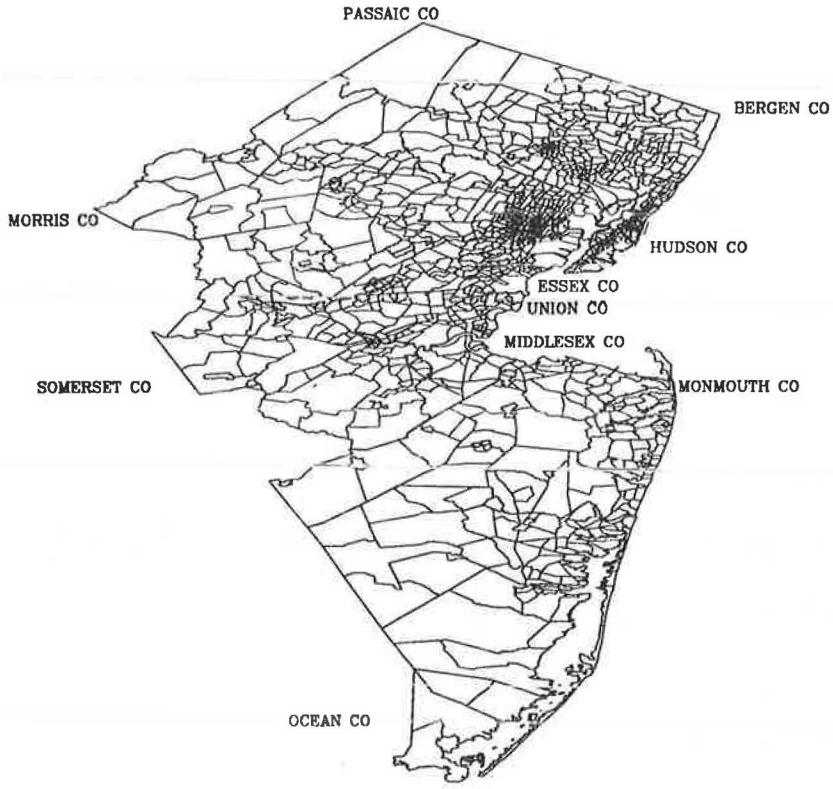

FIGURE 1 Study region: 1980 census tracts, northern New Jersey.

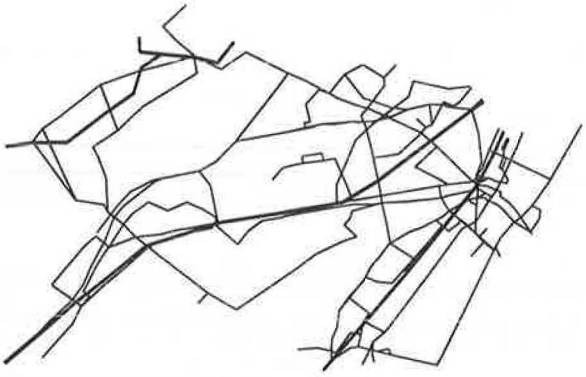

FIGURE 2 Union County transit routes.

common, geographically accurate set of coordinates was required (i.e., the two maps had to be fitted to the same scale and orientation).

The problem at first appeared to involve a simple rotation and translation of one data set to fit the other. So the first attempt was to transform the tract data and produce a transparent map to overlay on the Hagstrom. From these two maps, the routes were defined by digitizing the points of intersection between the route and tract boundaries as the routes traversed the tract map (see Figure 4).

This immediately led to two problems. First, routes often follow tract boundaries (because many boundaries are main roads), which creates difficulties assigning routes to a tract. The second and more serious problem occurs when random errors are introduced into the digitizing and transformation processes, which results in an assignment to the wrong tract of a route that is on or close to a border.

The only way to ensure that a route follows a boundary exactly is to assign the route nodes and boundary points the same X-Y coordinate. This is an extremely slow process and could not have been completed by the project deadline. Therefore it was decided to adopt a process developed by Walter G. Anderson of the Princeton University Interactive Computer Graphics Laboratory (ICGL) in which a band or service region is constructed around the route. This process--called the ribbon approach--is discussed in the next section.

