Caliper
Corporation

INTEGRATED TRANSPORTATION GIS
AND DEMAND FORECASTING SYSTEM

Prepared for the
NEW YORK CITY TRANSIT AUTHORITY
and the
METROPOLITAN TRANSPORTATION AUTHORITY

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CHAPTER 1

INTRODUCTION AND EXECUTIVE SUMMARY

The purpose of this project was to develop an integrated geographic data analysis and demand forecasting system to support transit planning by the New York City Transit Authority (NYCTA) and the New York Metropolitan Transportation Authority (MTA).

Three key objectives of the project were 1) to develop a system to forecast subway travel for use in matching subway service to demand; 2) to construct a system that exploits technical advances in modeling, computer graphics, and geographic information systems, making it possible to interactively generate graphic displays of key information associated with the transit system; and 3) to provide a broad transportation and geographic information and analysis capability for planners and operations management personnel.

A key design criteria required development of a system that is easy to use but did not compromise system capabilities or accuracy.

TECHNICAL APPROACH

The technical approach involved the development of subway demand models and the integration of these models and associated transit data in a Geographic Information System (GIS) software platform. The TransCAD GIS was chosen as the platform for this project in part because it was already in use at the MTA (where it had replaced mainframe UTPS models), and in part because of the system's flexibility and adaptability.

A classical four-step modeling methodology was employed, consisting of a trip generation model, a trip distribution model, a set of mode share models, and a subway trip assignment model.

The study area represented in detail four New York City counties (Bronx, Kings, Queens, New York). For modeling purposes, small area geography was used. Previously defined Corridor District traffic analysis zones were used within New York City. These zones were designed for analyzing subway demand, and were strict aggregates of census tracts, making it simple to develop census-based data sets for these zones. A simplified representation of Richmond County and surrounding suburban counties was used to analyze subway trips generated through transfers from commuter rail at Penn and Grand Central Stations or trips generated at the outermost subway stations.

Serious data inadequacies were encountered in the course of the project, as described below. As a result, the forecasting system was designed to be easily enhanced as improved data become available from the 1990 Census and other data collection efforts.

The GIS framework was chosen for model implementation because of its capabilities for examining and verifying model data, presenting and visualizing the results of quantitative analysis, and for production of presentation quality graphics. The analytic and modeling capabilities of the GIS were crucial to this project because of the need to calculate key demand model input data that was not available from other sources.

Trip Generation

The trip generation model for work trips is, in effect, a model of out-of-home labor force participation. This was formulated as a series of linear models which used population characteristics of sex, ethnicity, age distribution, and household size as explanatory variables. 1980 Census measures of population characteristics were the only available source of data at the Census tract level; GIS functions were used to aggregate these data to the level of analysis zones.

Trip attraction model development was prohibited by the lack of any sufficient and projectable data set of potential explanatory variables, such as business floor space by classification or SIC code. Instead, base year attraction estimates were determined exogenously by the distribution of employment by work place zone.

To generate trip attraction forecasts, a constant factoring approach was used to balance the sum of trip attractions (over all destination zones) with the forecast of trip productions (over all origin zones). This balancing method would be required even in the presence of an explicit trip attraction model in order to ensure a consistent region wide trip total.

Trip Distribution

Two trip distribution models were evaluated in the study. The first was a doubly-constrained entropy/gravity model that computes interzonal flows as a function of the generalized cost of travel between zone pairs. The second was a Fratar growth factor procedure that scales an O/D matrix as a function of the existing matrix and new estimates of origin and destination sums.

The entropy/gravity approach reflects the impact of transportation system changes upon trip distribution. However, the entropy/gravity model could not be calibrated to accurately reproduce the base case 1980 O/D flows. The Fratar method, on the other hand, guarantees replication of the base case flows without error, but its use assumes that transportation level of service has minimal effects upon work trip distribution. Because this is likely to be the case, and because replication of the base flows is an important consideration, we elected to use the Fratar method as the trip distribution model.

Mode Choice

Mode choice models of the binary logit form were estimated to predict the subway mode share for work trips between each zone pair in the study area. Because no disaggregate data were available for model estimation, the mode choice models used individual zone pairs as observations. Aggregate subway mode share for each zone pair was used as the dependent variable, and appropriate demographic and level of service measures were used as independent variables.

Separate equations were estimated for each county in the region, and for Manhattan and non-Manhattan destinations. The county-specific models made it possible to capture geographic variations in mode share determinants. Origin zone constants were included in the models to guarantee replication of base case shares without error. These constants presumably account for explanatory factors omitted from the models due to data limitations or unknown causal effects. Similar destination county constants were included in the models of travel to non-Manhattan locations.

Many different model specifications were tested, incorporating factors that travel demand theory suggests are possible determinants of mode share. Level of service for subway and auto modes was represented by line haul travel time and by access and egress characteristics. Demographic characteristics such as household auto ownership, income, and other population measures were also tested. In general only those explanatory factors that proved to be independent and statistically significant determinants of mode share were retained in the model equations.

Severe data limitations were experienced in estimating the level of service for auto and subway modes. Census journey-to-work estimates of zone-to-zone travel time by mode were both incomplete and biased. Information on access and egress modal characteristics were virtually unavailable.

Therefore, the capabilities of the TransCAD GIS were exploited to generate estimates of services characteristics. Existing MTA subway and highway networks were incorporated into the TransCAD GIS, and access, egress, and travel time estimates were generated for each zone based on the network characteristics and geography.

The mode choice models produce forecasts of subway work trips by zone of origin and zone of destination. A factoring method is used to convert the subway work trip table to an AM peak period trip table. The peak period trip table was then used as input for the subway assignment model.

Transit Assignment

A key objective of the project was the development of more effective subway trip assignment methods. Extensive experiments performed with UTPS style assignment models indicated that they produce forecasts that are neither behaviorally realistic nor consistent with empirical observations.

In particular, the assignment models in UTPS (and in microcomputer UTPS clones) do not perform well under conditions where many paths are available to serve each origin-destination pair. The NYCTA subway system, with its high density of service and numerous express and local service options, is extreme in this regard.

Capacity restraint, user equilibrium, and a Caliper-coded version of the EMME2 transit assignment procedure all failed to produce realistic subway demand forecasts. In particular, the distribution of demand between local and express services on major subway lines was inconsistent with empirical data.

In practice, travelers choose many different paths between an origin and a destination, with the choice varying by individual (and even by day for a particular individual) depending upon frequency of service, crowding, and perceptions of transit service characteristics such as speed, reliability, safety, seat availability, and number of transfers.

As a result, a model that reflects the stochastic nature of path choice is most appropriate. A stochastic user equilibrium (SUE) assignment algorithm, while computationally demanding, performed extremely well and generated assignment results that had flows which were consistent with base case observations. This finding was consistent with the positive results shown by SUE in commuter rail applications. Consequently, SUE was selected as the method for traffic assignment.

FORECASTING MODEL INTEGRATION

The TransCAD GIS was used as the platform for integrating the forecasting models developed in this study. TransCAD was designed with a modular, extendable architecture that allows external programs to be combined with the system in an integrated fashion. These external programs are known as procedures.

Each of the components of the demand model system was implemented as a TransCAD procedure, and then tied into the GIS platform. In addition, a forecasting "shell" was developed which enables users to define scenarios and run the entire series of forecasting models automatically. This shell is, in fact, another TransCAD procedure that executes the other procedures in the sequence selected by the user.

The individual models were written in the C computing language, and utilize the protected mode of the 80386 and 80486 CPU in IBM and compatible microcomputers. This means that the trip distribution and assignment procedures are not subject to the DOS memory limit of 640K, and also results in significant performance improvements.

CONCLUDING REMARKS

While sufficient to permit the development of forecasting models, the data available for modeling purposes remained fairly sparse. Data limitations strongly governed the form and content of the modeling procedures. For this reason, neither the trip distribution nor mode choice models are intended to substitute for other models utilized for short-term forecasting by the commuter railroads, nor are they intended to have a life span of more than limited duration.

New data arising from recent and future data collection by the MTA and its affiliates should be used to enhance these forecasting procedures. An important aspect of this project was to provide a suitable software framework and repository for future data collection and improved models.

Future directions for improved model building include disaggregate modeling of mode and destination choice. While it would be most desirable to perform data collection specifically to support improved modeling efforts, some of this work may be feasible with recent travel survey data while other aspects may be performed when the results of the 1990 census are available.

The integration of the models with the GIS provide a dramatically enhanced level of information access to planners, managers, and other potential users. Computerized systems that integrate planning models and GIS are relatively new and offer many advantages over stand-alone planning software packages. Most important among these are greater accuracy, transparency, flexibility, pertinence, and validity.

As an example, a GIS combined with planning models makes it possible to analyze data at different spatial scales in different steps of the modeling process. For example, trip generation may be studied at the parcel or land use level, rather than for aggregate zonal units. The data can then be aggregated to the zonal level using GIS capabilities, and trip distribution can be performed at the zonal level. Similarly, intersection data and simulated behavior can be linked with trip assignment methods to capture traffic flow characteristics more accurately.

The GIS also provides access to maps, schematics, photographs, engineering drawings, and other types of images, all of which can be geographically referenced. This expands broadly the range of potential application in a transportation agency.

INTRODUCTION TO THE REPORT

The remainder of this report details the methodology and results of the study. Chapter 2 provides an overview of TransCAD and the application of GIS to the project, and describes data preparation that was performed to support the modeling effort.

Chapter 3 presents the trip generation and distribution models. Chapter 4 describes the mode choice model development effort. Chapter 5 is devoted to a description of the transit assignment model evaluation and development.

Finally, Chapter 6 describes the forecasting model implementation and other database management and graphic applications for the GIS software. Chapter 6 also presents some concluding remarks and recommendations for future work.

CHAPTER 2

STUDY APPROACH

In the first part of Chapter 2 we provide an overview of the technical approach to this study. Subsequent sections describe TransCAD and summarize how it was used as the basic platform for the demand forecasting system. The final part of the chapter describes data preparation for the model development effort.

TECHNICAL APPROACH

The technical approach involved the development of subway demand models and the integration of these models and associated transit data in a Geographic Information System (GIS) software platform. The TransCAD GIS was chosen as the platform for this project in part because it was already in use at the MTA (where it had replaced mainframe UTPS models), and in part because of its flexibility and adaptability.

A classical four-step modeling methodology was employed, consisting of a trip generation model, a trip distribution model, a set of mode share models, and a subway trip assignment model. In the course of model development, many serious data inadequacies were encountered. These data problems are described in detail in this chapter.

The GIS framework was chosen for model implementation because of its capabilities for examining and verifying model data, presenting and visualizing the results of quantitative analysis, and for production of presentation quality graphics. The analytic and modeling capabilities of the GIS were crucial to this project because of the need to synthesize key demand model input data that were not available from other sources.

GIS FRAMEWORK FOR MODEL IMPLEMENTATION

A major focus of this effort was the integration of the transportation forecasting models within a microcomputer-based Geographic Information System (GIS). This section provides a brief introduction to the GIS and transportation analysis capabilities of TransCAD, and explains how the software was used as a platform for model integration.

Overview of TransCAD

TransCAD is a GIS that was designed specifically for transportation, marketing and operations research applications. TransCAD was also designed for high performance and ease of use on microcomputers.

TransCAD produces digital maps based on information contained in specially indexed geographic databases. It also provides many mechanisms for storing and retrieving geographic data; a series of transportation, operations research, and market analysis models; statistical procedures; and presentation graphics capabilities. These capabilities are integrated into a menu-driven, user friendly system that was designed for easy expansion and customization. TransCAD was carefully constructed so that it manages large, complex databases and solves large-scale analytical problems extremely efficiently.

TransCAD is the only GIS that specifically supports data structures that are essential for transportation applications. TransCAD has special data structures for transportation networks, flow matrices, link impedances, paths and tours, and more. These data structures are not implemented in most other GIS packages, or were implemented as an afterthought and are therefore not fully integrated with the geographic and spatial data management system.

TransCAD is also unique in that its design specifically provides for expansion and enhancement of the basic analytical capabilities of the commercial package. All analysis routines are implemented as separate, stand-alone programs, which can be written in any PC-compatible programming language. This made it possible to expand the system to incorporate the variations of the standard models and algorithms that were developed in this project.

Of particular relevance is that TransCAD can be easily used to implement travel demand forecasting model systems by combining the component models, customized versions of these models, and completely new modules that might be required to meet the needs of specific applications.

Basic GIS Capabilities

The TransCAD GIS provides many methods for performing geographic queries and spatial selection. Simple queries can be performed by pointing at any entity on the map display with the cursor; attribute data for the entity is displayed in a pop-up window on the map display. Spatial queries can locate all of the entities that are within a radius of any point, within any arbitrary, user-defined shape, or within buffer zones around any point, line, or region.

TransCAD provides many basic and advanced spatial analysis functions, including distances between points (both straight-line and across a network), aggregation of geographic data to trade areas or other defined regions or areas, identification of intersection and containment among features of many different types, centroid positioning, and many other functions.

TransCAD allows queries which test the values of attributes in the database. These conditions can be combined for compound queries, and can, in addition, be combined with spatial queries to provide significant flexibility in identifying records which meet arbitrarily complex criteria.

TransCAD provides control over many aspects of the screen display, including map scale, feature colors, line widths, icons, color shading, labeling, and map projection. Geographic data can be viewed at scale, from worldwide to the inside of a single building. Individual geographic layers can be activated or deactivated with a keystroke. TransCAD can limit the entities that are displayed in any geographic layer to those identified through a spatial or attribute query.

TransCAD has a comprehensive set of geography commands which can be used to update or modify geographic features and their characteristics. Points can be added, deleted, or moved; lines can be added, deleted, reshaped, joined or split; areas can be joined or split and their boundaries relocated using either the keyboard, a mouse, or digitizer input.

When geographic editing is performed, TransCAD automatically computes revised longitude and latitude coordinates and feature length and area, storing these new values and the associated topology of the database immediately and transparently to the user. The geography of records that are added, deleted, or modified is stored and indexed immediately.

The TransCAD Data Editor provides a spreadsheet-style view of the attributes associated with geographic entities. Attribute values can be added, deleted, or updated directly through keyboard input, or new values can be imported (using relational "join" capabilities) from external worksheet or comma-delimited text files. In addition, attribute values can be recomputed as a function of other database attributes (e.g., travel time can be computed based on speed limit and length).

TransCAD produces text output on any standard PC printer, and text output can also be redirected to a data file, to a comma-delimited file, or to a Lotus 1-2-3 format worksheet file. Maps and charts can be replicated on HPGL format pen plotters, HP LaserJet Series II and III laser printers, and certain Calcomp thermal printers and electrostatic color plotters. TransCAD also produces PCX file output, which permits maps and charts to be modified or annotated using many different PC software programs such as paint programs and desktop publishing software.

TransCAD includes utilities for importing and exporting geographic and attribute data from many formats, including fixed format or comma-delimited text, TIGER/Line, DLG, and satellite image formats such as SPOT and EOSAT.

Applications Development in TransCAD

TransCAD is designed so that analytic modules (procedures) can easily be integrated into the package. Procedures are developed as separate program files which can be written in any computer language.

Because procedures are stand-alone computer programs, they can make full use of the PC, and can even run in "protected mode" to take advantage of the large amounts of memory that can be made available on 80386 and 80486-based computers.

TransCAD has a procedure interface which allows the procedure developer to design and implement menus and prompts that collect input parameters for the procedure from the user. These input parameters, and all required data from the internal GIS database, are then made accessible to the procedure.

The programmable interface means that procedures appear to the user to be internal functions of the software. This makes it possible to develop and integrate a series of powerful analytical models in a consistent and easy-to-comprehend framework.

The extendibility of TransCAD was crucial to this project, because it permitted the specialized generation, distribution, and assignment models that were developed to be integrated into a unified forecasting system.

Basic Modeling and Analysis Functions

TransCAD in its commercial form has all of the analytical models required to support a four-step model implementation. What follows is a listing of some of the specific analysis functions that are included in the commercial TransCAD package:

Address Match Geocoding - Determines the longitude and latitude of items on a map based on their street address, cross-referencing information in a TIGER/Line or other street file.

ZIP Code Geocoding - Determines the longitude and latitude of items on a map based on their ZIP Code, cross-referencing a list of the locations of 5-digit ZIP Code centroids.

Linear Equation Application - Applies a linear equation or series of equations to a TransCAD database. This procedure has numerous applications, including applying travel demand based on previously estimated aggregate regression models.

Binary Logit Estimation - Estimates the parameters of a binary logit equation. This procedure is used to estimate the determinants and generate forecasts of mode shares.

Flow Balancing - Takes a vector of flow origins and a vector of flow destinations and scales the two vectors to a common total. This routine is used for balancing trip productions and attractions after the trip generation stage.

Gravity Model Calibration - Calibrates singly-and doubly-constrained models of spatial interaction. These models are used to model flows between regions, and are frequently used as the basis for modeling of trip distribution in a region.

Gravity Model Evaluation - Applies a previously calibrated singly- or doubly-constrained gravity model.

Fratar Matrix Scaling - Scales a matrix of flows based upon new values for the row and column sums. This iterative method is a frequently used alternative to gravity models.

Polygon Overlay Processing - This core spatial analysis function takes geographic layers which define regions such as trade and/or service areas and combine them to define new sets of regions that identify overlaps or intersections among the original regions. This capability makes it possible to convert data from one set of traffic analysis zones to another.

Network Builder - extracts link and node attribute information from a GIS linear feature database (e.g., a street file) and produces a structured binary file with a format well-suited for application of common operations research algorithms.

Network Update - activates or deactivates links in a network file based on spatial or attribute selection operations that have been performed on the corresponding database.

Shortest Path - Finds an optimal path through a network based on a user-defined objective function of link attributes.

Transit Shortest Path - Shortest path, except that cost penalties can be assigned for transfers between links of different types. This procedure is well-suited to transit and multimodal applications.

Shortest Path Via - Shortest path, except that the user can designate one or more intermediate points between the origin and destination.

Skim Tree - Shortest path, except that this procedure will in a single step find the optimal route between a single origin and any number of designated destinations.

Transit Skim Tree - Skim tree, except that transfer penalties are taken into account.

Shortest Path Table - Produces an impedance matrix containing the generalized cost of travel between any number of origins and destinations on a network.

Transit Shortest Path Table - Like shortest path table, except that transfer penalties are taken into account.

Traffic Assignment - Assigns the flows stored in a trip table or matrix to a network, determining the level of flow on each network link. This procedure assigns all flows to the lowest cost path between origin and destination, where cost evaluation is based on a user-defined objective function. Traffic assignment algorithms provide much more realistic estimates of travel times on metropolitan area networks than simple computation of shortest paths because they reflect the effects of congestion on road network service characteristics.

Traffic Assignment with Transfer Penalties - Assignment, except that transfer penalties are taken into account. Used for freight transportation and public transport.

Incremental Assignment - This procedure is sensitive to capacity constraints. Flow is assigned in increments, with alternate paths used if capacity constraints are reached on the lowest cost path.

Capacity Restraint Assignment - This procedure assumes that link costs increase as flow approaches capacity. This method averages successive all-or-nothing assignments to compute final flow estimates.

User Equilibrium and Stochastic User Equilibrium Assignment - Equilibrium methods are used that converge on a set of link flows and associated flow-dependent costs.

Stochastic User Equilibrium Assignment for Transit - A version of stochastic user equilibrium tailored for transit applications with provision for crowding and transfer penalties.

Critical Link Analysis - Identifies the origin-destination pairs and link volumes that comprise the flow on a link that results from a traffic assignment.

Traveling Salesman Problem - Finds a low cost tour that visits a user-defined number of points on a network. This procedure determines the best connections between the points in order to minimize a user-defined objective function.

Hitchcock Transportation Problem - Solves the minimum cost transportation problem on an uncapacitated network. This procedure can be used for optimal deadheading, servicing of demand points from depots or warehouses, and many other applications.

Vehicle Routing - determines the number of vehicles and optimal routes for each vehicle to service a set of demand points from a warehouse location. This procedure takes into account vehicle capacities and fixed and variable cost of delivery.

Vehicle Routing with Time Windows - Like vehicle routing, except that the depot and each demand point may have restricted time periods of operation, introducing additional constraints upon the delivery mechanism.

Arc/Node Partitioning - Assigns network nodes and links to service districts located on the network based on the minimum cost. This is useful for definition of service areas for transit and allocation of workloads for department personnel.

PREPARATION OF DATA FOR MODEL DEVELOPMENT

Estimation of the various travel models required consistent data on traveler demographics and trip choices for a given base period. The 1980 census provided the most comprehensive, albeit somewhat dated, set of such data. These data include measures of origin-destination patterns at sufficiently small spatial scale to be useful for predicting future trip distribution.

The data for this project and for the related RPA-based mode choice forecasting project were assembled in the Fall of 1989. The data were developed for a broader region than just New York City to facilitate regional forecasting for the latter project. Data preparation is described for both efforts. While not a part of this project, the commuter rail data and forecasting models are being used by MTA and have application for NYCTA in modeling transfers from commuter rail to the subway system. Documentation about the commuter rail models is provided in another report. The remainder of this chapter describes the census data as well as the supplemental data used for modeling and forecasting purposes.

Census Data

Two types of census information were used for the bulk of the modeling effort. Demographic measures of the origin areas were extracted from the Census of Population and

Housing (CPH). The Urban Transportation Planning Package (UTPP) provided trip data for origin-destination (O/D) census tract pairs.

The CPH contains a full array of demographic information for census areas at various levels of aggregation (e.g., tract, county, SMSA, etc.). Data for this study were extracted at the tract level, and included measures such as population; population breakdown by race, sex, and age; employed labor force (ELF); ELF breakdown by race, sex, and occupational category; households; household income; and vehicles per household.

The UTPP contains travel attributes solely for trips to work, which necessarily narrowed the primary focus of the study. For each tract-to-tract O/D pair, UTPP reports the number of workers traveling by each of several modes, and the mean travel time for each mode. The individual modes selected for analysis were auto (including truck or van), bus (including streetcar), railroad, and subway (including elevated). Like the demographic data, data on flows to Manhattan were extracted at the tract level.