One last improvement that permitted faster input of the routes was to digitize them without regard to tract boundaries. Because both the route and tract coordinate files are stored, it appeared logical and faster to let the computer calculate the points of intersection between the routes and the tracts.

ASSIGNING SERVICE TO TRACTS

Once the routes were stored in the computer as a set of points located within the census-tract map, the two data sets (demographic and transit service) had to be related for each route in each tract. The goal was to obtain a measure of service that was simple and meaningful.

The simplest relationship between the tracts and the routes was the distance each route extended through any given tract. This was easy to calculate but presented some modeling problems. Bus routes tend to fall along tract boundaries, but because of the random errors incurred in digitizing the points, the computer assigned everything to one tract or another. Obviously, a route running close to a boundary is actually serving the neighboring tract as well as the tract through which it travels. The

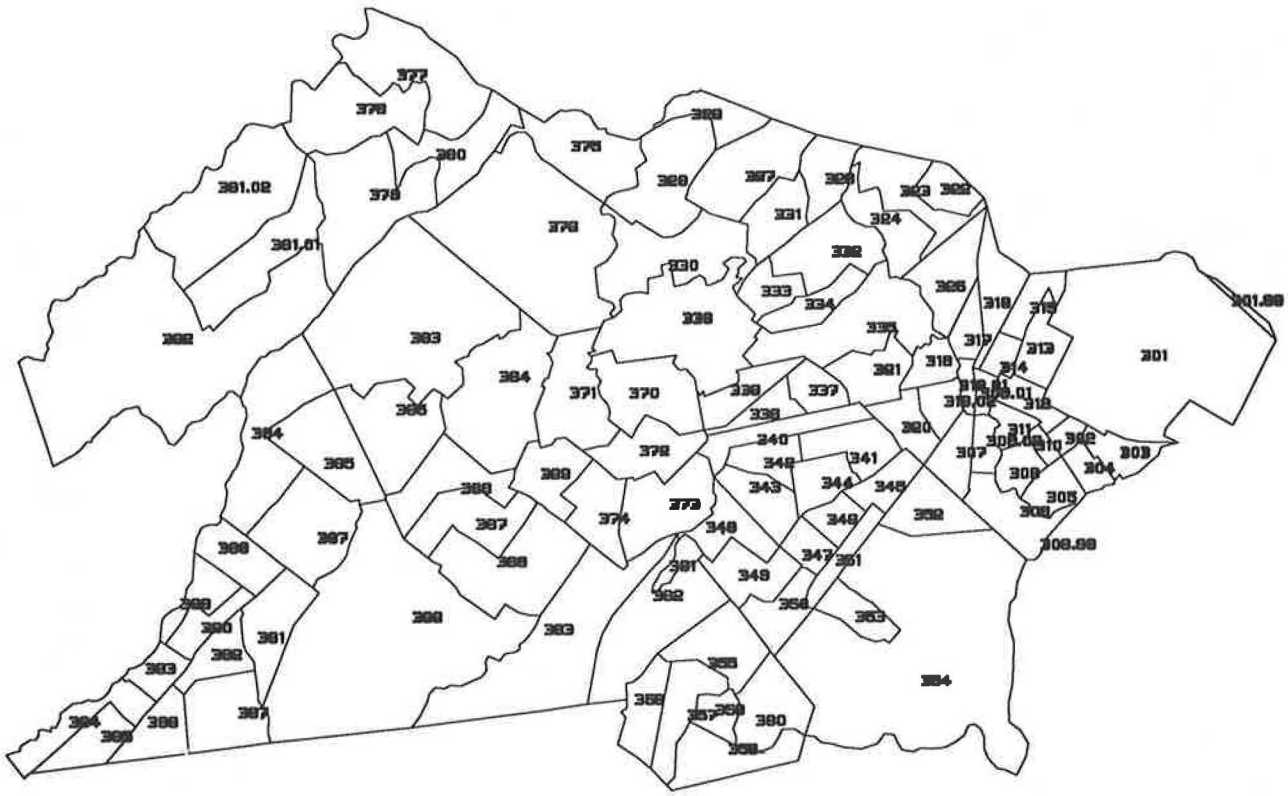

FIGURE 3 Union County 1980 census tracts.