It should be noted here that the definitions of many tract boundaries changed between the 1980 census and the 1989 release by the Census Bureau of the precensus TIGER files, from which census tract geographic boundary databases were constructed. These discrepancies were most pronounced in suburban counties, especially Suffolk. For consistency with the forecasting tools which operate on these databases, we corrected the 1980 tract definitions implicit in the census data to match the current boundaries.

For analysis purposes, tracts and their associated data were aggregated to zones consisting of between two and twenty tracts. This aggregation was intended to reduce the impact of various types of errors in the Census data and other data inputs constructed for the modeling effort. For the five New York City counties, the zones matched the Corridor District boundaries previously defined by MTA staff for planning purposes. For Nassau and Suffolk, we used a zoning system devised by Caliper for an earlier LIRR study in which the RailRider network planning model was developed.

For the remaining three northern counties, we followed a two-stage process in defining the zones. We first aggregated tracts according to "designated places," a level of aggregation defined by the U.S. Census Bureau. Then, using TransCAD's visual map display and geographic manipulation capabilities, we adjusted these boundaries in order to include all tracts not associated with Census

Designated Places and to ensure logical planning and analysis zones given the layout of the existing transportation corridors. This effort also took into account the locations of zip code boundaries and the larger travel analysis zones utilized in MTA's recent total travel survey.

Figures 2-1 through 2-5 provide an overview of key Census measures related to work trip travel patterns. Figure 2-1 shows the population of each county, one broad measure of the size of the transportation market. Figures 2-2A and 2-2B show the average income and number of vehicles per household in each county, two important demographic measures which may be expected to influence the choice of mode in the journey to work.

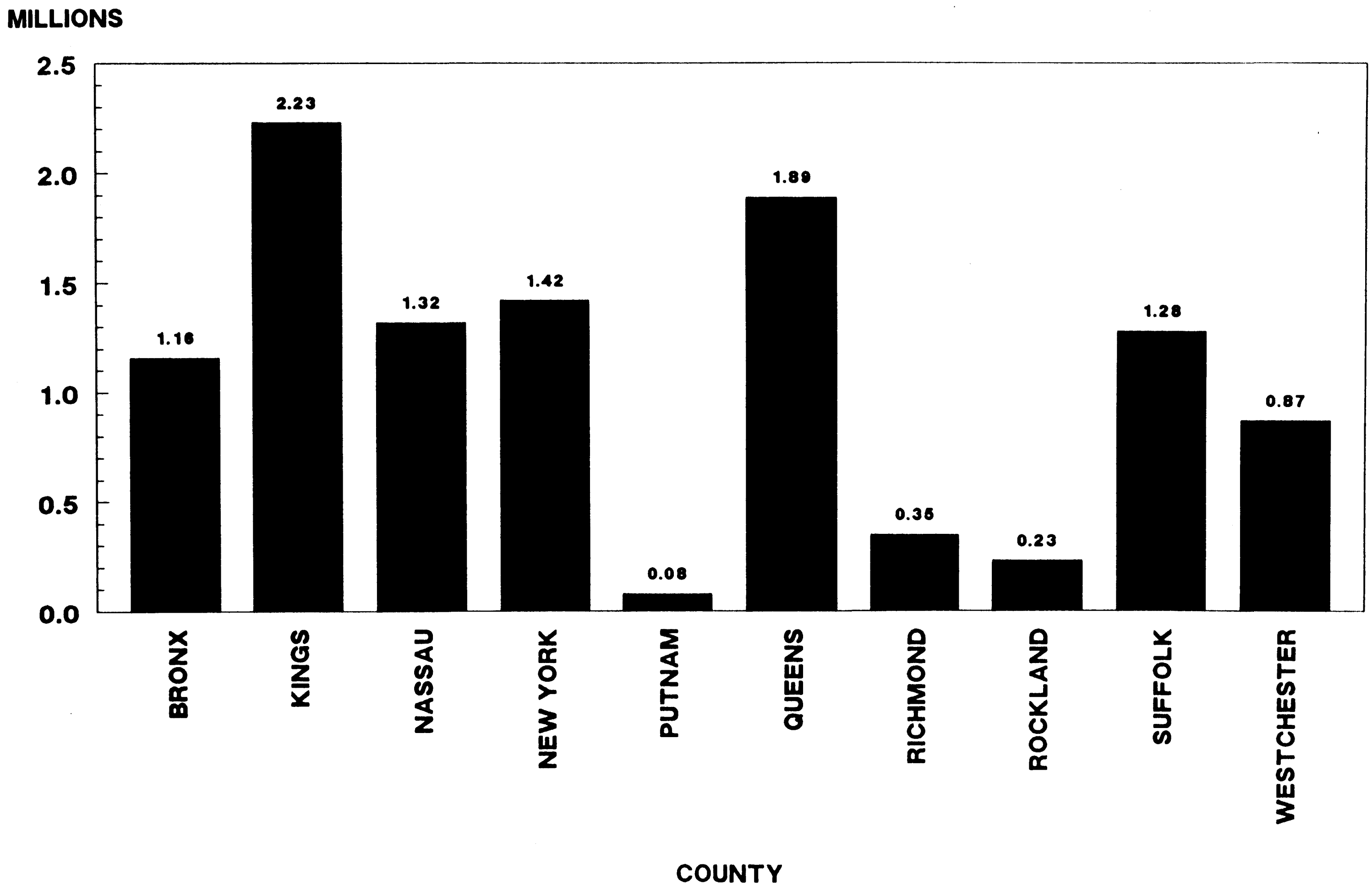
Figure 2-3 compares the total number of work trips into Manhattan with the size of the resident employed labor force (ELF) for each county. For the purposes of this study ELF serves better than population as a measure of market size, since it approximates the total number of work trips originating in any given county. For the modeling purposes of this study, work trips to Manhattan were distinguished from work trips to other locations. The actual number of Manhattan work trips originating in a given county, however, depends on proximity to Manhattan, since the choices of residential and work locations are to some extent interdependent. Note that 82 percent of the resident ELF in Manhattan works within the county, for example, while the shares of ELF working in Manhattan for Bronx, Kings, and Queens counties -- all well served by the subway network -- are only 46 percent, 42 percent, and 43 percent, respectively. Richmond county, with no direct subway links, shows a 35 percent share.

Figure 2-4 displays mode shares for each county for the Manhattan journey to work. This figure shows clearly that subway is the primary transit mode for New York City counties. One other point to note is the relatively high share of trips by "other" modes in New York County (Manhattan) and Richmond County (Staten Island). In Manhattan this share includes persons working at home (since both the origin and destination zones are in Manhattan) as well as work trips by such modes as walking, bicycle, taxi, etc. In Staten Island much of this "other" share likely represents trips made by ferry, a transit mode uniquely important to Staten Island.

The issue of transit mode definition in Staten Island illustrates the more general difficulty of mode definition throughout the Census data. The problem stems in some cases

FIGURE 2-1

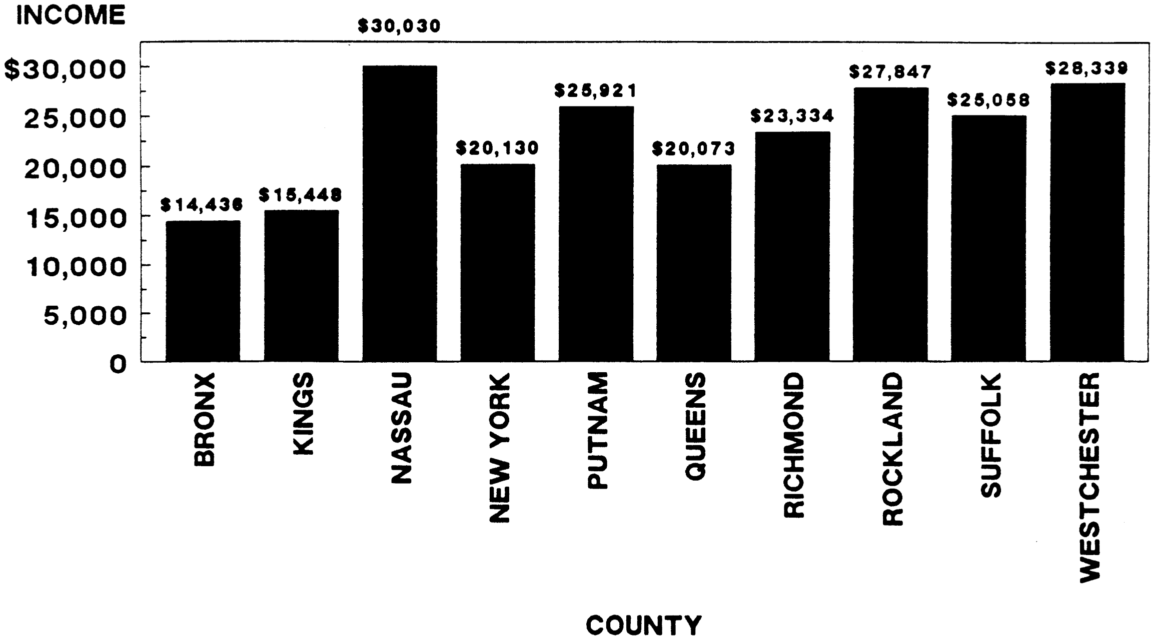
1980 NEW YORK METROPOLITAN REGION POPULATION



SOURCE: 1980 U.S. CENSUS

FIGURE 2-2A

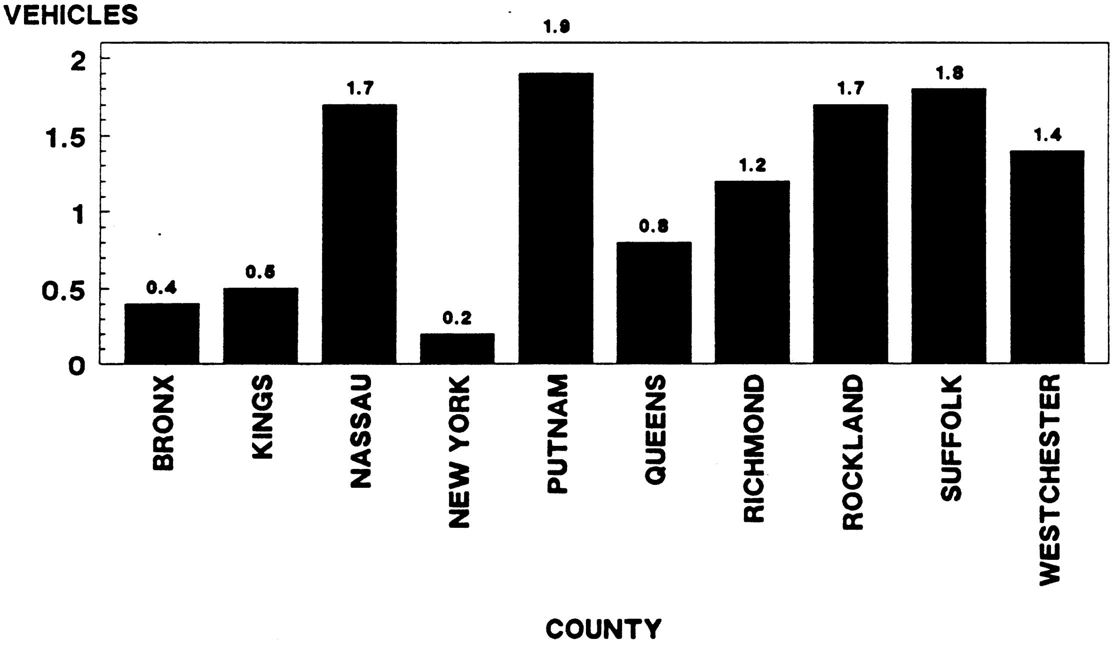
1980 AVERAGE HOUSEHOLD INCOME



SOURCE: 1980 U.S. CENSUS

FIGURE 2-2B

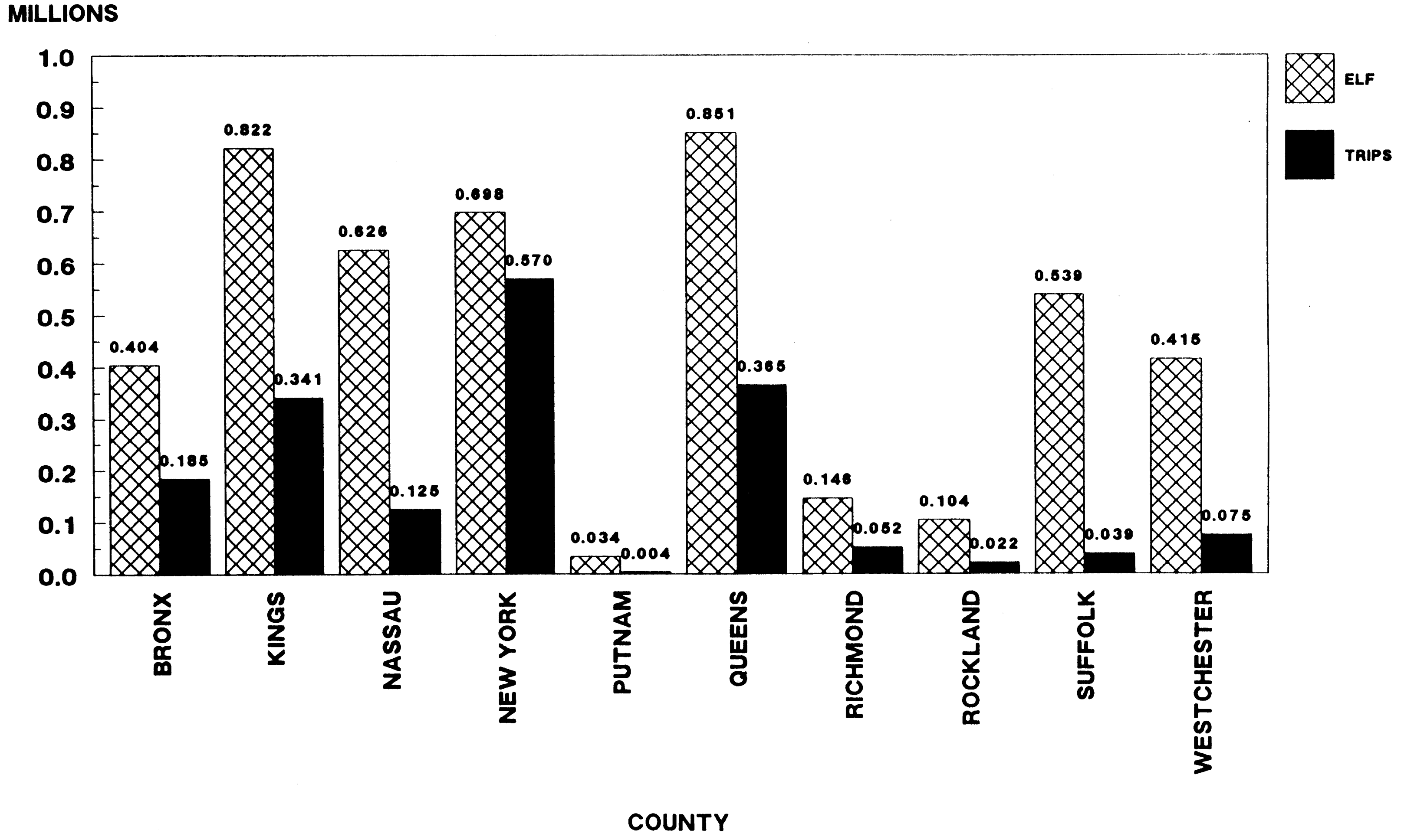
1980 AVERAGE VEHICLES PER HOUSEHOLD



SOURCE: 1980 U.S. CENSUS

FIGURE 2-3

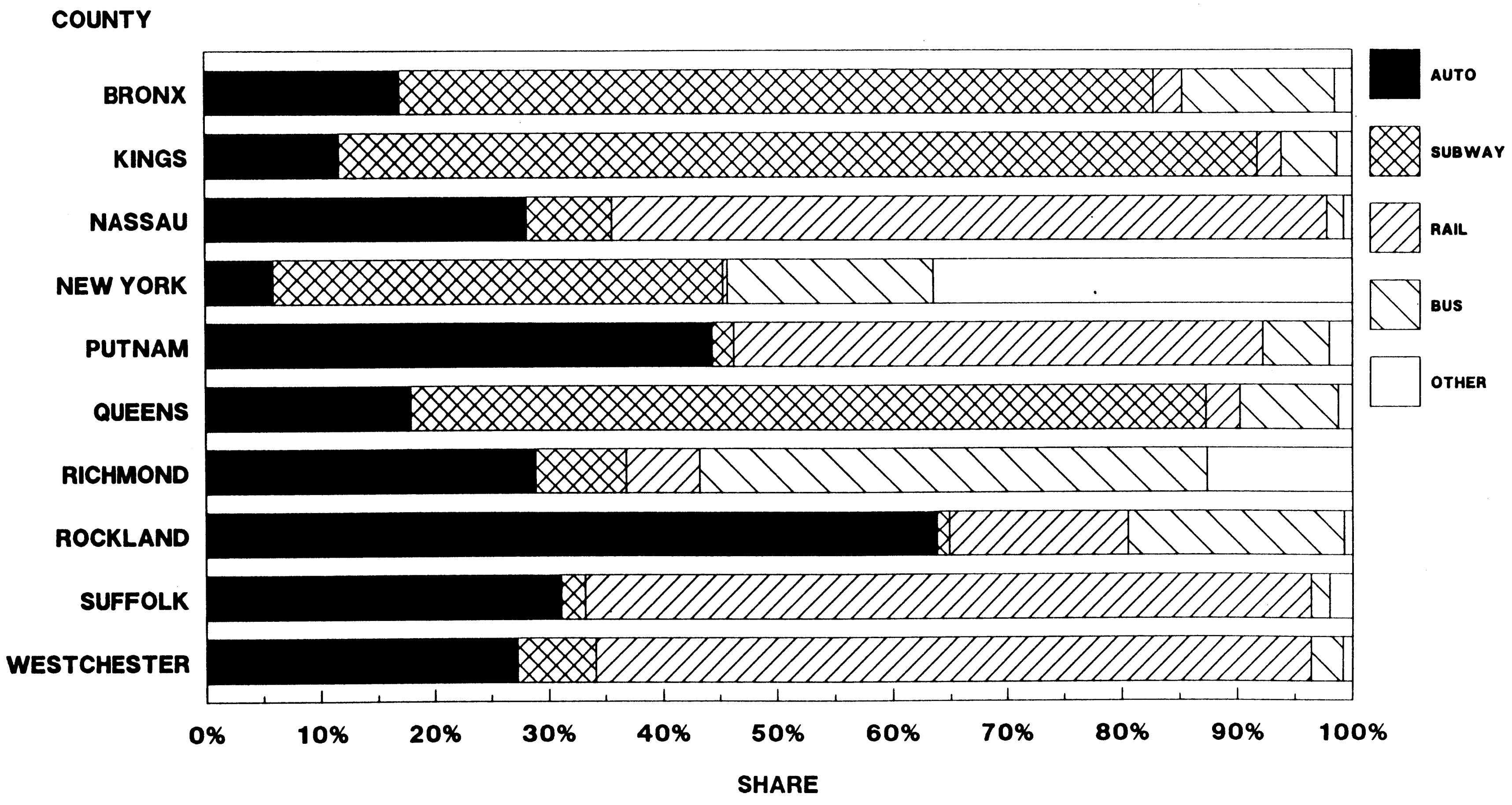
1980 RESIDENT EMPLOYED LABOR FORCE AND WORK TRIPS TO MANHATTAN



SOURCE: 1980 U.S. CENSUS

FIGURE 2-4

1980 MANHATTAN WORK TRIP MODE SHARES



SOURCE: 1980 U.S. CENSUS

from inaccuracy on the part of Census respondents in distinguishing between modes such as rail and subway, and in other cases from ambiguity when the journey to work involves more than one mode. In Staten Island, for example, both subway and rail have reported mode shares of about 7 percent, yet neither offers direct service to Manhattan. Respondents specifying rail most likely were referring to Staten Island Rapid Transit (SIRTOA) trains, which might have been used to access another mode such as the ferry. Subway respondents may have used the subway for the portion of their commutation trip that took place within Manhattan.

Neither type of problem is limited to Staten Island. As discussed in our proposal for this study, Census journey-to-work data is known to be unreliable for some tracts in Queens served by the Long Island Railroad (LIRR) because of confusion between subway and commuter rail modes. Subway trips reported for far-flung suburban tracts may stem from subway trips into Manhattan following long feeder-bus or auto access trips, or they may represent subway trips within Manhattan from the terminus of another mode -- such as rail -- to the place of employment.

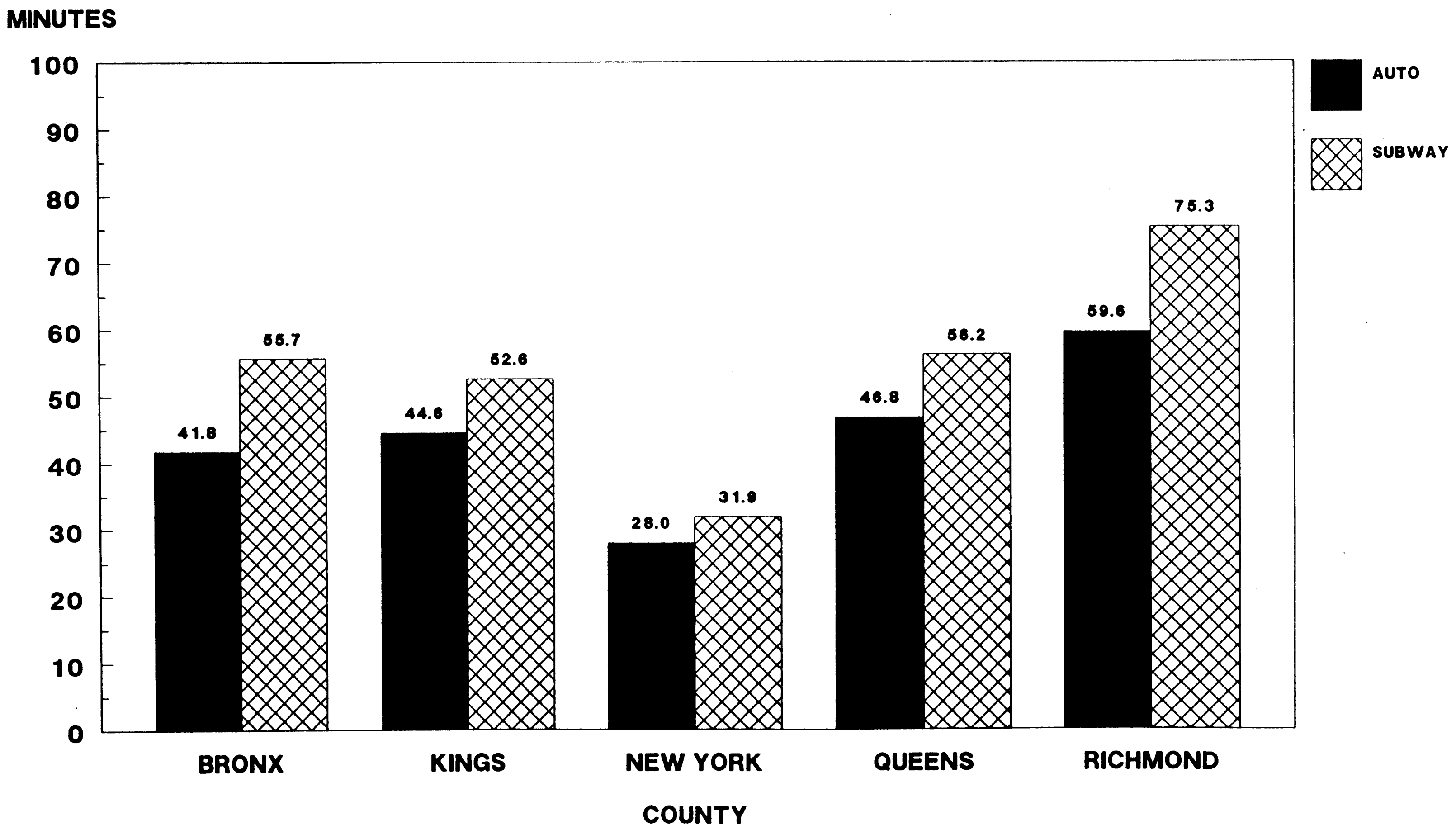
In most cases, we did not modify or limit the data used in the mode split models on the basis of the aforementioned problems. Implications of the problems on the interpretation of the models, as well as instances in which we did modify the data, are noted in the following chapters.

The census data problem is more acute and multifaceted in the case of reported travel times for each mode, shown in Figures 2-5A and 2-5B. The components of the problem include truncation, missing data, and various types of measurement error.

The truncation problem is not as significant for subway planning as it is for commuter rail service from suburban tracts, where travel times often exceed the 99-minute maximum value allowed in the census data. The problem of "missing" data applies throughout the region, since any O/D pair for which a given mode has no reported trips does not have a travel time associated with that mode. This would exclude the O/D pair from a mode split model in which the travel times for competing modes are specified as explanatory variables. In Brooklyn, for instance, about half of the more than 1800 O/D pairs would have normally been excluded due to missing auto or subway travel times. Our concern for measurement error also applies throughout the region, since reported travel times are known to reflect inconsistent and subjective assessments by the Census respondents.

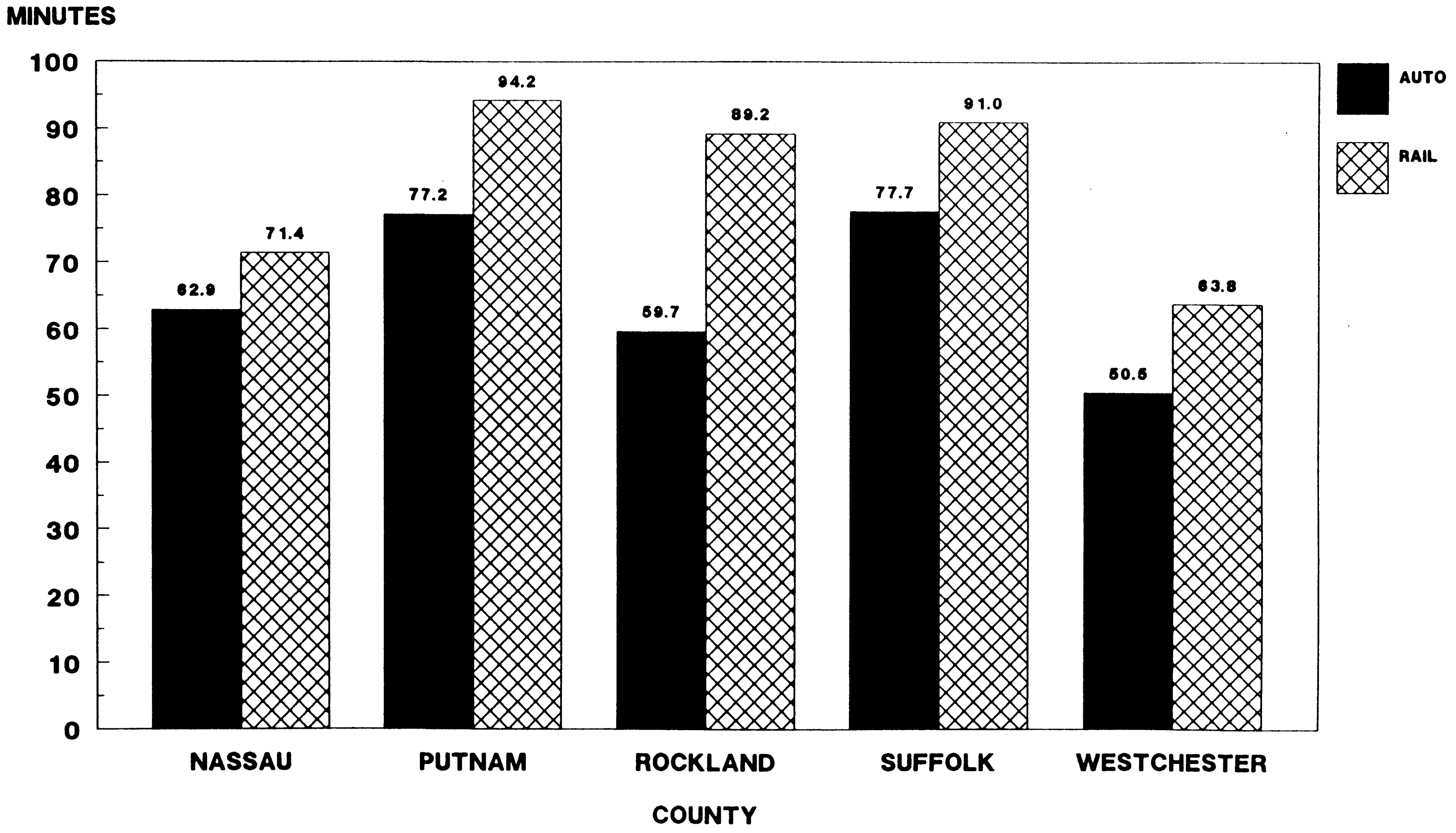
FIGURE 2-5A

AVERAGE TRAVEL TIMES TO MANHATTAN FROM NEW YORK CITY ORIGINS



SOURCE: 1980 U.S. CENSUS

FIGURE 2-5B
AVERAGE TRAVEL TIMES TO MANHATTAN FROM SUBURBAN ORIGINS



SOURCE: 1980 U.S. CENSUS

Supplemental Data

Obviously, accurate measures of travel time between zones were considered to be essential for the mode choice and assignment procedures, and it became apparent that the census data would be inadequate for this purpose. While brief consideration was given to supplementing the census data with engineering estimates of travel times, this mixing of different types of measurements was judged to be too biased for serious consideration.

We consequently were compelled to assemble data on the auto, subway, and commuter rail networks for calculating the needed measures. These data fully represent the corresponding physical networks, including attributes such as average speeds and headways on all highway and track segments as well as delays at all intersections and stations. We thus were able to exploit parallel efforts in the development of GIS databases and GIS-based analytic procedures to derive more accurate travel times. Due to the significant effort required and limitations of time and data availability, however, consideration of other modes such as bus and mixed mode trips was not feasible.

Somewhat dated networks were available for highway and commuter rail systems. This proved not to be a major limitation due to our need for historical (i.e., 1980) data to match the other data inputs. The actual networks utilized were converted from UTPS networks, with adjustments made by MTA and Caliper where these appeared to be absolutely essential for consistency in forecasting. In order to derive complete trip times, we connected the geometric center of each zone to the nearest node of each travel network, making realistic assumptions regarding the associated access and egress times.

Obviously, a much more detailed set of network building tasks beyond those performed in this study would have been preferable. With actual data on origin-destination patterns including access modes and boarding stations, much more accurate networks could be constructed. This is recommended for future work should such information become available.

A variety of other data was also utilized in the modeling effort. These include the RPA forecasts, a subway accessibility index, and data on the monetary costs of travel.

The RPA county-to-county work trip projections are shown in Table 2-1. These forecasts were derived based on RPA's

TABLE 2-1

RPA MANHATTAN EMPLOYMENT PROJECTIONS BY COUNTY OF RESIDENCE

	1988	1990	2005	2015
BRONX	227,839	227,421	247,696	256,629
KINGS	447,817	456,820	497,130	519,574
NASSAU	106,795	104,563	110,594	114,504
NEW YORK:				
All	645,597	657,195	705,744	732,491
Upper-to-Lower	217,694	223,584	243,798	254,984
PUTNAM	4,454	4,112	5,672	5,914
QUEENS	403,796	410,542	431,114	444,961
RICHMOND	67,760	68,956	78,343	83,253
ROCKLAND	18,668	16,901	21,342	21,515
SUFFOLK	32,828	32,004	35,981	35,988
WESTCHESTER	76,621	72,262	79,250	79,352

Source: MTA spreadsheets of RPA projections

extensive analysis of population and employment trends. This analysis is documented in the RPA report, "Physical Development and Economic/Fiscal Prospects - Implications for Transit."

Early in this study, before the network approach for deriving travel times was utilized, it was obvious that the subway mode share was systematically higher for origin zones that were directly served by the subway system. It was thus inferred that some measure of subway access should be considered as an explanatory variable. The MTA in a previous internal study identified all tracts within both 1/3-mile and 2/3-mile radii of the nearest subway station. From these data we derived an index of subway accessibility for each New York City zone, as shown in Tables 2-2A and 2-2B. The index takes on values between 0 and 1, with higher values indicating greater accessibility.

Since the data available for this study were of a cross-sectional nature (i.e., varying across zones but not over time), and because subway fares were constant throughout the region in 1980, we did not include out-of-pocket transit costs as an explanatory factor for the urban counties. Since commuter rail fares do increase with distance traveled, however, we did test fares as a variable in the suburban models developed for the RPA forecasting project. We also tested a measure of Manhattan parking costs, since these represent the most significant portion of out-of-pocket auto costs.

Additional discussion of any variable measures needed for a particular model component is included in the presentation of that model in the following chapters.

TABLE 2-2A
INDEX OF ACCESSIBILITY TO SUBWAY STATIONS WITHIN 1/3-MILE

	MEAN	(STD. DEV.)
BRONX	0.29	(0.25)
KINGS	0.70	(0.33)
NEW YORK	0.87	(0.20)
QUEENS	0.41	(0.33)

SOURCE: MTA DATA AND CALIPER CALCULATIONS

TABLE 2-2B
INDEX OF ACCESSIBILITY TO SUBWAY STATIONS WITHIN 2/3-MILE

	MEAN	(STD. DEV.)
BRONX	0.83	(0.31)
KINGS	0.89	(0.26)
NEW YORK	1.00	(0.00)
QUEENS	0.58	(0.39)

SOURCE: MTA DATA AND CALIPER CALCULATIONS

CHAPTER 3

TRIP GENERATION AND DISTRIBUTION MODELS

In this chapter, we describe the development of the trip generation and distribution models. We followed a traditional transportation planning approach in developing these models. However, in designing the forecasting system, we allowed the use of external forecasts of model components to enhance the traditional role of the trip generation and distribution models.

In a related MTA project, for example, independent forecasts of regional work trip patterns by the Regional Plan Association (RPA) provided county-to-county work trip origin-destination tables for future time periods. Based upon analysis of regional economic activity and demographic structure, these forecasts are arguably better for forecasting than mechanical estimates based upon more simplistic extrapolation or projection methods. Nevertheless, for transit planning the RPA forecasts needed to be disaggregated to the level of traffic analysis zones. The trip distribution procedures developed in the MTA project had this principal purpose.

The trip generation and distribution procedures developed for this study can be used to generate alternatives to the RPA forecasts and/or to revise those estimates in light of new data that become available on population, employment, and modal commutation.

TRIP GENERATION AND ATTRACTION

Trip generation for work trips is, in effect, a model of out-of-home labor force participation. This was modeled with a series of linear models that had population characteristics of sex, ethnicity, age distribution, and household size as explanatory variables.

Trip attraction was not modeled explicitly, because of the lack of sufficient and forecastable datasets of potential explanatory variables such as floor space by establishment type and SIC code. Under these circumstances, census measurements and RPA-like forecasting methods give the most reliable results for predicting the volume of work trips destined for small areas of New York City. Zone level trip attractions can be estimated, for example, by adjusting the RPA county level forecasts by the base year distribution of employment by zone.

Therefore, we compiled base year data on work trips by destination zone from the 1980 Census Journey-to-Work Data. We then included as part of the forecasting package a procedure to balance trip destinations to the total regional level of travel predicted by the work trip productions model. Because the TransCAD system is modular, any disaggregate model of trip attractions that is developed in the future, based on newly available data, can easily be integrated into the forecasting package.

A similar lack of disaggregate data precluded the estimation of models of other trip types such as school trips. As described later in this report, however, external estimates of non-work subway trips by O/D pair developed by cross-classification or other techniques may be added to the O/D estimates of subway work trips produced by the trip generation, trip distribution, and mode choice stages of the forecasting process. This would ensure that the trip table used as input to the final network assignment stage accurately reflects the AM peak load on the subway network.

MODEL FORMULATION AND ESTIMATION

As indicated above, work trip generation is obviously closely related to the out-of-home labor force. In this phase of the study, we therefore estimated a model of employment by zone of residence to represent the production of work trips by all modes in the New York City boroughs. This model was based on 1980 Census data on employment and other demographic measures available by census tract of residence, with the census tract data then aggregated to the level of the traffic analysis zones used in this study.

The model specification includes as an explanatory variable a measure of the size of the labor "pool" in each zone. We defined this "pool" as the population aged 16 years old and over, since the Census employment counts are for this segment of the population. This differs from the standard definition of labor force, which is normally limited to those members of the population either employed or seeking employment.

Our purpose in using the labor pool was to ensure the usefulness of the model as a forecasting tool; commercial demographic forecasts generally provide population breakdowns by age, but not by labor force status. The estimated coefficient on this variable represents the employed percentage of the labor pool, controlling for other explanatory factors, and is roughly equivalent to the labor force participation rate minus the unemployment rate.

As described in Chapter 2, the data used to estimate the work trip productions model came from the 1980 Census of Population and Housing (CPH).

It was required that independent variables included in the specification of the employment model be fully exogenous to the decision to participate in the labor force. Thus measures such as income and others closely correlated to income, such as auto ownership, were excluded from the model.

It was also important that forecasts of each independent variable be available at the zone level through commercially available forecasts of regional demographics, since such forecasts will be key inputs in future applications of these models. Finely detailed breakdowns of population segments, such as sex by race by age, were therefore deemed inappropriate.

The final models included measures of the size of the male and female labor pool, the black and Hispanic share of the total population, the share of the labor pool at least 65 years old, and average household size. The model was also tested to ensure uniformity across the five boroughs.

Two basic sets of trip generation models were estimated. In the first, it was assumed that the only population forecasts available would be for total population and population by ethnicity. This model, however, has two estimated equations -- one for zones with less than 10,000 residents and one for zones with 10,000 or more residents. Use of two equations captured some of the variation among zones of very different types and precluded difficulties of negative predictions for zones with few residents. Of course, other econometric means could have been employed for this means; however, we felt that this approach was the simplest effective solution. Also, these model estimates are thought to be more robust than those that might have resulted from tobit estimation.

Table 3-1 presents the estimation results for the first set of trip generation models. As can be seen there, trip generation is positively related to total zonal population

TABLE 3-1

NEW YORK CITY TRIP GENERATION MODELS: TOTAL EMPLOYMENT

Model I: High Population (10,000+) Zones

Dependent Variable:	Resident Employed Labor Force
Number of Observations:	138
Sum of Squares Explained:	0.96
Mean of Dependent Variable:	18,685

Variable	Coefficient	t-statistic
Constant	13,790	7.08
Population Aged 16 and over	0.54237	59.05
Black/Hispanic Share of Pop.	-5,841.2	6.57
Share of Pop. Aged 65 and over	-31,919	6.01
Average Household Size	-2,501.1	4.15

Model II: Low Population (under 10,000) Zones

Dependent Variable:	Resident Employed Labor Force
Number of Observations:	38
Sum of Squares Explained:	0.94
Mean of Dependent Variable:	2,224

Variable	Coefficient	t-statistic
Constant	1,837.5	4.13
Population Aged 16 and over	0.58382	20.32
Black/Hispanic Share of Pop.	-622.78	2.35
Share of Pop. Aged 65 and over	-3,079.5	2.81
Average Household Size	-503.74	3.26

and highly significant. Roughly one work trip is generated for every two persons; however, employment and trip generation are negatively related to the share of the population that is black and Hispanic, the share of the population that is 65 and over, and the average household size. These models have significant coefficients and fit the data well with an R-squared of between 0.94 and 0.96.

The second set of models assumed that both male and female population forecasts are available. Labor force participation is quite different for males and females, so a better forecast can be made if these data are available. It should be noted that we assumed that forecasts of male and female population levels would not be available by ethnicity. Thus we used the overall share of black and Hispanic resident population as an explanatory variable. This approach yields four estimated equations, with separate models for zones based upon the same population split.

Tables 3-2 and 3-3 present the estimation results for this second set of models. The results are similar to those described previously, with good fits obtained. Interestingly, household size is not a significant determinant of male work trip generation, whereas it is highly significant and of considerable magnitude as a determinant of female work trip generation. This is to be expected as it reflects the higher percentage of females that do not work because of child care responsibilities.

Also, all other factors being equal, black and Hispanic ethnicity is associated with a greater negative effect on employment for males than for females.

TRIP GENERATION MODEL IMPLEMENTATION

The trip generation model was implemented as a TransCAD procedure (TRIPGEN). The procedure allows the forecasting model to be applied to the entire region or to any subset of zones in the region. The procedure also allows the user to choose the desired set of model equations for each invocation of the model. This makes it possible for users to compare the results of forecasts generated from the different sets of model equations or from different sets of forecast inputs.

The trip generation model forecast results are stored in a data field in a transportation analysis zone database. As a result, TransCAD can be used to display or review the forecasts using color coded thematic maps, charts, or tabular presentation. Of course, these same presentation

TABLE 3-2

NEW YORK CITY TRIP GENERATION MODELS: MALE EMPLOYMENT

Model I: High Population (10,000+) Zones

Dependent Variable:	Resident Male Employed Labor Force
Number of Observations:	138
Sum of Squares Explained:	0.98
Mean of Dependent Variable:	10,196

Variable	Coefficient	t-statistic
Constant	3,887	4.93
Male Population Aged 16 and over	0.66157	74.41
Black/Hispanic Share of Total Pop.	-3,488.8	8.89
Share of Male Pop. Aged 65 and over	-14,307	5.63
Average Household Size	-239.44	0.92

Model II: Low Population (under 10,000) Zones

Dependent Variable:	Resident Male Employed Labor Force
Number of Observations:	38
Sum of Squares Explained:	0.94
Mean of Dependent Variable:	1,230

Variable	Coefficient	t-statistic
Constant	585.40	2.31
Male Population Aged 16 and over	0.67312	19.00
Black/Hispanic Share of Total Pop.	-394.95	2.46
Share of Male Pop. Aged 65 and over	-1,390.6	1.96
Average Household Size	-114.81	1.30

TABLE 3-3

NEW YORK CITY TRIP GENERATION MODELS: FEMALE EMPLOYMENT

Model I: High Population (10,000+) Zones

Dependent Variable: Resident Female Employed Labor Force
Number of Observations: 138
Sum of Squares Explained: 0.94
Mean of Dependent Variable: 8,489

Variable	Coefficient	t-statistic
Constant	9,103	7.18
Female Population Aged 16 and over	0.44418	43.79
Black/Hispanic Share of Total Pop.	-1,963.3	3.63
Share of Female Pop. Aged 65 and over	-15,636	5.17
Average Household Size	-2,156.9	5.75

Model II: Low Population (under 10,000) Zones

Dependent Variable: Resident Female Employed Labor Force
Number of Observations: 38
Sum of Squares Explained: 0.90
Mean of Dependent Variable: 994

Variable	Coefficient	t-statistic
Constant	1,120.3	4.18
Female Population Aged 16 and over	0.49779	15.97
Black/Hispanic Share of Total Pop.	-163.05	1.11
Share of Female Pop. Aged 65 and over	-1,360.8	2.45
Average Household Size	-363.23	3.85

methods can be used to display changes in trip productions between base and forecast years, or differences between forecasts generated using different sets of model equations.

Because the forecasting models produce estimates only of work travel, overall AM-peak trip production may be derived by combining work trip forecasts with independent estimates (e.g., via cross-classification) of other AM peak trips by origin zone. The spreadsheet capabilities of TransCAD make this a relatively simple process.

TRIP PRODUCTION/ATTRACTION BALANCING

The total trip productions generated by the forecasting model may not be equal to the estimated employment totals which are derived from census, RPA or other sources. Therefore, a constant factor may need to be applied to the trip production in each zone to yield a balance between productions and attractions.

This balancing process was also implemented as a TransCAD procedure (BALANCE2), so that it can be invoked by the user as necessary.

TRIP DISTRIBUTION

A trip distribution model transforms estimates of zonal work trip productions and trip attractions to estimates of work trips between origin-destination (O/D) zone pairs.