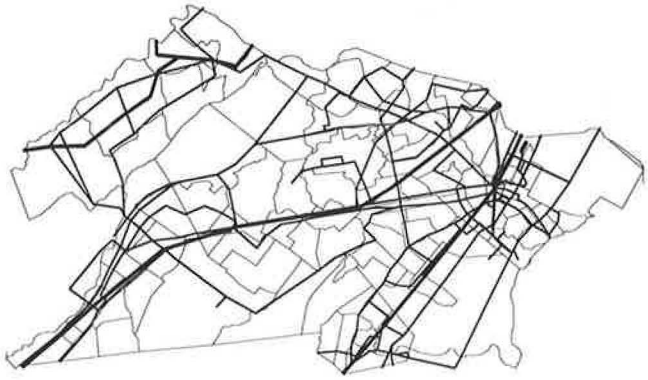

FIGURE 4 Union County tracts and routes.

route-miles measure did not make allowances for this situation. Another failure of this system was that differences in types of bus and rail service could not be considered in a realistic day. In order to distinguish between a local and an interstate bus, one would probably use a regression coefficient reflecting the probability that a person will board an interstate or intrastate bus. To find this coefficient would entail much time and data manipulation and the result would not be a clear or understandable representation of the measure of service.

After consideration of several other methods, the final decision was to pursue what is now referred to as the ribbon approach. The procedure is straightforward and logical in its methodology.

The theory centered around those boarding public transit. The person most likely to board a particular bus is someone standing in a location where the cost of the walk to the route is less than the value of the net benefit to be gained from the service at the end of that walk. A method was developed where it was possible to construct a ribbon of any width around a chain of links (a bus route) (Figure 5). This enabled a decision about what actually constitutes service to be made in a realistic and meaningful way. The final choice, made in consultation with

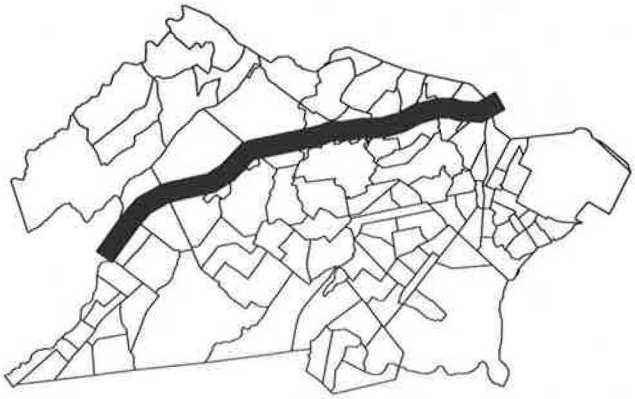

FIGURE 5 One-fourth-mile service ribbon: NJ Transit bus route 150.

NJ Transit, was to allow a 0.25-mile distance or service area on either side of the local bus routes and a 0.50-mile service area on either side of the interstate routes. Railroad stations were given circular service areas of a 0.50-mile radius because the stations are the only points where passengers can

board. These distances represent reasonable walking distances for their respective services.

The second step was to measure actual service to the tracts. The region lying in a route's service area (i.e., the route ribbon or station circle) was found and apportioned to each tract. The area computations were accomplished by drawing straight parallel lines close together inside the ribbon or circle (Figure 6). The area inside any tract is found by computing the length of each line in that tract and multiplying the total by a constant for the line spacing.