TransCAD provides several different trip distribution procedures, two of which were evaluated for use in this forecasting system.

The first of these is a doubly-constrained entropy/gravity model that computes interzonal flows as a function of the generalized cost of travel between zonal pairs. Gravity models are a family of spatial interaction models which estimate trip levels between a set of origins and a set of destinations based on fundamental sources of travel (such as population and employment) and some measure of "friction" or "impedance" between the origins and destinations (such as travel time). The model considered in this case is "doubly constrained" by the prior specification of both zonal production and attraction totals.

The second trip distribution model that was evaluated is a Fratar Growth factor procedure that scales an existing O/D matrix as a function of new estimates of the origin and destination sums. The Fratar method guarantees replication of the base case flows without error.

The entropy approach has the potential virtue of being able to reflect the impact of transportation system changes upon trip distribution. This presupposes that individuals adjust their workplace or their residence location in response to changes in the transportation system. For long range planning, this is reasonable, perhaps, if the models are likely to be capable of predicting the outcomes of these complex decisions. For short run planning this approach is poor in that it will overstate the likely effects. Research has indicated that disaggregate trip distribution methods have more promise for success in this regard than entropy/gravity models.

Another major difficulty with trip distribution models of the entropy/gravity genre is obtaining a reasonable fit to the base case data. Since this is an empirical matter, we estimated models for representative county to county pairs.

We tested this model using the weighted average travel time of the two major competing modes as the measure of impedance; however, a satisfactory model fit could not be found even when alternative functional forms were considered for the cost function. In fact, the fit of the model in replicating the base case was extremely poor. While not atypical for this type of model, such errors would propagate through the forecasting process, yielding highly inaccurate predictions of modal ridership. Because this characteristic is particularly undesirable for forecasting purposes, we decided to utilize the Fratar growth factor method to generate forecasts of origin/destination volumes.

The Fratar method of scaling matrices modifies cell values in a baseline matrix based on new row and column totals. This method guarantees replication of the base case when the baseline row and column totals are specified as the "new" totals, an especially desirable characteristic in a forecasting tool. Since new journey-to-work matrices will be available from the 1990 Census, the Fratar method can be used to scale the new trip matrices when they become available.

Both the gravity model and Fratar methods are available as TransCAD procedures. Procedure GRAV03 generates estimates of the gravity model parameter, and GRAV04 is used to produce forecasts of new trip distribution matrices. FRATAR2 is the Fratar matrix balancing procedure that was chosen for use in the NYCTA forecasting system.

CHAPTER 4

SUBWAY MODE SPLIT MODELS

This chapter describes the subway mode-split models that were developed in this project. The sections in this chapter address the general model formulation, describe the various model specifications that were tested, and discuss the estimated models and their parameters.

MODEL FORMULATION AND ESTIMATION

Several different subway mode share models were formulated in this study. For each of the five counties in New York City, a model was estimated to explain mode choice for Manhattan-bound work trips. In each of these models, the percentage of work trips made by subway was the dependent variable.

Four additional models were estimated for forecasting the subway share of work trips originating in Bronx, Queens, Brooklyn, and Manhattan, and terminating in locations outside Manhattan.

All of these mode choice models were formulated as share models, so that the dependent variables were limited by definition to values between zero and one (i.e., 0 percent to 100 percent). An appropriate functional form for this type of demand equation is the binary logit model. The general form of this model is:

$$\text{Transit Share} = 1 \ / \ [1 + e^{-(a+\mathbf{BX})}],$$

where $\mathbf{X}$ is a vector of explanatory variables, $\mathbf{B}$ is a vector of coefficients to be estimated, and a is an estimated constant. As $(a+\mathbf{BX})$ gets very large, the transit share approaches the upper bound of 100 percent, since $e^{-(a+\mathbf{BX})}$ approaches zero. As $(a+\mathbf{BX})$ decreases, taking on negative values, the transit share approaches zero, since $e^{-(a+\mathbf{BX})}$ becomes very large.

In the most common form of the binary logit model, the dependent variable takes on a value of either zero or one. Because the share variables defined here are distributed along the full range from zero to one, conventional binary logit estimators would not provide the correct results. Instead, we utilized a proprietary logit estimator that had previously been developed by Caliper for precisely this estimation problem. The estimated model is interpreted in the same way as other binary logit equations, and forecasting proceeds in the same manner as well.

The model for each county had one observation for every single O-D zone pair that had any work trips by any mode. Each observation was weighted by the total number of work trips made from the origin to the destination, in order to correctly reflect the impact of the O/D pair in predicting county wide travel to Manhattan.

A major focus of this portion of the study was the refinement of the model specifications for each county. The explanatory variables that were considered included both census-reported and network-derived travel times for the competing modes (auto vs. primary transit), average income, the percentage of the resident employed labor force (ELF) reporting a managerial or professional occupation, the percent of ELF that is white, the percent of ELF that is male, and average vehicles per household. Many of the socioeconomic measures are highly correlated with each other, so that only one might be included in any given model.

Access to subway stations was included as an explanatory variable, using the subway access index defined in Chapter 2. This access index is a measure of accessibility by walking, and thus distinguishes between origin zones in which the subway may be accessed directly and those which require an access trip by another mode (what MTA staff refer to as "two-fare" subway zones).

Monetary costs such as transit fare or out-of-pocket expenses for auto are usually considered important explanatory factors in determining mode share. However, subway fares are constant throughout New York City, and thus could not be included in the models.

Dummy Variables

The model specifications also included dummy variables to represent systematic zone-specific effects that were not explicitly captured by any of the other explanatory factors. A single dummy variable was used for each origin zone (with one origin zone excluded as the baseline). An origin zone dummy variable took on a value of one for those O-D pairs which emanated from that origin zone, and a value of zero for all other O-D pairs.

The presence of dummy variables reduces bias in other coefficient estimates for other demand determinants, and helps to insure close replication of the base case mode shares by zone of origin.

The estimated coefficient on a dummy variable is interpreted as an indicator of whether the transit mode share for trips originating in the zone is expected to be higher or lower than for other origin zones when all other factors are held equal. A positive coefficient for an origin zone dummy variable indicates that O-D pairs emanating from that origin zone will have a higher transit mode share, all other things being equal. A negative coefficient indicates a lower transit mode share, all other things being equal.

Non-Manhattan Bound Trips

As noted above, a separate set of models were estimated for non-Manhattan-bound work trips. Separate models of this type were estimated by county of origin, to better account for qualitative or otherwise unmeasured differences among the origin counties. The data were not rich enough to accommodate separate models for each county-to-county pair.

We followed the same general procedure in estimating these models as for the Manhattan work trip models. Model specifications were tested using similar performance and demographic variables along with origin zone dummies. Since the data for each model included trips terminating in three different counties (Bronx, Brooklyn, and Queens), we added dummy variables for destination county to capture destination-specific variations in trip behavior. It should be noted that subway accessibility at the destination, rather than at the origin, was a significant explanatory factor in each of these models.

MODEL SPECIFICATION AND MODEL ESTIMATION RESULTS

In this section we discuss the estimated transit mode share models for trips from each county to Manhattan. The development of the transit share model for Bronx County is presented in detail to illustrate the modeling process. For the other four counties, only the final model is presented.

Bronx to Manhattan

Transit mode share models were initially estimated without including zonal dummy variables, in order to confirm the significance of those demographic variables for which data were available. Table 4-1 shows the full model specification, including all demographic variables described above. The travel times are those derived from TransCAD-based network analysis, and the subway access index used is that based on 2/3-mile walk distances. Earlier modeling efforts had revealed the inferiority of Census reported times and of the 1/3-mile index.

The explanatory power of the model is reasonably strong for cross-sectional data, and most of the signs on the individual parameter estimates are as expected. For instance, as auto travel time increases (all other variables held constant), we would expect subway share to increase. Thus the positive coefficient associated with auto time is appropriate. Similarly, as the percentage of the employed labor force in managerial positions increases, presumably increasing income as well as employer-subsidized commutation expenses such as parking, we would expect subway ridership to decrease. This is confirmed by the negative coefficient estimate on this variable. Both of these variables are highly significant, with only one other coefficient estimate having a t-statistic approaching 2.0 and thus significant at the 95% confidence level.

Income is perhaps the most important socioeconomic variable in these models, since it is intuitively related to urban transit ridership and also captures much of the essential variation in several other measures such as vehicle ownership and managerial status. Thus, while the income measure is the least significant in this model, we retained it in refining the model.

Table 4-2 shows the results of successively dropping the male and white labor force shares from the model. Since the income coefficient remained insignificant at any reasonable confidence level, further refinements were tested dropping one each of the income, vehicle ownership, and management variables. The best of these model specifications is shown in Table 4-3. Note that all of the estimated coefficients (besides the constant) are significant at the 95% confidence level, with all signs as expected.

Finally, to this model specification we added dummy variables for each Bronx zone originating work trips to at least some Manhattan zones. No dummy variable was included for Bronx Corridor District BX1.1, which was designated as

TABLE 4-1

BRONX COUNTY -- INITIAL MANHATTAN-BOUND MODE CHOICE MODEL

Dependent Variable:	Subway Share of Manhattan Work Trips
Number of Observations:	967
Sum of Squares Explained:	0.50
Mean of Dependent Variable:	0.678

Variable	Coefficient	t-statistic
Constant	-1.18	1.49
Subway Travel Time	-0.00771	1.78
Auto Travel Time	0.0308	9.37
Subway Access Index	1.18	12.37
Household Income	-0.00003	0.70
Vehicles per Household	-0.575	1.27
Male Share of Labor Force	1.94	1.53
White Share of Labor Force	-0.328	1.67
Mgmt. Share of Labor Force	-2.30	1.96

TABLE 4-2

BRONX COUNTY -- INTERIM MODE CHOICE MODEL I

Dependent Variable: Subway Share of Manhattan Work Trips
Number of Observations: 967
Sum of Squares Explained: 0.50
Mean of Dependent Variable: 0.678

Variable	Coefficient	t-statistic
Constant	-0.0802	0.34
Subway Travel Time	-0.00763	1.77
Auto Travel Time	0.0297	9.21
Subway Access Index	1.18	12.40
Household Income	-0.00002	0.69
Vehicles per Household	-0.753	1.96
Mngt. Share of Labor Force	-2.88	2.84

TABLE 4-3

BRONX COUNTY -- INTERIM MODE CHOICE MODEL II

Dependent Variable:	Subway Share of Manhattan Work Trips
Number of Observations:	967
Sum of Squares Explained:	0.50
Mean of Dependent Variable:	0.678

Variable	Coefficient	t-statistic
Constant	0.216	1.16
Subway Travel Time	-0.00858	2.01
Auto Travel Time	0.0300	9.27
Subway Access Index	1.17	12.44
Household Income	-0.00008	6.19
Mgmt. Share of Labor Force	-1.35	2.09

the baseline zone. Corridor Districts BX7.1, BX99.1, BX99.2, and BX99.3 originated no trips and were also excluded.

Because the dummy variables account explicitly for differences between the origin zones, their inclusion tends to "crowd out" the effect of the demographic variables specified in the model. The final model specification for Bronx County, presented in Table 4-4, retains household income as an explanatory factor but drops the management share of the employed labor force. Again, all of the (non-dummy) independent variables are significant at the 95% confidence level, with all signs as expected.

One property of these demand models is non-constant elasticities. Specifically, the elasticity of subway share with respect to a particular explanatory factor changes depending upon the value of the dependent as well as all independent variables in the model. "Average" elasticities may be computed with all variables at their respective weighted mean values. Such elasticities are primarily for illustrative, rather than formal predictive, purposes.

The elasticity of subway share with respect to subway travel time, for instance, is -0.16. This implies that subway share declines by an average of 0.16 percent for each 1 percent increase in travel time. The average elasticities with respect to the other independent (non-dummy) variables are: auto travel time, 0.56; subway access index, 0.39; and average household income, -0.56. These values indicate that subway share is relatively insensitive to any of the explanatory factors included in the model. A change of one percent in any of these factors results in a change of much less than one percent in subway share. The extremely low elasticity with respect to subway travel time, for instance, suggests that subway commuters into Manhattan represent a highly captive market segment.

Bronx is the only county, however, in which the sensitivity of subway share is higher in magnitude with respect to auto travel time than to transit time. This may indicate that auto is a more viable mode for Bronx origins than for other counties. Bronx has the most direct, non-toll highway access into Manhattan, supporting this inference.

TABLE 4-4

BRONX COUNTY -- FINAL MANHATTAN-BOUND MODE CHOICE MODEL

Dependent Variable:	Subway Share of Manhattan Work Trips
Number of Observations:	967
Sum of Squares Explained:	0.55
Mean of Dependent Variable:	0.678

Variable	Coefficient	t-statistic
Constant	0.0	0.0
Subway Travel Time	-0.0107	2.30
Auto Travel Time	0.0367	10.46
Subway Access Index	1.47	5.00
Household Income	-0.0001	13.84
Origin Zone Dummies:		
BX1.2	0.0	0.0
BX1.3	0.153	0.48
BX1.4	-0.682	1.41
BX2.1	-0.239	0.68
BX2.2	-0.229	0.24
BX2.3	0.560	0.77
BX3.1	-0.691	2.26
BX3.2	0.101	0.19
BX3.3	-0.365	0.98
BX3.4	0.0	0.0
BX4.1	-0.0064	0.01
BX4.2	0.0913	0.35
BX5.1	-0.300	0.78
BX5.2	-0.358	1.34
BX6.1	-0.399	2.18
BX6.2	0.135	0.31
BX6.3	-0.0408	0.07
BX7.1	0.146	0.59
BX7.3	0.997	2.38

(cont'd.)

TABLE 4-4 (cont'd.)

BRONX COUNTY -- FINAL MANHATTAN-BOUND MODE CHOICE MODEL

Variable	Coefficient	t-statistic
Origin Zone Dummies (cont'd.):		
BX8.1	0.0	0.0
BX8.2	-0.222	0.92
BX8.3	-0.132	0.43
BX8.4	0.247	0.68
BX9.1	0.487	3.01
BX9.2	0.124	0.48
BX10.1	0.368	1.31
BX10.2	0.595	2.92
BX10.3	0.0	0.0
BX10.4	-0.0047	0.02
BX11.1	-0.508	2.00
BX11.2	-0.771	2.31
BX11.3	0.0703	0.30
BX11.4	0.443	0.92
BX12.1	0.0	0.0
BX12.2	-0.230	0.96
BX12.3	-0.0382	0.15
BX12.4	1.30	1.09

Brooklyn to Manhattan

The final demand model for Brooklyn (Kings County) is shown in Table 4-5. The model for this and all other counties was developed in the same manner as the Bronx, refining a full specification of demographic measures and then adding zonal dummy variables. Corridor District B1.1 is the baseline zone, and no dummies were included for B99.1 and B99.2 since they originated no work trips to Manhattan.

The main difference between the final Brooklyn model specification and that for the Bronx is the absence of household income as an explanatory variable. When income was included the estimated coefficient was positive, implying that subway share increases with the income level of the originating zone. This contradicts reasonable expectations of the determinants of urban transit demand, and suggests that in the Brooklyn model income serves as a proxy for some other demographic measure. The explanatory power of the model as a whole did not diminish when income was dropped, leading to the final model form shown here.

The amount of variation explained by the model is low relative to the Bronx and Queens models (the most analogous of the other counties), suggesting that other uncaptured factors have significant effects on Brooklyn subway ridership. Such issues as the inherent barriers to auto ownership due to parking limitations, or attributes of the auto and subway networks between Brooklyn and Manhattan not reflected in travel time measures, were raised in consultation with MTA staff but could not be included in this type of model.

The parameter estimates and associated elasticities are consistent with those in Bronx and Queens. The average elasticity with respect to subway travel time is -0.16 here as well, again suggesting highly captive subway commutation. The rather high 81 percent subway share for the county as a whole reinforces this inference. The elasticity with respect to the subway access index is 0.34, and only 0.05 for auto travel time. This last estimate suggests that auto may not be a viable alternative for Brooklyn commuters not already driving to work.

Queens to Manhattan

The final Queens demand equation, presented in Table 4-6, is identical in specification to the Bronx model. Corridor District Q1.1 is the baseline zone, and dummies were omitted for zones Q99.1 through Q99.5, which originated no Manhattan work trips.

TABLE 4-5

KINGS COUNTY -- MANHATTAN-BOUND MODE CHOICE MODEL

Dependent Variable:	Subway Share of Manhattan Work Trips
Number of Observations:	1858
Sum of Squares Explained:	0.21
Mean of Dependent Variable:	0.811

Variable	Coefficient	t-statistic
Constant	0.0	0.0
Subway Travel Time	-0.0185	5.95
Auto Travel Time	0.00522	3.11
Subway Access Index	2.05	10.31
Origin Zone Dummies:		
B1.2	0.306	1.07
B1.3	-0.956	4.70
B2.1	0.444	1.79
B2.2	-0.852	2.81
B2.3	0.0855	0.34
B3.1	-0.407	1.62
B3.2	-0.366	1.39
B3.3	-0.443	2.17
B4.1	-0.182	0.68
B4.2	-0.218	0.57
B4.3	0.0385	0.14
B5.1	0.154	0.61
B5.2	0.530	0.66
B5.3	0.256	0.83
B5.4	-0.409	1.34
B5.5	0.562	3.35
B5.6	0.476	1.25
B6.1	-0.524	1.60
B6.2	0.00251	0.01
B6.3	0.315	1.05
B6.4	0.322	1.08
B6.5	0.350	1.12
B7.1	0.0	0.0

(cont'd.)

TABLE 4-5 (cont'd.)

KINGS COUNTY -- MANHATTAN-BOUND MODE CHOICE MODEL

Variable	Coefficient	t-statistic
Origin Zone Dummies: (cont'd.)		
B7.2	0.122	0.54
B7.3	0.244	0.93
B8.1	0.404	1.00
B8.2	0.0707	0.25
B8.3	0.295	1.21
B9.1	0.113	0.41
B9.2	0.236	0.94
B9.3	0.160	0.55
B9.4	-0.266	0.85
B10.1	0.00792	0.04
B10.2	-0.669	3.16
B10.3	0.183	0.53
B11.1	0.0839	0.42
B11.2	0.449	1.89
B11.3	0.844	1.71
B12.1	0.0742	0.29
B12.2	0.377	1.58
B12.3	0.0265	0.13
B12.4	-0.178	0.58
B13.1	-0.528	2.12
B13.2	0.840	3.87
B13.3	0.0925	0.28
B13.4	0.209	0.87
B14.1	0.226	1.16
B14.2	0.795	1.97
B14.3	1.22	2.45
B14.4	-0.0146	0.03
B15.1	-0.0111	0.04
B15.2	0.298	1.41
B15.3	0.763	4.60
B16.1	-0.725	1.44
B16.2	0.186	0.55
B16.3	0.113	0.40
B16.4	-0.718	1.55
B17.1	0.0983	0.48
B17.2	0.726	5.12
B17.3	-0.271	1.15
B18.1	0.168	0.56
B18.2	0.652	4.55
B18.3	1.10	5.58
B18.4	1.05	5.89

TABLE 4-6

QUEENS COUNTY -- MANHATTAN-BOUND MODE CHOICE MODEL

Dependent Variable:	Subway Share of Manhattan Work Trips
Number of Observations:	1145
Sum of Squares Explained:	0.58
Mean of Dependent Variable:	0.711

Variable	Coefficient	t-statistic
Constant	0.0	0.0
Subway Travel Time	-0.0164	6.40
Auto Travel Time	0.00243	1.55
Subway Access Index	2.06	5.32
Household Income	-0.00001	1.75
Origin Zone Dummies:		
Q1.2	0.412	1.07
Q1.3	0.0904	0.25
Q2.1	0.603	0.68
Q2.2	-0.0561	0.14
Q2.3	0.771	1.51
Q3.1	0.509	1.47
Q3.2	0.684	2.32
Q4.1	0.690	1.18
Q4.2	0.794	1.86
Q4.3	0.277	0.72
Q5.1	0.827	3.85
Q5.2	0.715	3.64
Q5.3	0.576	1.45
Q5.4	0.856	4.51
Q5.5	0.661	0.96
Q5.6	0.792	2.51
Q6.1	0.240	0.63
Q7.1	0.398	0.94
Q7.2	0.704	4.89

(cont'd.)

TABLE 4-6 (cont'd.)

QUEENS COUNTY -- MANHATTAN-BOUND MODE CHOICE MODEL

Variable	Coefficient	t-statistic
Origin Zone Dummies: (cont'd.)		
Q8.1	0.547	3.20
Q8.2	0.466	1.47
Q9.1	0.188	0.44
Q9.2	0.320	0.78
Q9.3	0.217	0.52
Q10.1	0.928	4.13
Q11.1	0.375	2.26
Q11.2	0.0	0.0
Q12.1	0.999	4.72
Q12.2	0.549	2.58
Q12.3	1.22	8.29
Q13.1	1.09	7.10
Q13.2	1.01	6.12
Q13.3	0.937	3.41
Q14.1	1.83	10.58

Income was retained in the model since the estimated coefficient has the expected sign and is significant at the 90 percent confidence level. Auto travel time, while not significant even at this level, was nevertheless retained as a fundamental attribute of the competing mode.

Again, the parameter estimates are consistent with the previous models, while the overall explanatory power of the model is greater than even the Bronx model. The sensitivity of subway share to subway travel time is slightly higher than in the other urban models. The average elasticity of -0.21 is still so low, however, as to suggest captive ridership. The sensitivity with respect to income, with an elasticity of -0.08, is much lower than that estimated for Bronx County. The average elasticity of subway share with respect to the subway access index is identical to that estimated for Brooklyn (0.34).

Intra-Manhattan

Due to the absence of data on other important intra-county modes such as bus and walking, the Manhattan mode share model was also specified as a binary logit model of subway mode share. A subway vs. bus sub-mode split model, for instance, was not feasible due to the lack of reliable bus travel time data for all O/D pairs.

With the model specified as for the other counties, the estimated coefficient for subway travel time was positive, which does not make sense when subway mode share is the dependent variable. A revised specification was tested using the difference between the subway and auto network-derived times as an independent variable. This measure is included in the final model, shown in Table 4-7, and has an associated elasticity of -0.08. While rather small, the coefficient is significant and takes on the expected sign, implying that an increased time differential will decrease subway ridership. The estimated elasticities for subway access and household income are 0.47 and -0.42, respectively, consistent with the other boroughs.

It should be noted that subway access was measured with regard to stations within a 1/3-mile radius rather than 2/3-mile as in the other boroughs. This was necessary as a means of differentiating among the Manhattan zones, since every populated tract in Manhattan is within 2/3 mile of at least one subway station. Note further that Zone VS6 was specified as the baseline, with Zones M11.3, M12.1, and M99.1 omitted since they originated no work trips and Zones

TABLE 4-7

NEW YORK COUNTY -- MANHATTAN-BOUND MODE CHOICE MODEL

Dependent Variable:	Subway Share of Manhattan Work Trips
Number of Observations:	1204
Sum of Squares Explained:	0.43
Mean of Dependent Variable:	0.455

Variable	Coefficient	t-statistic
Constant	-0.422	0.74
Difference between Subway and Auto Travel Times	-0.0257	9.36
Household Income	-0.00004	2.61
Subway Access Index	0.992	2.11
Origin Zone Dummies:		
LM1	1.03	0.93
LM2	-0.0268	0.07
LM3	-0.968	1.89
M10.1	-0.0537	0.27
M10.2	0.266	0.87
M11.1	-0.0398	0.15
M11.2	0.647	3.23
M12.2	0.755	3.75
M12.4	0.905	3.30
M12.5	0.931	3.60
M12.6	1.37	5.80
M7.2	0.227	1.02
M7.3	0.677	3.55
M7.4	0.615	3.10
M8.1	0.00	0.00
M8.2	0.636	2.82
M8.3	0.0877	0.18
M9.1	0.607	3.35
M9.2	0.281	1.06
ME1	-0.824	1.24
ME2	-1.16	3.47

(cont'd.)

TABLE 4-7 (cont'd.)

NEW YORK COUNTY -- MANHATTAN-BOUND MODE CHOICE MODEL

Variable	Coefficient	t-statistic
Origin Zone Dummies: (cont'd.)		
ME3	-1.21	2.23
MW1	0.00	0.00
MW2	-0.714	3.24
MW3	-0.842	2.35
MW4	0.00	0.00
VN1	-1.32	0.31
VN2	0.349	1.83
VN3	-0.166	0.70
VN4	0.0592	0.23
VN5	-1.25	3.56
VS1	0.376	1.13
VS2	0.255	1.13
VS3	-0.379	1.76
VS4	0.999	4.67
VS5	0.970	2.97
VS7	0.102	0.20

M7.1 and M12.3 omitted because no demographic data were reported for the census tracts comprising them.

Limiting the data to work trips from Upper Manhattan to Lower Manhattan, with 60th Street defined as the boundary, obviates some of the data problems by eliminating the overlap among origin and destination zones. The "other" mode share in this segment is only 14 percent vs. 37 percent for the entire county.

A similar model was estimated for this data, as shown in Table 4-8 (separate modal times again yielded a positive subway time coefficient), with Zone M10.1 specified as the baseline. The average elasticities with respect to the travel time difference, household income, and subway access are -0.02, -0.37, and 0.30, respectively. While the sum of squares explained by this model is significantly higher than in the county wide model, the latter was implemented in the forecasting procedures due to the county wide nature of the forecasting model.

<u>Staten Island to Manhattan</u>

As described previously, the data for Staten Island exhibited numerous problems. Confounding of SIRTOA and subway trips, as well as the absence of a separate mode category for the ferry, render the census reported mode shares extremely unreliable. Furthermore, with no direct subway link to Manhattan, subway travel times could not be derived using TransCAD without making overly broad assumptions about subway users' access patterns.

Due to these additional weaknesses in the Staten Island data, a revised model structure was used for this demand model. The share of work trips using <u>all</u> public transit modes (subway, bus, and rail) was specified as the dependent variable. Census reported travel times for auto as well as the public modes were used as independent variables, with the public mode time specified as the weighted average of the component modes' travel times.

The final model is shown in Table 4-9, with Zone S1.1 specified as the baseline (no trips originated in Zones S99.1 and S99.2). As in the Manhattan models, the estimated coefficient for public mode travel time was positive when separate modal travel time variables were included in the model. The final model shows the more sensible result of specifying one travel time variable as the difference between the average public mode and the auto travel times. The elasticity associated with this measure is -0.11. The estimated coefficient for income was positive, so this

TABLE 4-8

NEW YORK CTY. -- UPPER MANHAT. TO LOWER MANHAT. MODE CHOICE MODEL

Dependent Variable:	Subway Share of Work Trips
Number of Observations:	344
Sum of Squares Explained:	0.65
Mean of Dependent Variable:	0.614

Variable	Coefficient	t-statistic
Constant	0.00	0.00
Difference between Subway and Auto Travel Times	-0.0165	5.45
Household Income	-0.00004	6.64
Subway Access Index	0.892	6.12
Origin Zone Dummies:		
M10.2	0.626	1.93
M11.1	0.166	0.69
M11.2	0.810	4.95
M12.2	0.998	4.96
M12.4	1.46	4.42
M12.5	1.38	4.29
M12.6	1.50	6.03
M7.2	0.165	0.96
M7.3	0.818	5.70
M7.4	0.837	5.46
M8.1	0.00	0.00
M8.2	0.595	3.51
M8.3	0.0588	0.16
M9.1	0.727	4.44
M9.2	0.466	1.80

TABLE 4-9

RICHMOND COUNTY -- FINAL DEMAND MODEL

Dependent Variable:	Public Mode Share of Manhattan Work Trips
Number of Observations:	90
Sum of Squares Explained:	0.34
Mean of Dependent Variable:	0.592

Variable	Coefficient	t-statistic
Constant	0.190	1.79
Difference between Public Mode and Auto Travel Times	-0.0205	3.60
Zonal Dummies:		
S1.2	0.616	4.73
S1.3	0.775	5.86

measure was dropped from the model. No access measure could be specified for the public modes.

Because this model does not forecast subway trips, it is not included in the master forecasting procedure. However, the model can readily be used for analysis if this is desired.

Non-Manhattan-Bound Subway Share Models

Several common results characterize these four models. Except for trips originating in Manhattan, the average subway share of non-Manhattan-bound work trips is significantly lower than for Manhattan-bound trips. This reflects the cumbersome nature of subway trips among the three other counties. The explanatory power of each of these models is also lower than that of its Manhattan-bound counterpart (except for Brooklyn-originating trips).

The elasticities of subway share with respect to subway travel time, auto travel time, and income are all significantly higher in each of these models than in the respective Manhattan-bound models. This result as well reflects the less attractive nature of the subway mode for trips to non-Manhattan destinations.

Bronx Non-Manhattan-Bound

The final demand model for non-Manhattan-bound work trips originating in Bronx County is shown in Table 4-10. In specifying origin zone dummy variables, Corridor District BX1.1 was the base zone, and dummy variables were included only for zones originating work trips to destinations outside of Manhattan. For the destination county dummy variables, Bronx was used as the base destination county.

The amount of variation explained by this model is 44 percent, versus 55 percent in the Bronx-Manhattan work trip model, and the average subway share for these trips is only 17.2 percent (vs. 67.8 percent for trips to Manhattan).

The "average" elasticity of subway share with respect to subway travel time is -0.39 (vs. -0.16). The average elasticities with respect to the other independent (non-dummy) variables are: auto travel time, 0.50 (0.56); subway access index, 0.75 (0.39); and average household income, -1.93 (-0.56). These results illustrate the higher sensitivity of subway share to the explanatory factors, reflecting the subway mode's lower attractiveness for non-Manhattan-bound trips.

TABLE 4-10

BRONX COUNTY -- NON-MANHATTAN-BOUND MODE CHOICE MODEL

Dependent Variable:	Subway Share of Non-Manhat. Work Trips
Number of Observations:	1631
Sum of Squares Explained:	0.44
Mean of Dependent Var.:	0.172

Variable	Coefficient	t-statistic
Constant	-0.5010	1.41
Subway Travel Time	-0.0134	3.32
Auto Travel Time	0.0277	5.07
Subway Access Index (Destination)	1.0400	7.31
Household Income	-0.0002	7.66
Brooklyn Dest. Dummy	0.8320	3.38
Queens Dest. Dummy	0.6950	4.05
Origin Zone Dummies:		
BX1.2	1.6000	2.12
BX1.3	0.1030	0.45
BX1.4	-1.4700	1.75
BX2.1	0.2800	1.15
BX2.2	-1.2000	1.35
BX2.3	0.1660	0.53
BX3.1	-0.2620	1.05
BX3.2	-0.3530	0.89
BX3.3	-0.3600	1.16
BX3.4	-7.5500	0.00
BX4.1	10.1000	0.00
BX4.2	0.2020	1.06

(cont'd.)

TABLE 4-10 (cont'd.)

BRONX COUNTY -- NON-MANHATTAN-BOUND MODE CHOICE MODEL

Variable	Coefficient	t-statistic
Origin Zone Dummies (cont'd.):		
BX5.1	0.0743	0.21
BX5.2	0.0291	0.14
BX6.1	-0.8970	3.55
BX6.2	-0.0128	0.04
BX6.3	0.9760	2.36
BX7.2	0.2010	1.09
BX7.3	0.5670	0.86
BX8.1	0.8660	0.00
BX8.2	0.2930	1.16
BX8.3	-0.7010	1.95
BX8.4	-0.5130	0.38
BX9.1	-0.0379	0.17
BX9.2	0.4600	2.55
BX10.1	0.0830	0.26
BX10.2	-0.8380	1.59
BX10.3	-1.9900	0.48
BX10.4	-0.3020	1.04
BX11.1	-0.0183	0.09
BX11.2	0.0563	0.11
BX11.3	0.3090	1.06
BX11.4	-0.5410	0.49
BX12.1	0.0000	0.00
BX12.2	0.6650	3.37
BX12.3	0.3870	1.63
BX12.4	0.8650	1.11

The county dummies suggest that subway is a more attractive alternative for trips to Brooklyn and Queens than within the Bronx, all other factors being equal, perhaps due to the need to make a toll crossing when traveling by auto.

Brooklyn Non-Manhattan-Bound

The final demand model for Brooklyn is shown in Table 4-11. Corridor District B1.1 served as the base origin zone, and Brooklyn was the base destination county. This model explains 25 percent of the variation in the data, compared with 21 percent in the Brooklyn-Manhattan work trip model. The average subway share for these trips is 24.5 percent, vs. 81.1 percent for Manhattan-bound trips.

Income was a significant explanatory factor in this model. The average elasticity of subway share with respect to average household income is -0.39. The average elasticities with respect to the other independent variables are: subway travel time, -0.77 (vs. -0.16 in the Manhattan-bound model); auto travel time, 1.09 (0.05); and subway access index, 0.93 (0.34). These results are consistent with the higher sensitivities exhibited in the Bronx models.

The estimated coefficients for the county dummies are also consistent with the Bronx results, with subway a significantly more attractive mode for trips within the contiguous Brooklyn/Queens area relative to trips from Brooklyn to Bronx (all other factors being equal).

Manhattan Non-Manhattan-Bound

The final model for work trips from Manhattan (New York County) to locations in Queens, Bronx, and Brooklyn is shown in Table 4-12.

Average subway share for non-Manhattan-bound work trips, 54.5 percent, is in fact higher than for intra-Manhattan trips (45.5 percent). The intra-Manhattan trip universe of course includes a large number of short trips for which modes such as walk are more feasible than for non-Manhattan destinations. (When intra-Manhattan trips were restricted to two mutually exclusive areas -- Upper Manhattan to Lower Manhattan -- subway share increased to 61.4 percent). Bus is also a much more common alternative for intra-Manhattan trips.

The average elasticities of subway share with respect to subway travel time, -0.47, and auto travel time, 0.52, were higher than in the intra-Manhattan model (-/+ 0.08). Household income was not a significant explanatory factor in

TABLE 4-11

KINGS COUNTY -- NON-MANHATTAN-BOUND MODE CHOICE MODEL

Dependent Variable:	Subway Share of Non-Manhat. Work Trips
Number of Observations:	4599
Sum of Squares Explained:	0.25
Mean of Dependent Var.:	0.245

Variable	Coefficient	t-statistic
Constant	-2.07000	99.99
Subway Travel Time	-0.02900	13.05
Auto Travel Time	0.06760	21.56
Subway Access Index (Destination)	1.37000	14.67
Household Income	-0.00003	2.83
Bronx Dest. Dummy	-1.1800	7.71
Queens Dest. Dummy	0.2280	3.50
Origin Zone Dummies:		
B1.2	-0.4620	2.56
B1.3	-0.2250	1.40
B2.1	0.0349	0.15
B2.2	-0.0386	0.14
B2.3	0.1480	0.79
B3.1	-0.1970	1.17
B3.2	-0.1340	0.73
B3.3	0.4630	3.45
B4.1	-0.2550	1.39
B4.2	0.2160	1.00
B4.3	0.2670	1.78
B5.1	-0.1240	0.68

(cont'd.)

TABLE 4-11 (cont'd.)

KINGS COUNTY -- NON-MANHATTAN-BOUND MODE CHOICE MODEL

Variable	Coefficient	t-statistic
Origin Zone Dummies (cont'd.):		
B5.2	0.8210	3.03
B5.3	-0.0458	0.27
B5.4	0.2080	0.94
B5.5	-0.5730	3.03
B5.6	0.0193	0.08
B6.1	-0.5680	2.32
B6.2	-0.1780	0.82
B6.3	0.0952	0.48
B6.4	0.4910	1.89
B6.5	0.4410	1.77
B7.1	-0.0588	0.11
B7.2	-0.1210	0.76
B7.3	0.1240	0.57
B8.1	0.7950	3.43
B8.2	0.4620	2.61
B8.3	0.8880	5.91
B9.1	0.8280	4.66
B9.2	0.6950	4.11
B9.3	0.4830	2.61
B9.4	0.0895	0.33
B10.1	-0.3870	1.86
B10.2	-0.8800	2.89
B10.3	-0.2460	0.80
B11.1	-0.3970	2.16
B11.2	0.0510	0.27
B11.3	-0.2190	0.81
B12.1	-0.2610	1.10
B12.2	-0.0193	0.11
B12.3	-0.0265	0.14
B12.4	-0.7100	1.88
B13.1	-0.4670	1.70
B13.2	-0.7240	3.91
B13.3	-0.9920	2.76
B13.4	-0.2790	1.49
B14.1	0.2390	1.46
B14.2	0.0846	0.34
B14.3	0.0815	0.22
B14.4	-0.6190	1.20
B15.1	-0.3280	1.22

(cont'd.)

TABLE 4-11 (cont'd.)

KINGS COUNTY -- NON-MANHATTAN-BOUND MODE CHOICE MODEL

Variable	Coefficient	t-statistic
Origin Zone Dummies (cont'd.):		
B15.2	-0.4350	2.24
B15.3	-1.1600	4.59
B16.1	-0.7000	1.16
B16.2	-0.0175	0.09
B16.3	-0.0160	0.10
B16.4	0.1090	0.32
B17.1	0.3740	2.32
B17.2	-0.5810	2.77
B17.3	0.2490	1.29
B18.1	-0.0548	0.24
B18.2	-1.5100	5.89
B18.3	-1.1200	3.32
B18.4	-0.9910	3.68
B99.2	2.3200	1.34

TABLE 4-12

NEW YORK COUNTY -- NON-MANHATTAN-BOUND MODE CHOICE MODEL

Dependent Variable:	Subway Share of Non-Manhat. Work Trips
Number of Observations:	1954
Sum of Squares Explained:	0.21
Mean of Dependent Var.:	0.545

Variable	Coefficient	t-statistic
Constant	6.4900	0.01
Subway Travel Time	-0.0240	5.09
Auto Travel Time	0.0276	5.95
Subway Access Index (Destination)	1.2500	9.23
Brooklyn Dest. Dummy	0.5160	5.22
Queens Dest. Dummy	0.5840	6.21
Origin Zone Dummies:		
LM2	-8.0200	0.01
LM3	-7.3900	0.01
M10.1	-7.7900	0.01
M10.2	-7.6500	0.01
M11.1	-7.4300	0.01
M11.2	-7.5100	0.01
M12.2	-7.6800	0.01
M12.3	-7.7400	0.01
M12.4	-8.0600	0.01
M12.5	-7.7600	0.01
M12.6	-7.8000	0.01
M7.2	-8.0300	0.01
M7.3	-7.4900	0.01
M7.4	-7.6300	0.01
M8.1	-9.1900	0.01

(cont'd.)

TABLE 4-12 (cont'd.)

NEW YORK COUNTY -- NON-MANHATTAN-BOUND MODE CHOICE MODEL

Variable	Coefficient	t-statistic
Origin Zone Dummies: (cont'd.)		
M8.2	-8.6000	0.01
M8.3	-9.8000	0.01
M9.1	-7.5800	0.01
M9.2	-7.3200	0.01
ME1	-9.4400	0.01
ME2	-8.9200	0.01
ME3	-8.2200	0.01
MW1	-8.4700	0.01
MW2	-7.6500	0.01
MW3	-8.2500	0.01
MW4	0.0000	0.00
VN2	-7.0000	0.01
VN3	-8.3600	0.01
VN4	-8.8100	0.01
VN5	-8.8400	0.01
VS1	-7.4600	0.01
VS2	-7.1900	0.01
VS3	-8.0600	0.01
VS4	-7.7300	0.01
VS5	-8.0600	0.01
VS6	-7.2500	0.01
VS7	-7.6800	0.01

this model, however, and the subway access elasticity was not significantly different (0.49 vs. 0.47).

The county dummy estimates were as expected, with commuters to Brooklyn and Queens more likely to use subway than those to the Bronx, all other travel factors being equal.

The relatively low explanatory power of this model (21 percent) and the extremely insignificant origin zone dummy estimates suggest that this model is a weaker forecasting tool than the other models developed for this study.

Queens Non-Manhattan-Bound

The final demand model for Queens is shown in Table 4-13. Corridor District Q1.1 served as the base origin zone, and Queens was the base destination county. This model explains 41 percent of the variation in the data, compared with 58 percent in the Queens-Manhattan work trip model. The average subway share for these trips is only 10.9 percent, vs. 71.1 percent for Manhattan-bound trips.

In the model for Manhattan-bound trips, the elasticity of subway share with respect to auto travel time was not computed since the estimated coefficient was not significant. In this model, however, the auto travel time coefficient is highly significant, with an associated elasticity of 1.19. The average elasticities with respect to the other independent variables are: subway travel time, -0.90 (vs. -0.21); average household income, -3.13 (-0.08); and subway access index, 0.96 (0.34). Each of these measures, and its increase over the corresponding Manhattan-bound model result, is greater than the respective estimates in the other county origin models, emphasizing the less captive nature of subway ridership for non-Manhattan-bound travel.

The estimated coefficients for the county dummies are also consistent with the other models, with subway a significantly more attractive mode for trips within the contiguous Brooklyn/Queens area relative to trips from Queens to Bronx (all other factors being equal).

TRANSIT MODE SHARE MODEL IMPLEMENTATION

The mode split model, like all other components of the forecasting system, was implemented as a TransCAD procedure (MODESPLT). This procedure takes forecasting inputs from several different sources. Zone-specific variables come directly from the traffic analysis zone geographic database.

TABLE 4-13

QUEENS COUNTY -- NON-MANHATTAN-BOUND MODE CHOICE MODEL

Dependent Variable: Subway Share of Non-Manhat. Work Trips
Number of Observations: 2764
Sum of Squares Explained: 0.41
Mean of Dependent Var.: 0.109

Variable	Coefficient	t-statistic
Constant	-0.73800	1.51
Subway Travel Time	-0.02770	10.73
Auto Travel Time	0.05560	14.12
Subway Access Index (Destination)	1.62000	16.71
Household Income	-0.00017	5.29
Bronx Dest. Dummy	-0.56800	4.72
Brooklyn Dest. Dummy	0.44900	6.95
Origin Zone Dummies:		
Q1.2	1.06000	4.80
Q1.3	0.58900	2.37
Q10.1	0.60300	1.84
Q11.1	0.17500	0.33
Q11.2	-0.00343	.
Q12.1	0.42900	1.76
Q12.2	-0.22900	0.87
Q12.3	0.52200	1.91
Q13.1	0.42800	1.01
Q13.2	0.34500	0.79
Q13.3	0.01920	0.04
Q14.1	-0.47100	1.92

(cont'd.)

TABLE 4-13

QUEENS COUNTY -- NON-MANHATTAN-BOUND MODE CHOICE MODEL

Variable	Coefficient	t-statistic
Origin Zone Dummies: (cont'd.)		
Q2.1	0.76800	2.20
Q2.2	1.36000	5.34
Q2.3	1.80000	6.41
Q3.1	1.56000	5.02
Q3.2	1.48000	6.17
Q4.1	1.38000	3.82
Q4.2	1.74000	7.48
Q4.3	1.59000	5.76
Q5.1	-0.32000	0.48
Q5.2	-0.60000	1.00
Q5.3	0.17100	0.66
Q5.4	0.08980	0.21
Q5.5	-1.05000	2.07
Q5.6	-0.09820	0.31
Q6.1	1.94000	5.22
Q7.1	1.43000	5.56
Q7.2	0.69400	1.79
Q8.1	1.02000	2.52
Q8.2	1.38000	3.33
Q9.1	1.19000	3.22
Q9.2	0.89700	2.89
Q9.3	0.21200	0.63
Q99.2	-7.24000	0.00
Q99.5	0.00000	0.00

Estimated travel times by auto and subway modes are stored in a travel time matrix file. The model parameters themselves are also stored in a file where they can be updated easily in the future. The mode split model produces share estimates in the form of an O-D matrix. In cases where input data are missing or otherwise unavailable, subway shares from the base case are preserved in forecasting.

The resulting O-D matrix has the same size and format as the all mode O-D flow matrix produced by the Fratar trip distribution model.