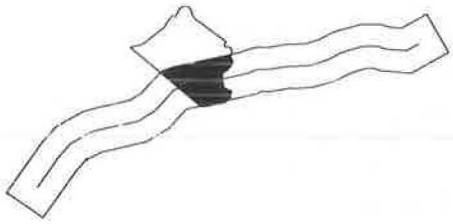

FIGURE 6 Intersection between Union County Census Tract 378 and 0.50-mile service area around NJ Transit bus route 150.

The shaded or ribbon area for each route in each tract is then divided by the total area of that tract, giving a percentage of the area in any particular tract served by a given route. This is shown as follows:

Percentage of $TRACT_i$ served by $ROUTE_j$ = RIBBON $AREA_i^j$/TOTAL $AREA_i$.

Each of these percentages was then multiplied by Q_i^j, which was the frequency of ROUTE through TRACT on a typical workday. For the train stations, Q_i^j was the number of scheduled trains at each individual station. This allows the frequency to be set to zero for closed-door bus service to some tracts and to remain at its normal value through tracts that are fully served. The percentage of area served represents the probability that a bus route will be available to a person in $TRACT_i$, and the frequency represents the number of buses in a typical day. This service level is for each individual route for each tract; therefore, total service to a tract is the sum over all the routes for that tract.

This measure of service is in reality a measure of service to the geographical section of land represented by the tract. Thus it represents the service an individual in that tract will encounter. The numbers are compared with the census data by (a) assuming uniform distribution of the population within a tract and (b) comparing the service level with a measure of the probability that a certain person standing in $TRACT_i$ will be of a particular background (e.g., the probability that the person standing in $TRACT_i$ is black equals the percentage of the population of $TRACT_i$ that is black).

There are many advantages to using the ribbon approach for calculating service to an area, the most important of which is the simple reasoning behind the weighting of the service. However, it also allows flexibility in setting frequencies, changing the width of the ribbon of service, and relating the service measures to different segments of the population data base.

BLOCKING TRACTS BY MINORITY CLASSIFICATIONS

Once the level of transit service has been determined for each tract, it becomes important to find the classifications and number of minorities who are receiving the service. The selection of the minority groups included in the study came after consultation with NJ Transit and UMTA representatives. Minority data were obtained from the 1980 census Summary Tape File 3A (1). It was decided by NJ Transit, UMTA, and Princeton that the following seven minority classifications were appropriate for the purposes of this study (the census files from which the data were extracted are given in parentheses): carless households (97, 123), black (12), elderly (65 and over) (54), income level (family) (73), minority (total) (12, 14), Spanish (12, 14), and transit handicapped (54).

Each tract was assigned a percentage of the minority for six of the seven categories, the exception being income, which was assigned as the median level for the tract. It was necessary to determine regional means and medians from county-level data because small values are often suppressed at the tract level. The tracts were grouped by different shadings to permit viewing of high minority concentrations in the region or county. The gradations for the shadings were selected with reference to the magnitude of the regional mean (see Figures 7 and 8).

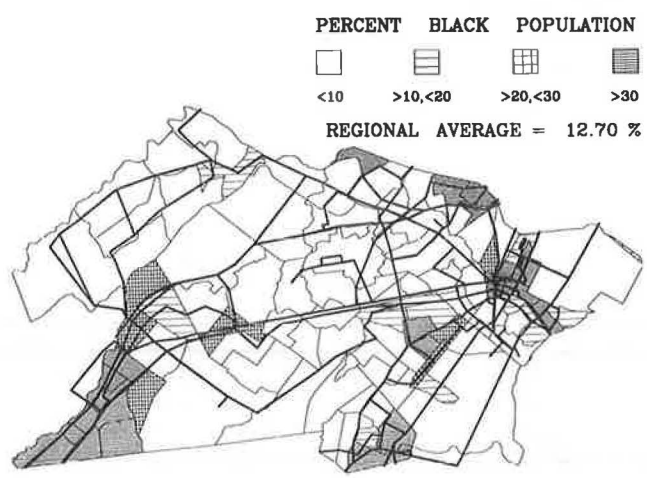

FIGURE 7 Percentage of black population.

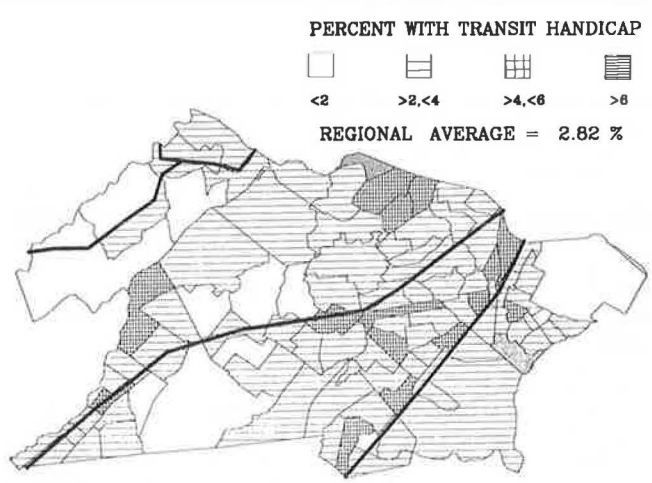

FIGURE 8 Percentage with transit handicap (shaded tracts).

Means provide a good measure unless the data contain "wild shots" (extreme values). It was therefore decided to use medians also, which give a more robust measurement. To do this, all tract values were ranked and a regional median and two hinges (i.e., quartiles) were established. These quartiles, taken from regionwide values, permitted comparison of minority concentrations not only within one county but also between counties (see Figure 9). This method proved to be misleading because of areas of high minority concentration. For example, the regional median for blacks is 1.9 percent (65 blacks per tract) compared with a mean of 12.7 percent (the difference being attributed to several areas with more than 90 percent black population). Therefore, Figure 9 identifies tracts with 2 percent black population as above the median and thus high-minority areas.

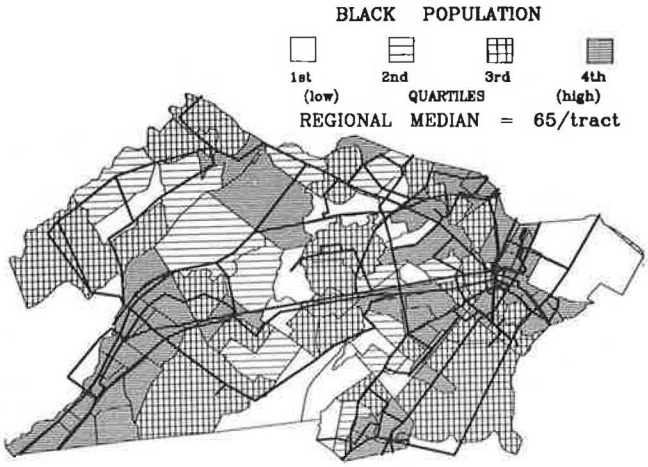

FIGURE 9 Black population (quartiles).

By multiplying the percentage of tract area by the frequency served (as described in the previous section), a measure of amount of service to that tract is obtained. Summing over all tracts provides totals for minor civil division or county. The major assumption made in these calculations is that each tract is homogeneous and of uniform density, which means that variations in population densities within tracts are not considered. However, it provides a reasonable approximation.

EFFECTIVE PRESENTATION OF RESULTS

Once the service levels were calculated and the minority groups identified, it was necessary to provide clear and concise representations of the combined data. Several different formats that allowed simultaneous scanning of both transit service and demographic data for a county or the entire region were tried. These formats centered around combinations of shadings, skyscraper plots, and variable bandwidths.