PREPARATION FOR TRAFFIC ASSIGNMENT

Two other steps are necessary to use the results of the mode share model and prepare for traffic assignment. First, the mode shares must be converted to actual subway trips. Second, the subway work trip matrix must be modified to reflect AM peak hour subway demand, since the NYCTA performs subway service planning for the AM peak hour.

The actual number of subway trips generated in each O-D pair is computed by multiplying each cell of the O-D matrix with the corresponding cell in the transit mode share matrix. A standard TransCAD procedure (TABOPR) performs this calculation.

The AM peak hour factors are applied in the same fashion; the table of subway work trips is multiplied by a table of peak hour factors to produce a peak hour trip table. In this project, a constant factor of 0.4 was recommended by MTA staff. However, as more accurate data on peak hour shares become available, by county or by zone, these data can easily be used to refine the constant factor.

Because of the data limitations noted earlier, no forecasts were generated of subway mode share from Staten Island and the four zones outside of New York City (Long Island, Upstate NY, Connecticut, and New Jersey) to Manhattan. As a result, the subway trip matrix does not contain trips originating in these areas. The TransCAD matrix editor allows users to combine external estimates of trips from these zones with the forecast numbers at this stage.

CHAPTER 5

SUBWAY TRIP ASSIGNMENT

A significant component of the project was the development of an improved trip assignment algorithm and network structure that would capture and predict key aspects of utilization of the subway system by travelers. In this chapter, we describe the development and subsequent application of the subway trip assignment model.

The organization of this chapter is as follows. First, we provide some technical background on traffic assignment methods and on factors that affect assignment in a transit network. Second, a comparison is made of the performance of various assignment methods. The final section describes the implementation of the stochastic user equilibrium assignment algorithm that was chosen for the forecasting system.

TECHNICAL BACKGROUND

The final step in the traditional four-step planning model sequence is taking matrices of modal origin-destination flows and determining how these flows move through the transportation network. This process of assigning trips to the network results in estimates of the flow on each link in the network. These link flows are used to identify locations in the network where additional capacity is required or where service deficiencies exist. Also, these flows are used to generate estimates of total systemwide travel time, used to calculate the user benefits associated with capital projects and alternative operating strategies.

There are many different technical methods that are used for solving the traffic assignment problem. A major objective of this project was to develop and implement the most effective trip assignment method. In this section we provide an overview of the technical issues that affect the choice of method.

Overview of Assignment Methods

The transit trip assignment problem can be posed in non-mathematical terms as finding an assignment of trips for each origin-destination pair to the subway network such that the aggregate network link volumes reflect actual utilization of the subway system by travelers. In practical terms, this does not require that we be able to predict the route choice behavior of each and every traveler; however, the goal is to obtain aggregate estimates of link flows that are within a small percentage error of measured flows (i.e., counts or estimates thereof) for a base case, and to have a procedure that gives a reasonable forecast when transit service levels are changed.

Mathematical and eminently logical criteria for a useful assignment procedure include conservation of flow, link volumes that are a function of level-of-service and capacity, and consistency between the flows assigned and the level of service.

The simplest assignment method is known as "all-or-nothing" assignment. This method assumes that all travelers between an origin and a destination use the same route, where the route that is chosen is the one that is shortest in time or distance. Using this method, simple bookkeeping produces estimates of the flow on each link in the network. Despite its simplistic representation and numerous limitations, the all-or-nothing assignment method is commonly used for transit in many UTPS-style software packages.

The all-or-nothing approach has many technical flaws. The first and most obvious is that, in practice, rarely do all travelers between an origin and a destination choose the same path.

The second flaw is that if there are two or more equivalently "best" routes, the all-or-nothing method assigns flow to only one of these routes. In most software, the selection of routes among those with equivalent minimum cost is arbitrary.

A third flaw is that all-or-nothing assignment can result in estimates of demand that exceed capacity on any number of links in the network. This violates obvious physical constraints.

Finally, all-or-nothing assignment methods ignore the interaction between supply and demand. In most networks, as demand (and congestion) increases, there are impacts on network performance. In particular, travel times increase as the number of boardings and alightings increases, and the congestion results in discomfort to the transit rider. The end result is that the minimum cost path is often less attractive (and has a higher generalized cost) than originally computed. In theory, a good assignment method should produce "equilibrium" between demand and service; that is, the assigned flows should be consistent with the network level of service characteristics that were used in producing the assignment.

In response to these flaws, a variety of other assignment methods have been developed. Many of these were developed expressly for highway assignment, including two particular methods known as incremental assignment and capacity restraint.

Incremental assignment is performed through a series of all or nothing assignments, each of which assigns a fraction of the origin-destination demand to the network. The fraction is equal to one divided by the number of increments. Before each increment is assigned, the link costs are updated based upon previously assigned flows. This can result in multiple paths being used for some O-D pairs.

Capacity restraint is also performed through a series of all or nothing assignments, with link cost updated after each iteration based on the volume to capacity ratio. At each iteration, the travel time is computed as a weighted average of the travel times that result from the previous two iterations. The flow values which result from the final four all or nothing assignments are averaged to produce the final set of link flows.

These ad hoc methods result in more reasonable assignment results, mostly because multiple paths can be used between each origin and destination. However, neither method yields a true equilibrium solution to the trip assignment problem, and neither is guaranteed to converge in a finite number of iterations (Sheffi, 1985). For these reasons, neither method is attractive.

A more appropriate solution to the problem of the interdependence of flow levels and level of service is an assignment method known as user equilibrium, or UE.

The UE assignment method is mathematically intricate, and, like incremental assignment and capacity restraint, is calculated from a series of all-or-nothing assignments. However, the mathematical methods that are used insure that equilibrium is reached.

At user equilibrium, no traveler can choose a different path from his origin to his destination without increasing the total cost for all travelers. A characteristic of the UE solution is that the costs of all used paths between an origin-destination pair are equal, and are no greater than the cost of any unused paths.

In practice, however, UE fails to produce a behaviorally realistic, multipath distribution of trips. In particular, user equilibrium assignment assumes that paths with a cost greater than the minimum cost are never used. Empirical evidence, though, indicates that paths through a network may be inferior in travel time, but nevertheless are utilized by a minority of travelers. This is certainly true in the NYCTA subway network, where travelers often choose relatively uncongested local trains over crowded express trains.

In prior research, we have found that UE systematically assigns flow to too few links (Caliper, 1986). While calibration can address this problem to some degree in the base case, we also found that the forecasts that resulted from UE for rail transit reflected the same pathology.

An alternative to UE that addresses some of these behavioral deficiencies is stochastic user equilibrium, or SUE. SUE produces an assignment in which alternative paths receive flow levels that are a function of relative path cost, so that less attractive routes are utilized, but less heavily utilized than more attractive paths.

Under SUE, no user believes that he or she can increase his/her expected utility by choosing an alternative path. Because of variations in perceptions among travelers or variations in level-of-service provided, utilized paths are not required to have equivalent generalized costs.

The general solution method involves a series of all or nothing assignments, with link costs updated after each iteration to reflect current link volumes and to include some stochastic variation. At each iteration, the link flows from the prior iteration are updated in the direction of the results of the all or nothing assignment. It has been shown that given an appropriate update procedure, the results converge to an equilibrium solution (Sheffi (1985); Daganzo and Sheffi (1977); Powell and Sheffi (1982)).

SUE should not be confused with the stochastic loading assignment method that is found in some UTPS-type packages. In stochastic loading, a random component is added to the link cost at each iteration, and the results of a series of all-or-nothing assignments are averaged. However, link costs are not flow dependent and equilibrium is not achieved.

SUE should also be distinguished from the STOCH algorithm, which has been somewhat discredited in the literature (Sheffi, 1985). The STOCH algorithm is a logit route choice model in which flow is assigned to a subset of the paths connecting an origin to a destination. STOCH is a stochastic loading method, not an equilibrium formulation. Also, the STOCH method requires that all possible paths between an origin and destination be enumerated. Assignment methods which require path enumeration invariably restrict path choices unduly.

Transit-Specific Issues

Factors involved in transit route choice differ significantly from those involved in highway route choice, and these differences need to be addressed in transit trip assignment. These factors include headways, transfers, crowding on transit vehicles, and the effects of multiple services (e.g., express versus local) on particular routes.

Service headways on transit lines are the determinant of waiting time, and are thus an important factor in route choice. When more than one transit line can be used to reach a traveler's destination, the choice of which line to use may depend on which transit vehicle arrives first at the boarding point.

Transfers are another issue unique to transit route choice. Transfers are often required for transit trips, and there may be numerous alternatives with differing transfer requirements and characteristics. Transfers typically require additional wait time which is a function of the service frequency on the line to which the transfer is made. Also, some travelers will prefer trips that minimize the number of transfers, independent of the time or cost involved.

Congestion also has different effects on transit networks than on highway networks. On highway networks the principal effect of congestion is a deterioration in speed and a corresponding increase in travel time. On transit networks, congestion does cause some delays in boarding and alighting, but the inability of riders to board a vehicle is also a significant effect. When a train is full, travelers typically wait on the platform until another train arrives.

The New York City subways also present some additional complications in implementing good assignment methods. In particular, the importance of the multipath issue is heightened because there are a large number of express and local routes that can be used to make a trip between an origin and a destination. These routes will typically vary widely in speed, service reliability, perceived safety, seat availability, number of transfers, etc.

A final issue concerns connections between traffic analysis zones and transit stations. Connections to the network are not ubiquitous for transit as they are for highway, and access characteristics and access mode choice behavior are major factors in influencing the assignment of transit ridership.

The factors described above exacerbate the shortcomings of standard trip assignment methods and required that we perform research to determine an effective method for NYCTA. In the next section we describe the empirical comparisons that were made among the alternative transit assignment methods.

COMPARISON OF ALTERNATIVE TRANSIT ASSIGNMENT METHODS

Because almost all of the assignment methods described above are part of the standard TransCAD package, we were able to evaluate their performance empirically.

The evaluation of transit assignment algorithms focused on three formulations that are available within TransCAD: capacity restraint, UE, and SUE.

Also considered was an ad hoc method developed for transit and available as part of the EMME2 transportation planning package (Speiss and Florian, 1989). Caliper implemented a version of this method as a TransCAD procedure.

Capacity restraint was included in the evaluation because it was already being used for some applications at MTA. User equilibrium was considered because it is sometimes thought that in congested networks, UE and SUE will give similar results, and UE has the virtues of more rapid convergence and easier calibration. Our previous experience with SUE in modeling the Long Island Rail Road network had given us confidence that SUE could work well for the subway system too.

A station-to-station network was utilized for preliminary testing. This made it possible to study the effects of each assignment algorithm more closely and without the compounding of errors resulting from connection of the network to zones.

In preliminary testing, it was apparent that the capacity restraint and user equilibrium assignment methods left too many links in the network without any assigned flow. We therefore restricted our detailed empirical work to the two other alternatives.

Transit Assignment Model by Speiss and Florian

The Speiss and Florian assignment model uses a two pass approach to assigning transit trips to a network. In the first pass, travelers identify a set of reasonable alternative routes; in the second pass, demand between an origin and a destination is distributed among the candidate routes.

The first pass of the algorithm utilizes information on headways and travel times to generate a "strategy" that allows each traveler to reach the destination with the minimum expected (generalized) cost. A "strategy" is defined as a set of attractive transit lines, and for each line the node on the line at which the traveler alights (which may or may not be the ultimate destination). The "strategy" is determined based upon the combined headway of all lines which serve an origin node and the travel time along each line.

In the second pass, a trip is assigned to the network as follows:

1. Start at the origin node
2. Board the transit line which arrives first at that node
3. Alight at the predetermined node (which was identified as part of the strategy in the first pass)
4. If the current node is the destination, the trip is complete. Otherwise, continue with step 2.

The model is solved by a method akin to a Markovian decision process.

This algorithm uses link travel times together with waiting time distributions as the basis for constructing a reasonable strategy in the first pass. However, as can be seen from Step 2 of the second pass, the actual choice of transit line is dependent solely upon the relative headways of available lines. Factors such as travel time and congestion are ignored. As a result, the algorithm may generate unrealistic flow patterns.

This is most evident when comparing local and express transit lines which serve the same stations. As a simple case, assume that both lines have identical headways, and the we are assigning trips between an origin and a destination station that both receive express and local service.

Under this circumstance, the optimal "strategy" that is identified in the first pass of the assignment algorithm may indicate that both the local and express routes are candidates for the trip. In this case, ridership will always be split among the routes based on relative headway, so that, in this case, 50 percent of riders use the express service and 50 percent use the local service. Even more disturbing, if the headway on the local service is shorter than the headway on the express service, the local service could be assigned more than 50 percent of the traffic.

The algorithm also prohibits behavior that is in many cases quite reasonable. For example, take the case of a traveler on the Lexington Avenue line who boards an express train at an express station and is destined for a local station. In practice, he might make a cross-platform transfer to the local at any one of many different points along the way, depending upon whether a local train is already at the station, the level of crowding on the express train, and so on. The Florian and Speiss algorithm assumes that the choice to board the express train also commits the rider to making his transfer at a particular station, so that no choice of transfer point is permitted.

In the simple case where riders are choosing between and express or local service with identical headways, the algorithm always does one of three things: assigns all flow to the express train; assigns all flow to the local train; or splits the flow 50-50 between the express and local (because the headways are equal). None of these results is realistic, and the fact that the flow distribution is a step function rather than a continuous one makes the model difficult, if not impossible to calibrate.

The deficiencies in the Florian and Speiss approach appear to be severe when applied to the NYCTA network because there are so many cases where many routes operate in parallel. Under other network configurations (e.g., in a bus network where routes criss-cross at many different locations), the deficiencies of the algorithm are less severe. However, for this application, we concluded that the Florian and Speiss approach would not be useful.

Stochastic User Equilibrium

The stochastic user equilibrium method described earlier was tested extensively using the subway network and station-to-station O-D matrix. A version of SUE that made provision for line to line transfer penalties was used in testing. Despite the complexity of the subway network, reasonable results were obtained without any significant calibration effort.

In particular, the assignment of flow to parallel local and express services was reasonable in most corridors. Generally heavier volumes were assigned to express lines, but significant flows were also loaded onto parallel local services. MTA staff reviewed the assignment results, focusing on key express and local services and on river crossings where benchmark and base case counts were available, and confirmed that the loading patterns produced by SUE held the most promise for the forecasting system.

IMPLEMENTATION OF STOCHASTIC USER EQUILIBRIUM

Once SUE was selected as the basis for the subway assignment model, efforts focused on the development of a suitable analytical network with associated data and on a variety of refinements to the SUE algorithm itself.

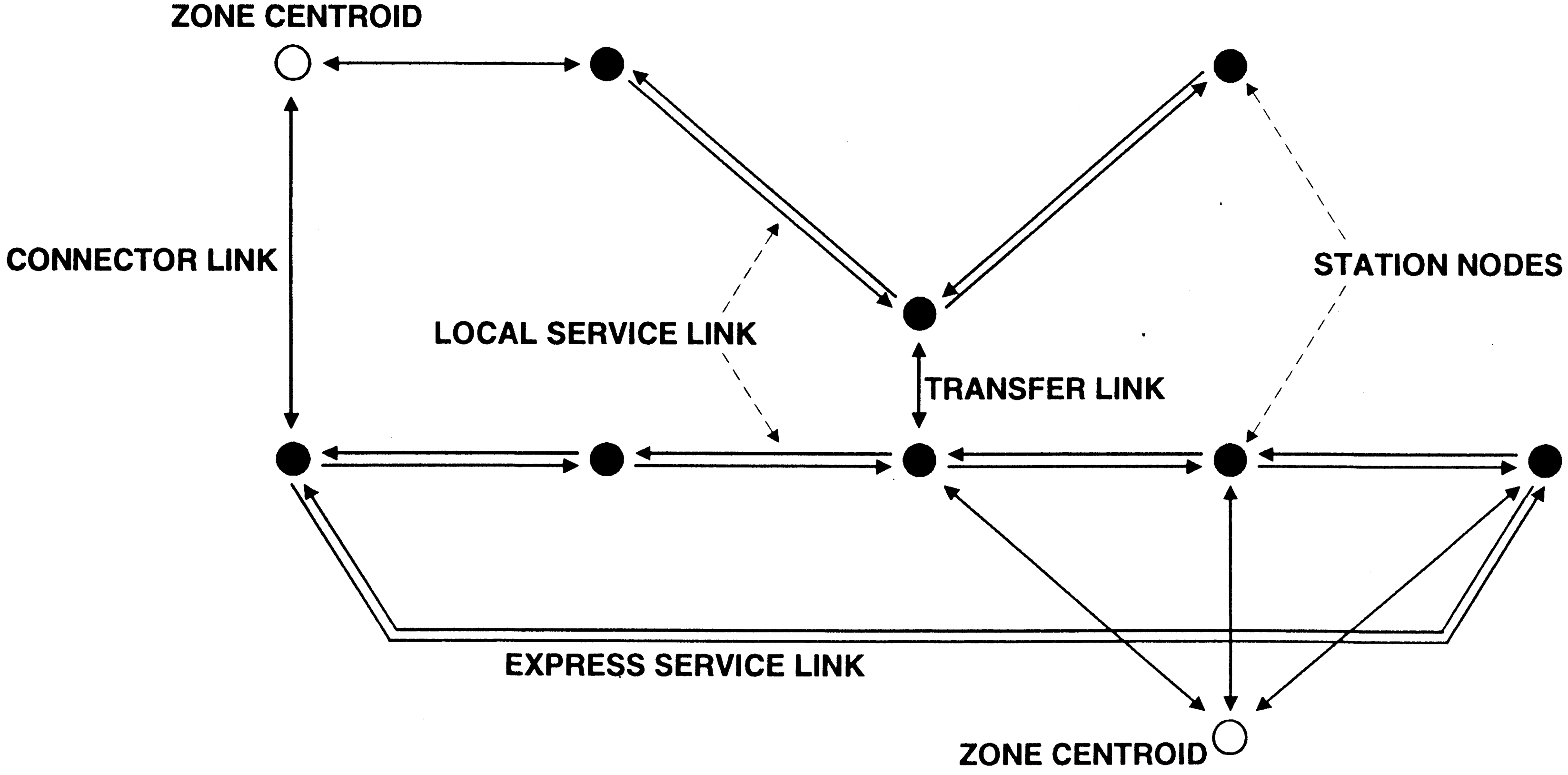
The SUE algorithm as implemented constructs a path from an origin to a destination based on in-vehicle travel time, wait time, and congestion effects. The in-vehicle travel time is determined by vehicle schedules, with a random "stochastic" term added to simulate variability in service characteristcis and rider perceptions thereof. Waiting time that occurs when boarding a transit line or transferring to a vehicle on a different transit line is determined as half the headway.

A crowding penalty term, based on the ratio of link flow volume to link capacity, is also added to reflect the influence of vehicle congestion on travelers' route choice. In this implementation, crowding effects are restricted to the points at which travelers board a vehicle (either the initial boarding point or a transfer point). This assumes that the choice of which transit line to take at a given station depends upon how crowded the trains are as they enter the station, independent of the crowding effects downstream.

Network Development

The network development focused on representing the NYCTA system in such a way that the route choices available to subway travelers are accurately portrayed. Figure 5-1 shows a schematic of the network structure.

FIGURE 5-1:
NYCTA SUBWAY NETWORK SCHEMATIC DIAGRAM



The network has two kinds of nodes -- stations and zone centroids. Many stations in the NYCTA system have multiple sets of tracks and/or platforms, and one or more transit lines serving each of these sets of platforms. In some cases a single node is used to represent the entire station, but in cases where train platforms are some distance apart, more than one node is used to represent the station. Times Square, for example, is represented by four separate network nodes.

Travelers enter and leave the network only at zone centroids, which are connected to stations via access and egress links (also known as connector links). Zone centroids were located at the area centroid of each transportation analysis zone.

The network has three basic types of links: transit service links representing train service, connector links which connect zone centroids to stations, and walk transfer links which connect subway station nodes. The transit service links were further differentiated by type of service, local or express.

The transit service links were derived by MTA planning staff based on actual train service. Separate links were created for each transit route, so that a single pair of stations could be connected by many different links. (For example, on the Sixth Avenue line, the Rockefeller Center and 42nd Street Stations are connected by 8 links; the northbound F Local, the northbound B, D, and Q express, and the four corresponding southbound services.) Each link was assigned a route number, and headways and travel times between stations on each line were determined from schedules.

The connections between centroids and stations were generated automatically based on the proximity of stations to zones. Obviously, survey data on stations used by residents of each zone would have been a preferable source, but no such data were available.

The general rules for generating station to zone connections were 1) all stations within a zone were connected to the zone centroid, and 2) any zone that contained no stations was connected to the nearest station. The automated procedure also generated estimates of access time between zones and stations. MTA Planning staff used the graphic and interactive editing capabilities of TransCAD to review and modify the centroid connector links as they felt necessary.

Transfer links were created by MTA staff as needed to represent locations where passengers could walk between station platforms. Estimates of walking time required to make each transfer were added to the network by MTA staff.

The final transit network developed in this study has 201 nodes at the centroids of travel analysis zones, and 501 subway stations, for a total of 702 nodes. Of the 501 stations, 187 are associated with the IRT division, 164 with IND division, and 150 with the BMT. The network contains 4,028 links, of which 1454 are local service links, 268 are express links, 400 are transfer links, and 1906 are access links. There are 54 distinct routes in the service network.

Provision was made in the network and related demand files for travelers from external zones who make use of the subway for part of their trips. These travelers are primarily railroad commuters from Long Island, Westchester County, Connecticut, and New Jersey. Ferry commuters from Staten Island to Manhattan also use the subway in substantial percentages for work trips. These external zones can be connected to the principal commuter rail termini and Lower Manhattan subway stations as additional data become available. The Census contains no data on utilization of subway by travelers whose principal mode is commuter rail or ferry. However, this information may be derived in the future from travel surveys.

TRANSIT ASSIGNMENT MODEL IMPLEMENTATION

The transit trip assignment model was implemented as a TransCAD procedure (TASSIGN). This procedure assigns a complete or partial O-D trip table to the NYCTA subway network. The procedure produces forecasts of the number of passengers on each link in the network. These link flows are stored in the subway network database.