The two plots most appropriate for displaying census data were shaded tracts and skyscrapers. The tracts were shaded based on even gradations using means as reported in the previous section (see Figure 7). The skyscraper plots are vertical bars drawn at tract centroids proportional in height to the data item being displayed (see Figure 10). The advantage of the skyscrapers over shading is that shading implies sharp differences between tracts

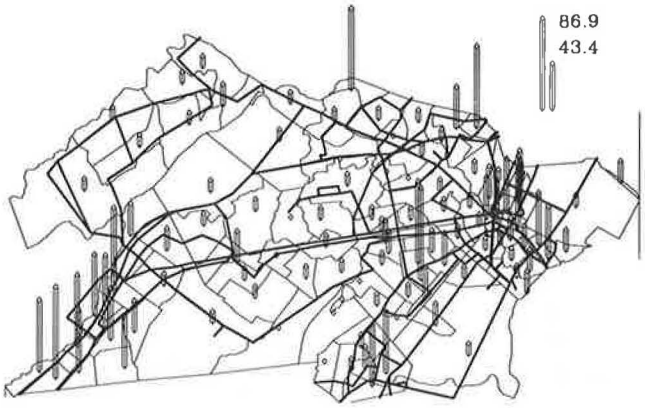

FIGURE 10 Percentage of black population (skyscraper plots).

when in some cases they may only be 1 or 2 percent apart. The skyscraper or bar plots reflect the actual percentage for each tract.

In attempting to display transit service, both frequency and coverage have to be considered for each tract. Frequency can be shown as bandwidths where the thickness is proportional to the number of buses traveling on that link (see Figure 11). Coverage can be easily visualized by shading the service regions (ribbons) around each route and noting the unserved (unshaded) areas (Figure 12). By multiplying frequency by percentage of tract served, a number reflecting service within a tract can be

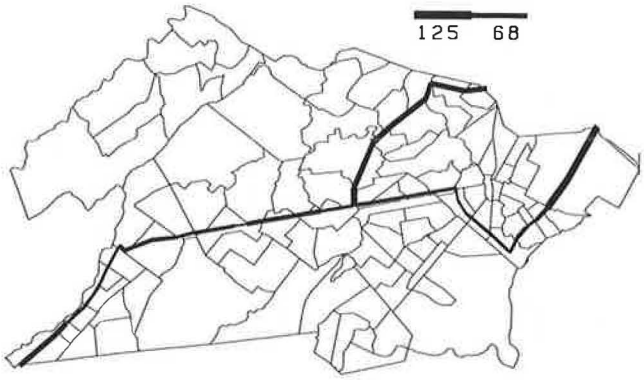

FIGURE 11 Transit frequency in buses per day.

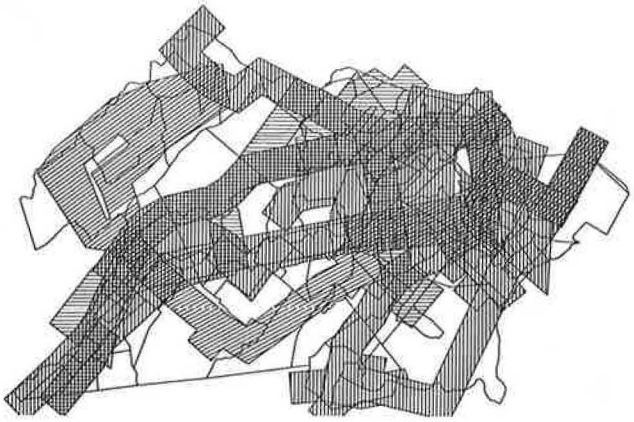

FIGURE 12 Transit coverage.

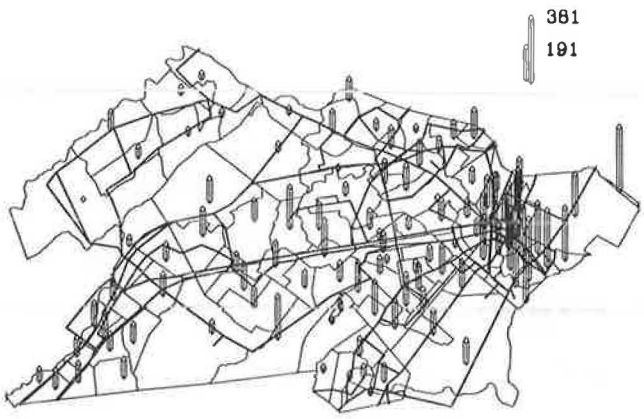

FIGURE 13 Bus service in Union County.

obtained and displayed using skyscrapers (Figure 13). This value represents the number of times per day the average tract resident can board a bus or a train.