The assignment procedure gives the user a variety of options for controlling model application. These options include the choice of network and service levels, choice of O-D input matrix, the ability to set specific congestion penalty parameters, the number of iterations to be used in the assignment, and convergence criteria. Error terms can also be specified for travel and access/egress links; these error terms control the level of random variation in link costs.

Because assignment results are stored directly in the subway network database, users can easily generate a variety of forecasts and compare them using color coded thematic maps, bandwidth plots, or tabular forms of presentation.

Experiments with the assignment procedure indicated that convergence to an acceptable tolerance was reached in ninety iterations. After ninety iterations, the average change in link flow from one iteration to the next is less than one percent. The computing time required is approximately two and one-half hours on an 486-25 MHZ computer. This was felt to be an acceptable computational burden for the size of the network to be solved and the assignment method that was utilized.

The results of the assignment, even without calibration, are encouraging, with plausible assignments of trips. The calibration effort is being performed by the MTA Planning department as part of a multistage process of updating planning data and corresponding models. Final calibration will not be possible until some additional data are collected on network loadings.

CHAPTER 6

TRANSCAD SYSTEM APPLICATIONS

In this chapter, we describe the implementation of the TransCAD demand forecasting modeling system. This is followed by a discussion of some of the other potential uses and applications of the GIS software. The final section of the chapter presents some concluding thoughts on the project and recommendations for future work.

TRANSCAD IMPLEMENTATION OF THE 4-STEP MODELING SYSTEM

As discussed in the preceding chapters, the forecasting models were implemented as TransCAD procedures so that they could be accessed as an integrated package.

The model system consists of the classical four step transportation planning method, including trip generation, trip distribution, mode split, and network assignment modules. As implemented in this study, the system actually has seven steps, with three additional steps used for data adjustments.

The seven steps are:

1. Trip generation
2. Trip balancing
3. Trip distribution
4. Mode share evaluation
5. Transit trip calculation
6. Peak hour adjustment
7. Transit network assignment

The first two steps of the modeling process make use of a transportation zone database which covers the entire geographic study area. This zone database contains all of the essential population and labor force model input data and base 1980 trip production and attraction information. Step three takes the trip productions and attractions and generates a zone-to-zone matrix of work trips. Step four uses zone characteristics and travel time data from zone-to-zone matrix files and produces a zone-to-zone subway share matrix. Steps five and six combine the various matrices to produce a peak hour subway trip table. This table and the subway network itself are used in step seven to generate actual link flows.

To facilitate forecasting and scenario definition, an additional procedure called the UTP Commander was created. The UTP Commander provides an integrated framework for setting up and applying UTP-style models. As shown in the flow chart on the following pages, the Commander allows users to run all of the model components automatically in sequence, or to run a subset of the model components. When models are run in sequence, the output of each step is automatically used as input to the subsequent step. The UTP Commander enables the user to develop partial forecasts or to use the results of previous forecast runs or external data as inputs to a selected model.

OTHER TRANSCAD FUNCTIONS

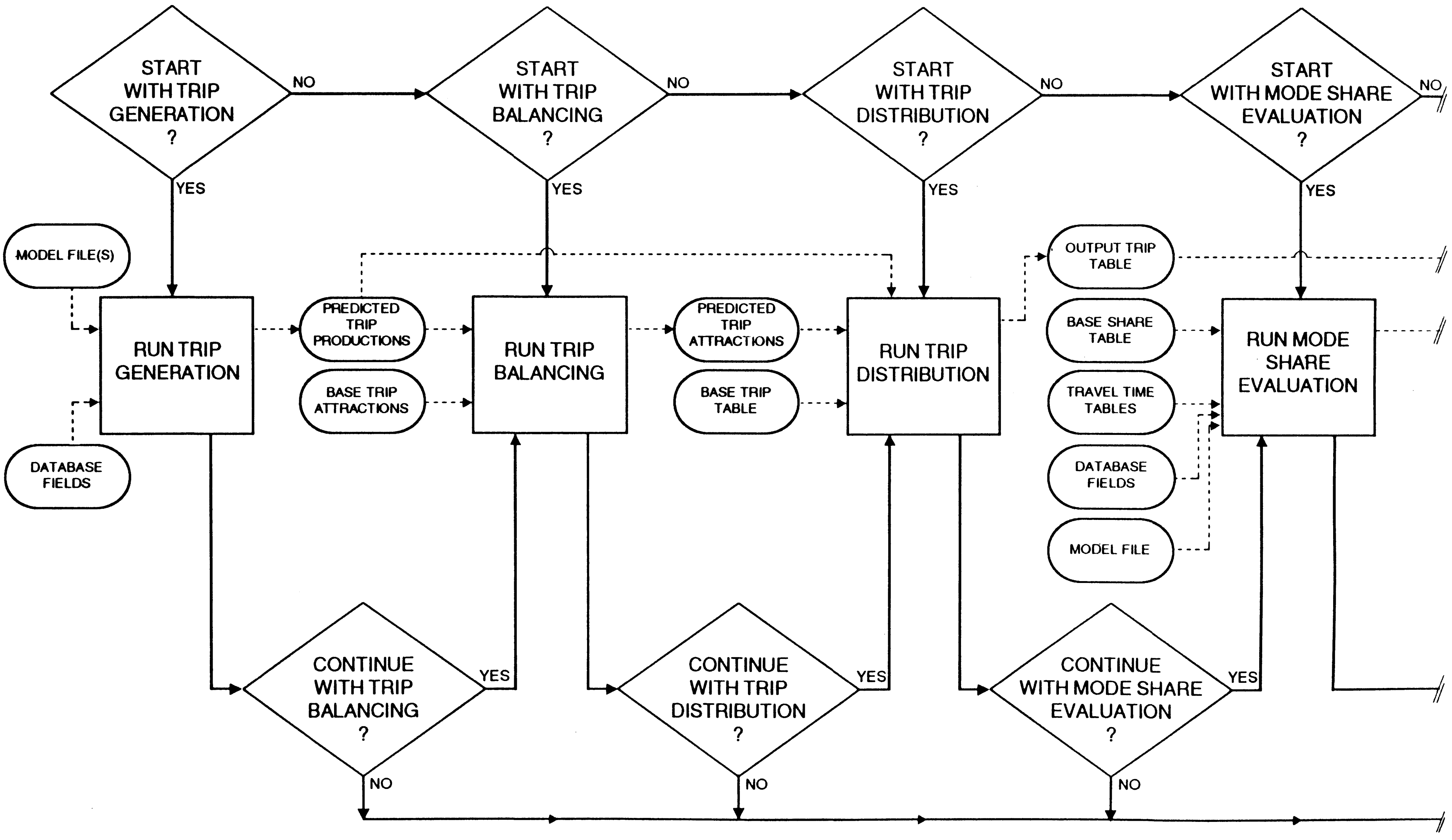
TransCAD's multifaceted capability in displaying geographic and attribute data as well as analytical results was an important factor in deciding to build the forecasting system on a GIS platform. This section presents a few illustrations of this capability.

TransCAD can produce many different types of thematic maps that illustrate the model inputs and results. Figure 6-1, for example, shows the NYCTA study area in its entirety. As noted earlier, most of the forecasting models were defined at the corridor district (zone) level, where corridor districts were defined as aggregates of Census tracts. Figure 6-2 displays both the census tract boundaries and the defined corridor districts for Upper Manhattan and the Bronx. The geographic data management capabilities of TransCAD make it simple to redefine the traffic zones by clicking on individual tracts.

The graphic display capabilities of TransCAD make it possible to generate meaningful and informative maps which describe characteristics of the study area. Figure 6-3 is a simple thematic map of a portion of Queens, indicating the work trip productions by zone. Figure 6-4 illustrates average household income for the entire study area.

Some regions of the study area are both major trip producers and attractors. The downtown area of Brooklyn for example, is a major employment center which attracts sizable numbers of subway commuters. Figure 6-5 uses pie charts to indicate

UTP COMMANDER FLOWCHART



UTP COMMANDER FLOWCHART (cont.)