The relationship between the census data and the level-of-service measure is the key step in attempting to define the equity of service. In Figure 14 the values for percentage of minority and local bus service are given to provide a clear, graphical

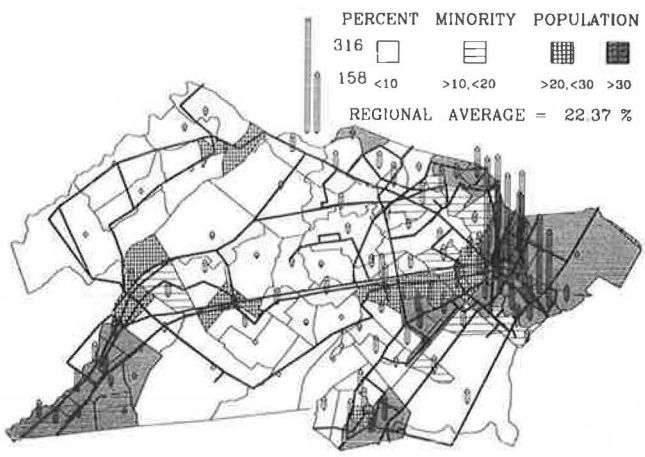

FIGURE 14 Bus service and minority population.

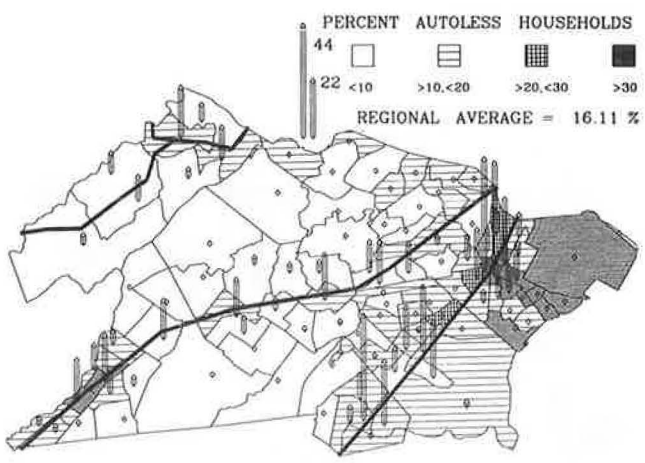

FIGURE 15 Rail service and carless households.

representation of transit service to minorities in Union County. A similar diagram is presented in Figure 15 for carless households and rail service.

CONCLUSION

This research was undertaken by Princeton University with the intent of exploring quick and economical methods for relating census data and transit service. The application of this comparison, as presented in this paper, was to provide a measure of the equity of service to minority groups for reporting Title VI requirements. A series of criteria and measures were selected that presented the information in a realistic and beneficial manner.

It became obvious during the course of this project, however, that many of the techniques used could be expanded into other areas of transit planning and analysis. In determining equity of service, it was also possible to identify unserved areas and compare intrastate and interstate bus and rail service levels. Expanding on this process can lead the planner to methods for determining new transit needs in view of changing land use patterns or prediction of ridership potentials along proposed routes. Thus, it is believed by the authors that this method for assigning transit service based on demographic data is not restricted to the determination of equity of service but can be applied to a wide range of future research.

The question that remains for UMTA and others to answer is whether transit service (in this example in Union County) is equitable. If one measures the number of opportunities per day per capita to board a transit vehicle (the measure of service to each tract) and multiplies that by the number of persons in each minority group in each tract, a composite number can be generated for the county.

After this had been done, the following number of daily opportunities were found in Union County for minority, white, and total population for local and interstate bus service:

Category	Total No. of Opportunities	Transit Service Frequency Per Capita: Local	Transit Service Frequency Per Capita: Interstate
Minority	127,818	68.2	43.5
White	376,276	46.3	34.7
Total	504,094	51.8	36.9

If populations in each tract are homogeneous and evenly distributed and if the availability of a bus (or train) over an average weekday is a fair measure of transit service, the conclusion drawn is that service is better (more frequent and closer) in those tracts with a higher percentage of minority population. But this is known because low-income households live more densely and have fewer cars. Therefore, this is where bus customers are more likely to be.

ACKNOWLEDGMENT

The authors would like to express their appreciation to the people who donated expertise and direction to this study. Walter G. Anderson of the Princeton University Interactive Computer Graphics Laboratory provided the algorithms for creating the ribbons, calculating the intersections, filling the tracts and service regions, and retrieving the census-tract coordinates, all of which were crucial elements in this study. Jeffrey Zupan and the staff at NJ Transit contributed key suggestions for service levels and formats along with timely delivery of data.

Also, Bernard P. Markowicz kept this study moving with insightful advice on some difficult problems. A polygon version of the 1980 Census Tract Boundary Coordinate File, leased by Geographic Data Technology, Inc., was made available through the Princeton University Computer Center courtesy Judith Rowe, Shirley Robbins, and Doug Mills, who also made available Summary Tape File 3A through the Princeton-Rutgers Census Data Project. Finally, Alain Kornhauser, director of the Princeton University Transportation Program, provided the overall direction of this effort.

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Abridgment

Design of a Nighttime Transit System for Salt Lake County, Utah

RAYMOND C. MILLER

ABSTRACT

Salt Lake County, Utah, has experienced tremendous population growth along with an increased demand for transit services since 1970. The Utah Transit Authority (UTA), a publicly funded organization, was conceived in 1970 and is responsible for providing public transportation to Salt Lake County. UTA has continuously modified services to accommodate the growth and changing travel patterns throughout its history. However, transit service after 7:00 p.m. had not been changed since its implementation more than 10 years ago. Analysis of the nighttime transit service in this region revealed that this service was not functioning effectively. Three conceptual systems were developed, and the system that best met the goals is described. The new system was implemented on November 22, 1982.

Currently, transit systems throughout the United States are undergoing serious financial problems (1). The transit company basically has two alternatives to balance the budget. One is to increase revenue by increasing either ridership or fares. The other is to decrease costs or service.

The Utah Transit Authority (UTA) operates approximately 27,000 revenue miles per weekday, 5.6 percent of which are operated after 7:00 p.m. Therefore, approximately 1,500 revenue miles of service make up the night system, which is defined as all trips departing from the central business district (CBD) after 7:00 p.m.

Historically, UTA's night service has been one of the least efficient in the system. The service terminated at 9:30 p.m., which is when the last trips departed from the CBD. The service was implemented during the early 1970s when the UTA system was originally conceived. Since that time, the region as well as the travel demands of the population have continued to grow.

The primary goal of this research was the development of a nighttime transit system that offers the public a better service. The first objective in accomplishing this goal was to accurately identify the characteristics of the existing service. The second objective was to determine regional characteristics such as activity centers, population densities, and trip origins and destinations. The third objective was to reduce operating costs and maintain or increase the existing ridership level. The fourth objective was to extend the hours of service.

The primary goal and set of objectives lead to the hypothesis that decreasing transit coverage during the evening and night period and extending the hours of service will improve the economic efficiency of transit service after 7:00 p.m.

OPERATING CHARACTERISTICS OF PRIOR SYSTEM

The night transit system was made up of 26 routes operating 134 one-way trips, most of which originated in downtown Salt Lake City. With the exception of one route that serviced Ogden from Salt Lake City, all of the routes operated within Salt Lake County. The service provided extensive coverage or accessibility, especially to the east side of Salt Lake Valley. The system was implemented in the early 1970s, at which time a large percentage of the population resided in the east portion of the valley. Since the early 1970s, a large amount of commercial and residential development has occurred in the southwest portion of the valley, yet little service existed within this area. Comparing the