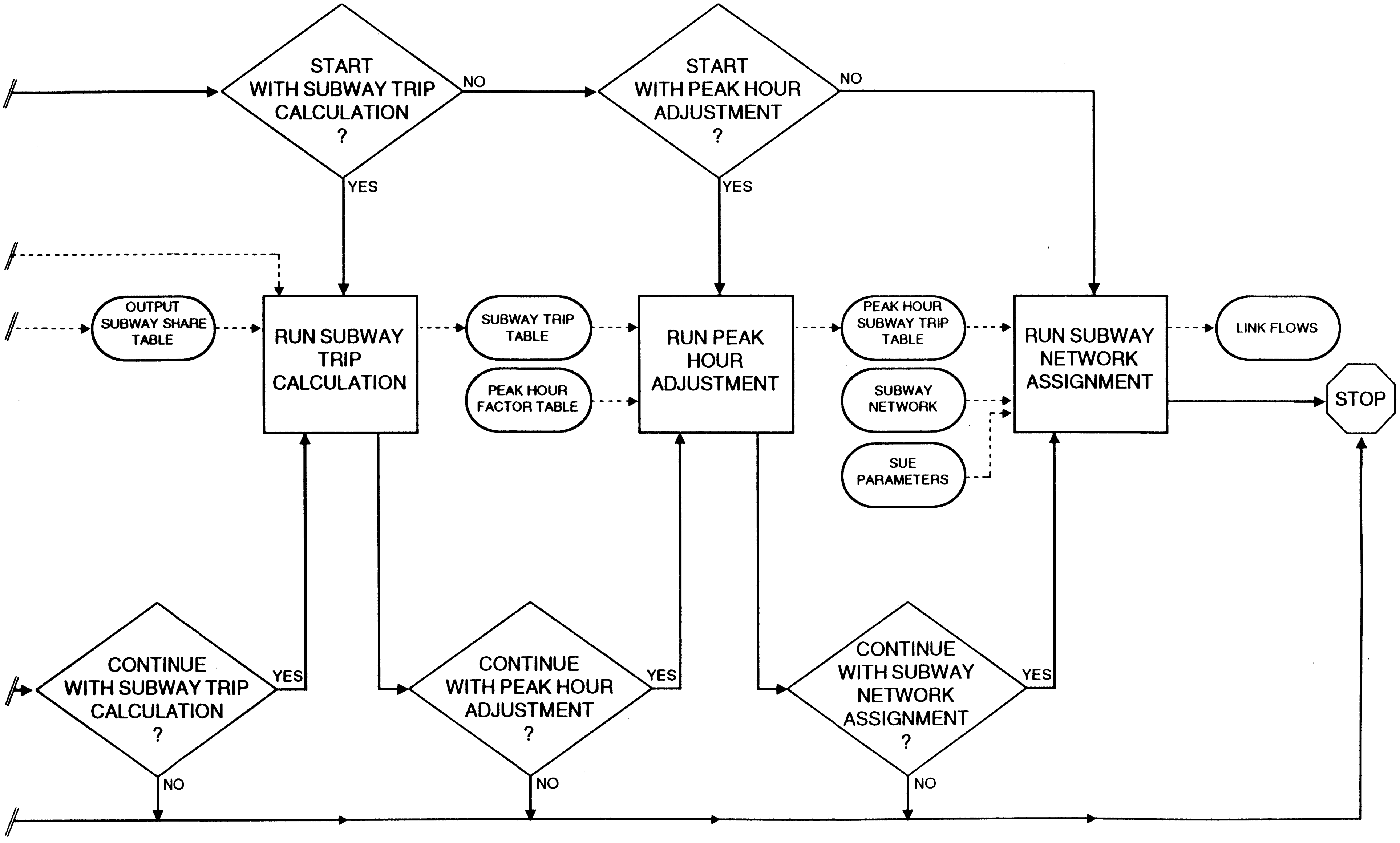


Figure 6-1

NYCTA FORECASTING SYSTEM STUDY AREA

Figure 6-2

CENSUS TRACT/CORRIDOR DISTRICT BOUNDARIES

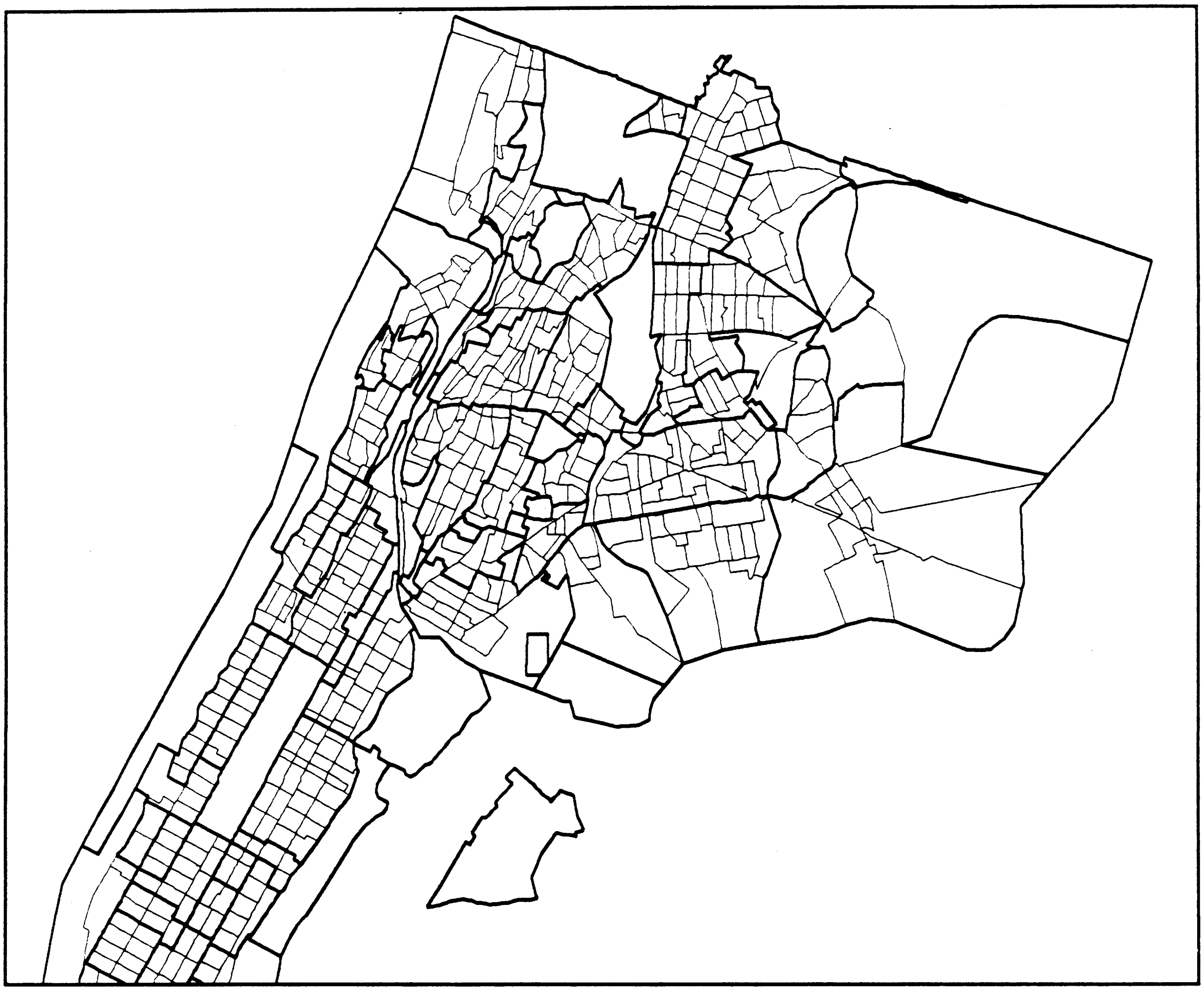


Figure 6-3

1980 TRIP PRODUCTIONS IN QUEENS

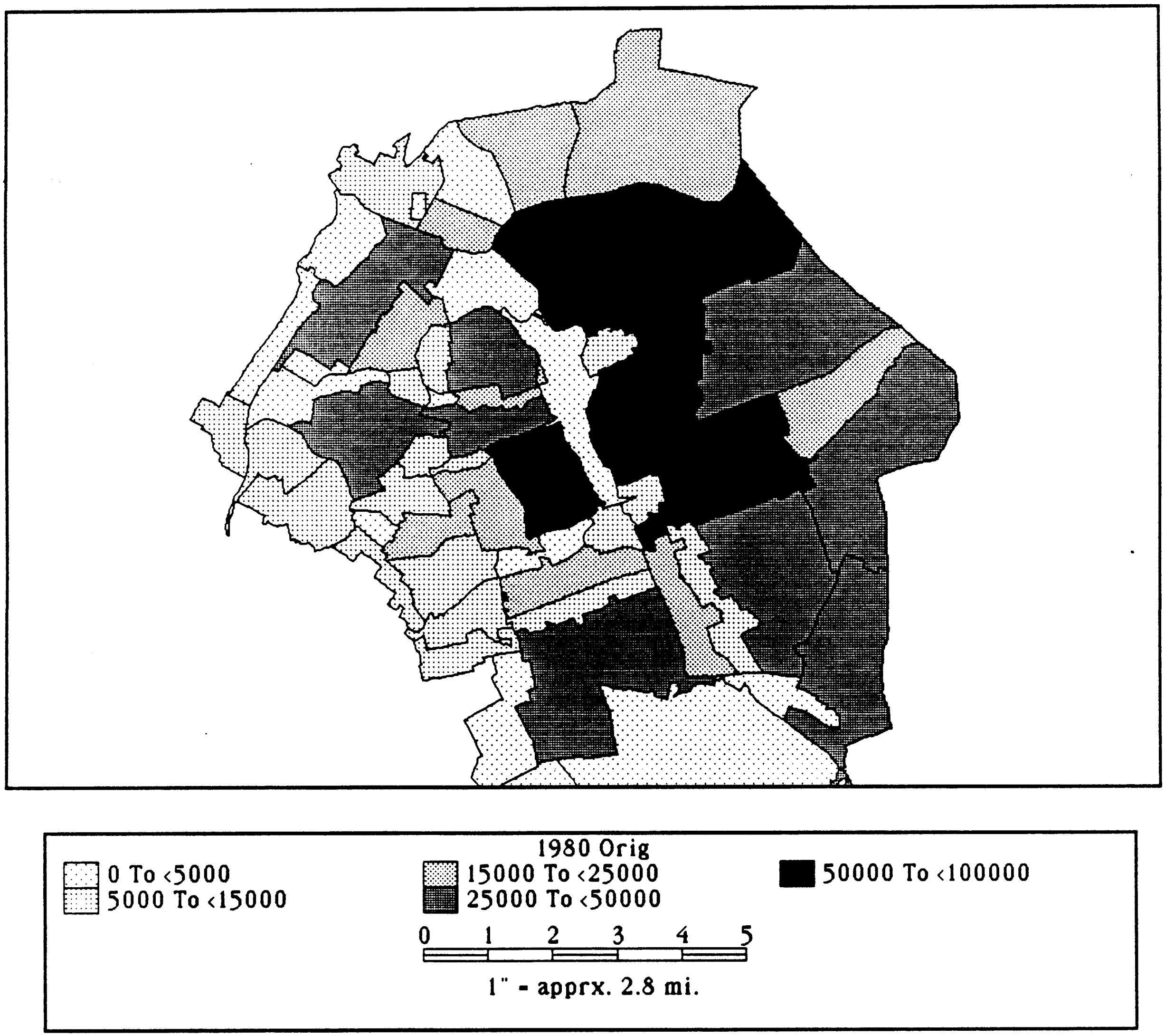


Figure 6-4

AVERAGE HOUSEHOLD INCOME (1980) BY ZONE

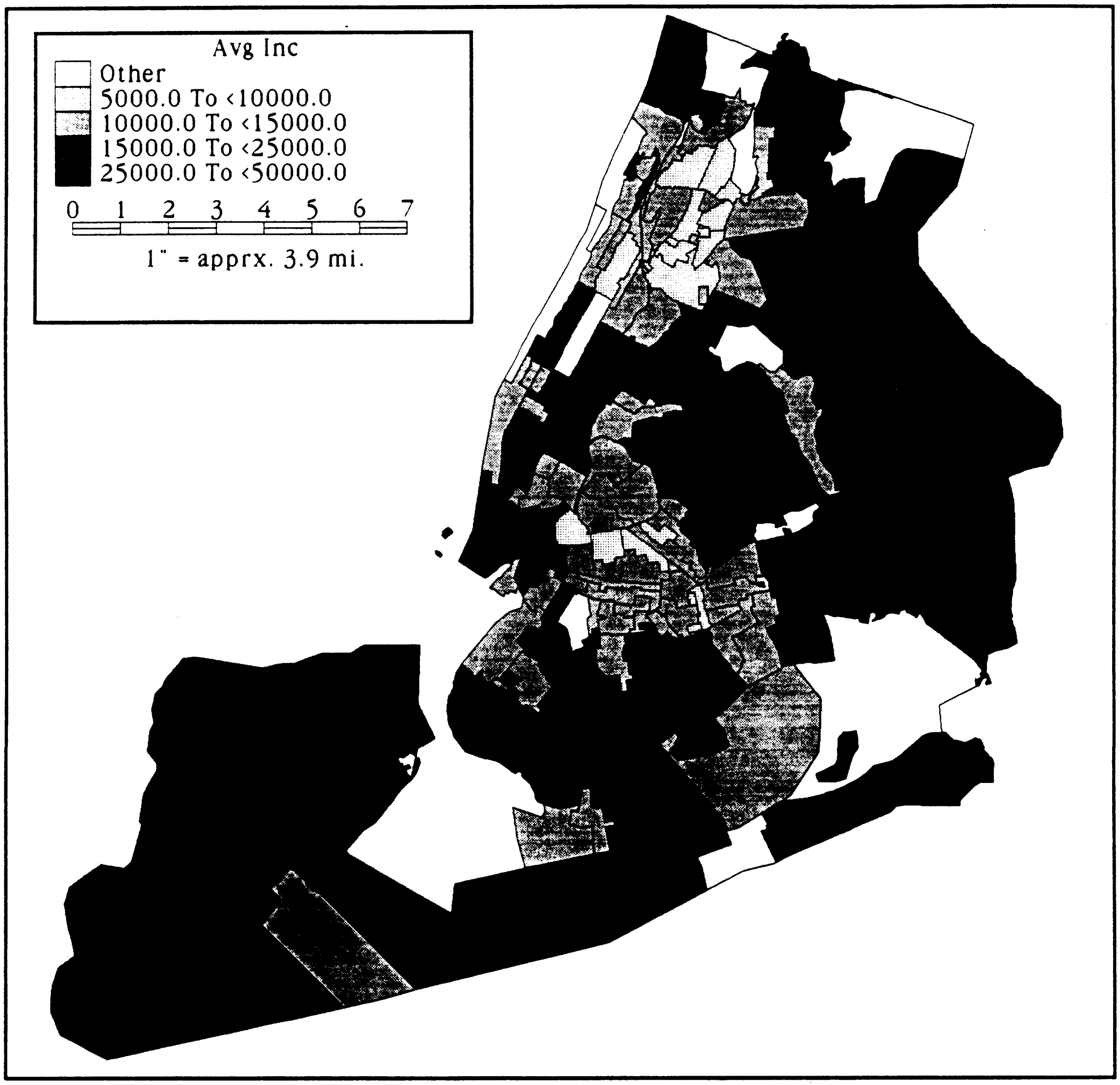
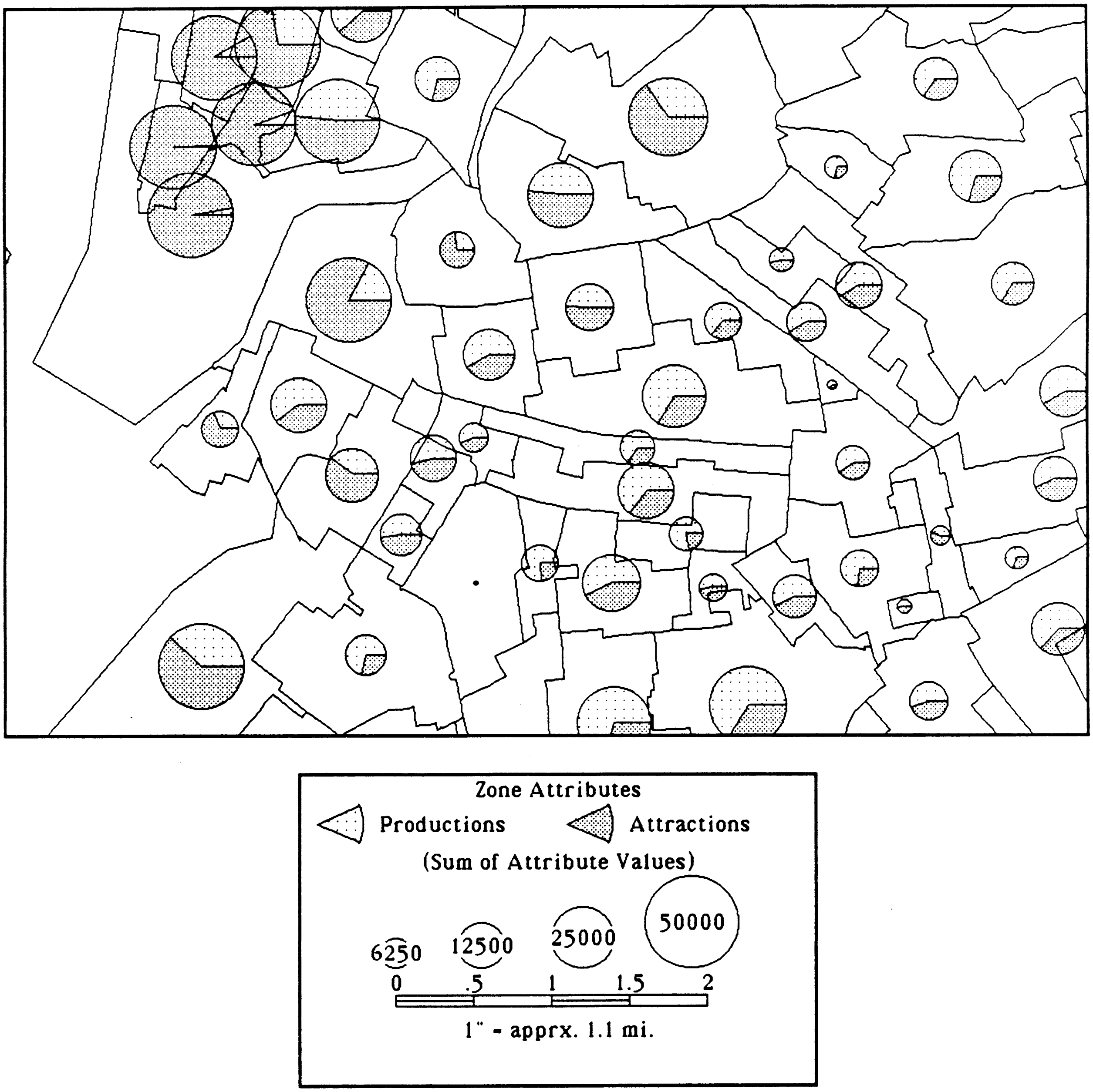


Figure 6-5

<u>1980 PRODUCTIONS/ATTRACTIONS BY CORRIDOR DISTRICT</u>



the trips produced and attracted to the region. The size of the pie that is displayed within each zone indicates the total trip productions and attractions in the zone; the solid and shaded portions of the pies indicate the relative numbers of attractions and productions.

This same display technique can be used to produce graphic displays of transit mode share. Figure 6-6, for example, was produced using 1980 Census journey-to-work data for upper Manhattan, and indicates the mode share for trips to the Manhattan CBD.

The graphic capabilities of TransCAD can also be used to display and access network information. Figure 6-7 indicates the locations of NYCTA stations and zone centroids in Midtown. Figure 6-8 is a schematic of the downtown subway network. Figures 6-9 and 6-10 show AM peak hour ridership on the E and F lines from Queens through midtown Manhattan. As indicated, the volumes can be displayed using labels on the map and/or bandwidths scaled according to the level of flow.

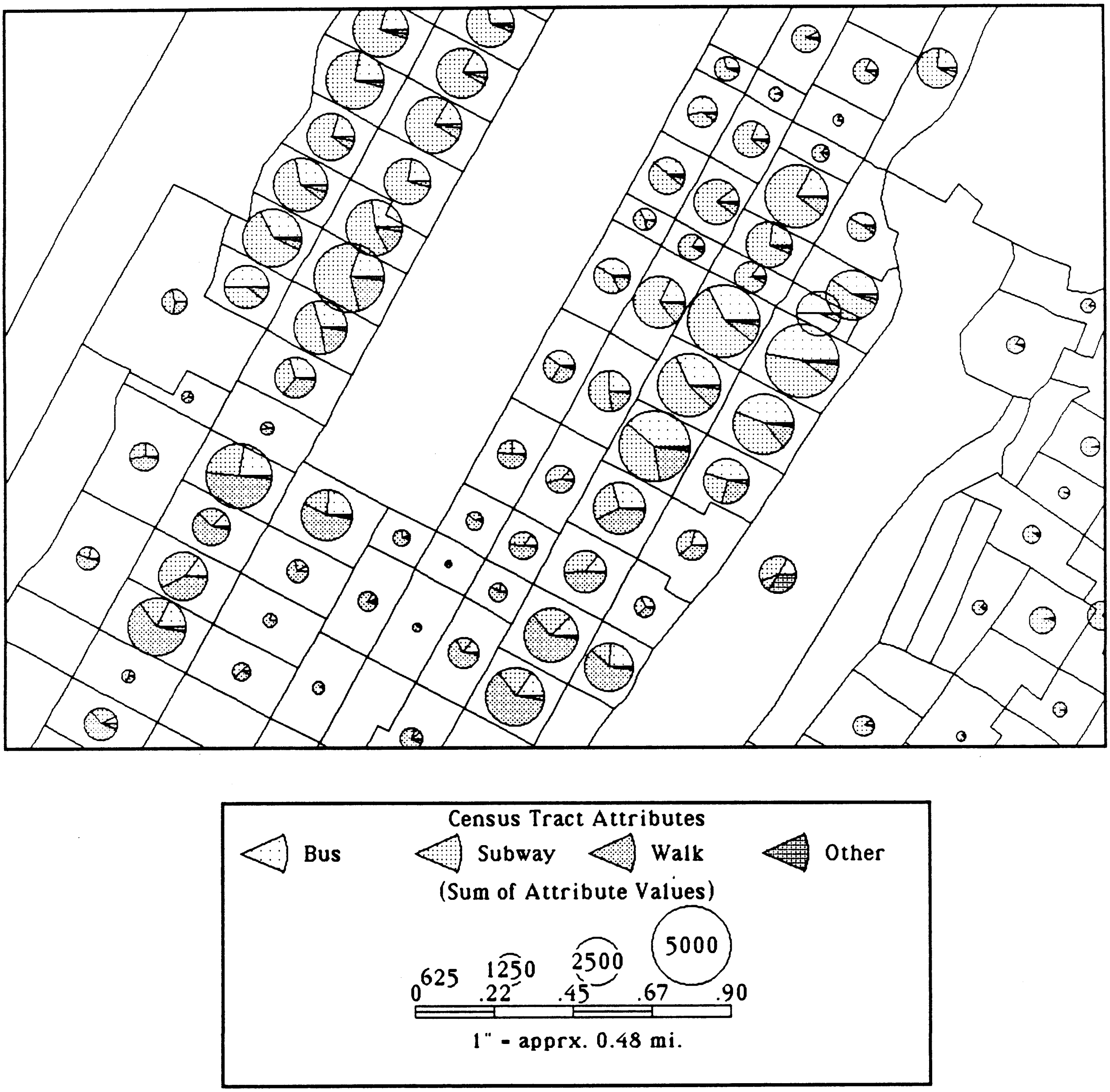
Figure 6-11 uses a pie chart to illustrate the percentage of time spent by NYCTA passengers under various levels of crowding on the NYCTA subway system. As indicated, in this subway demand scenario over 21 percent of total travel time in the system is spent under crowded conditions, with 6.2 percent of travel time spent in vehicles that are more than 25 percent over capacity.

The TransCAD graphic editing capabilities make it possible to increase the geographic accuracy of the subway networks. For example, Figure 6-12 shows the initial version of the NYCTA subway network in downtown Brooklyn. As is evident, this is a simple stick network that has no geographic precision. Using the raster/vector capabilities of TransCAD, this network was visually overlaid on the NYCTA map shown in Figure 6-13. Geographic editing functions were then used to bring the network into its final form, shown in Figure 6-14.

CONCLUDING REMARKS

In this project a complete four-step demand model implementation was accomplished within a GIS framework. A significant component of this project was the development of a transit assignment algorithm and network structure that would capture key behavioral aspects of subway ridership. The research performed in this study identified significant differences among the assignment methods currently in use.

Figure 6-6



1980 JOURNEY TO WORK MODE SHARE (TO MANHATTAN CBD)

Figure 6-7

SUBWAY STATIONS AND ZONE CENTROIDS; MIDTOWN

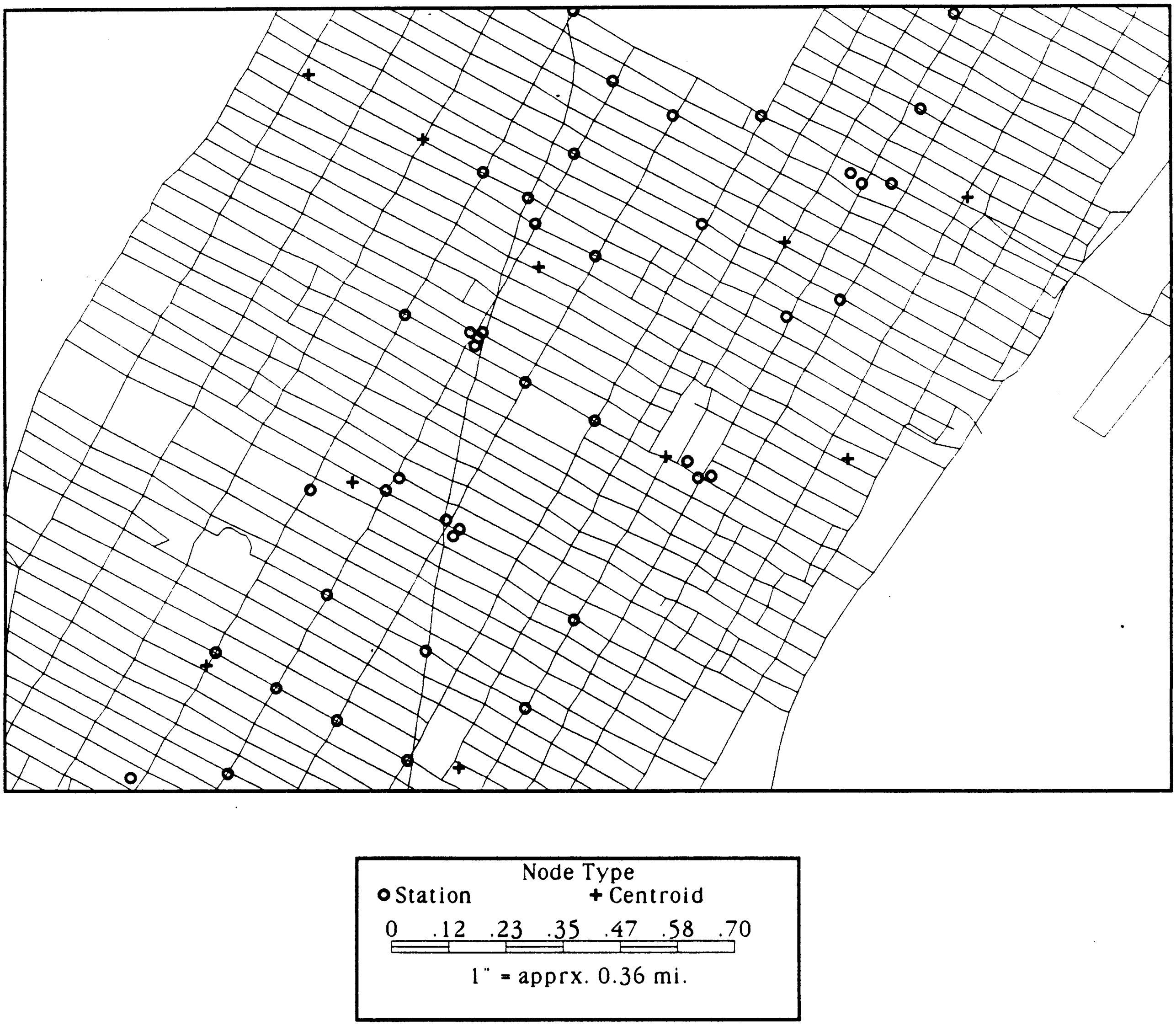


Figure 6-8

LOWER MANHATTAN SUBWAY NETWORK

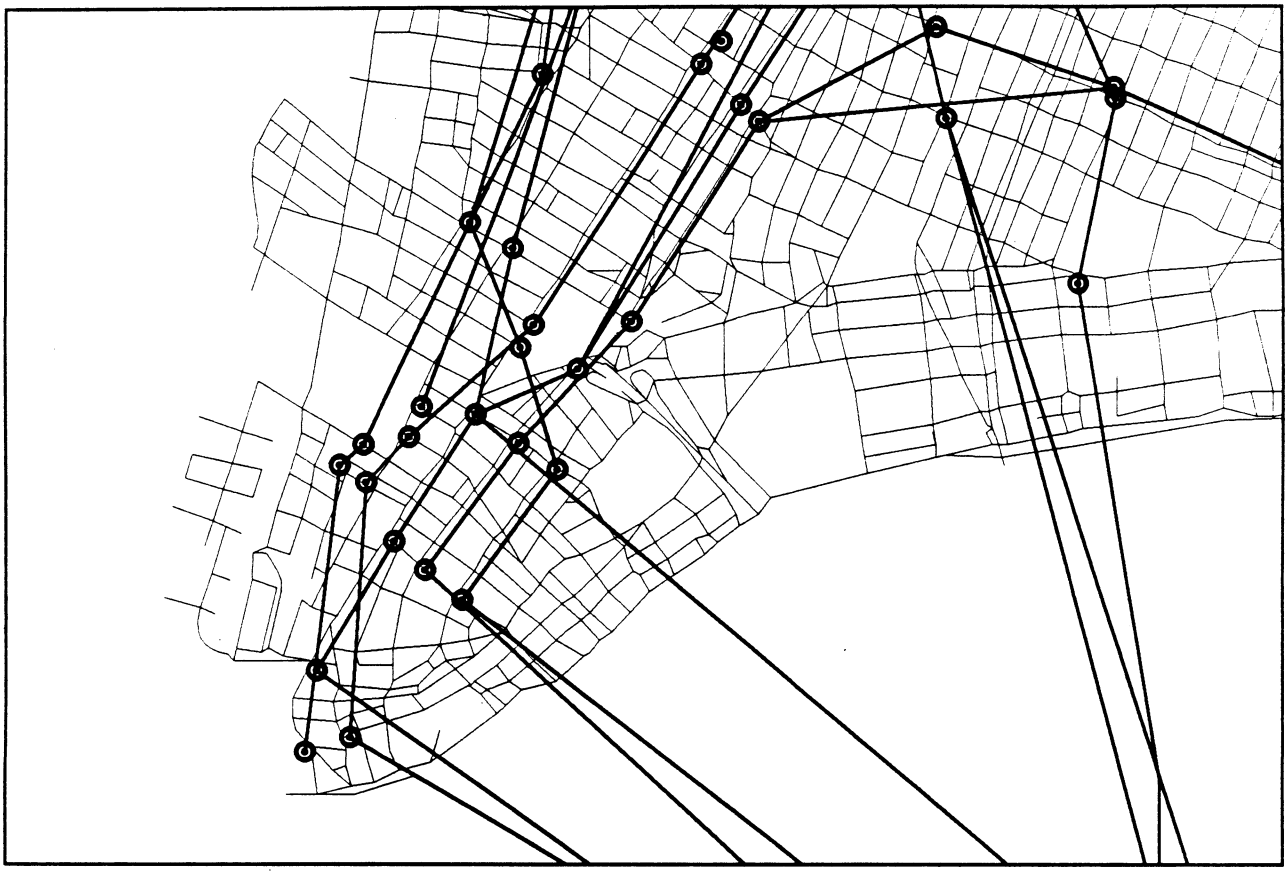


Figure 6-9

LOCAL "E" TRAIN PEAK HOUR LOADINGS

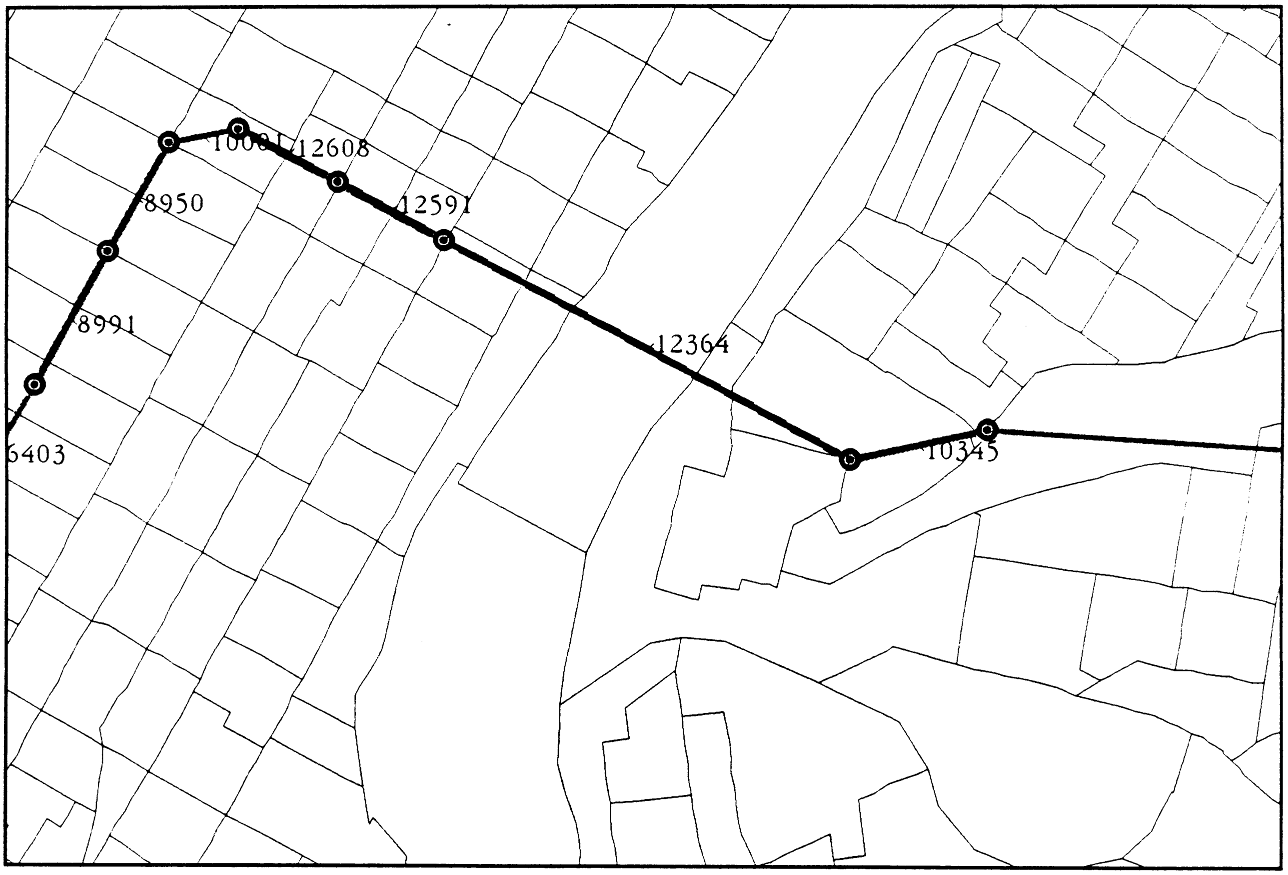


Figure 6-10

EXPRESS "F" TRAIN PEAK HOUR LOADINGS

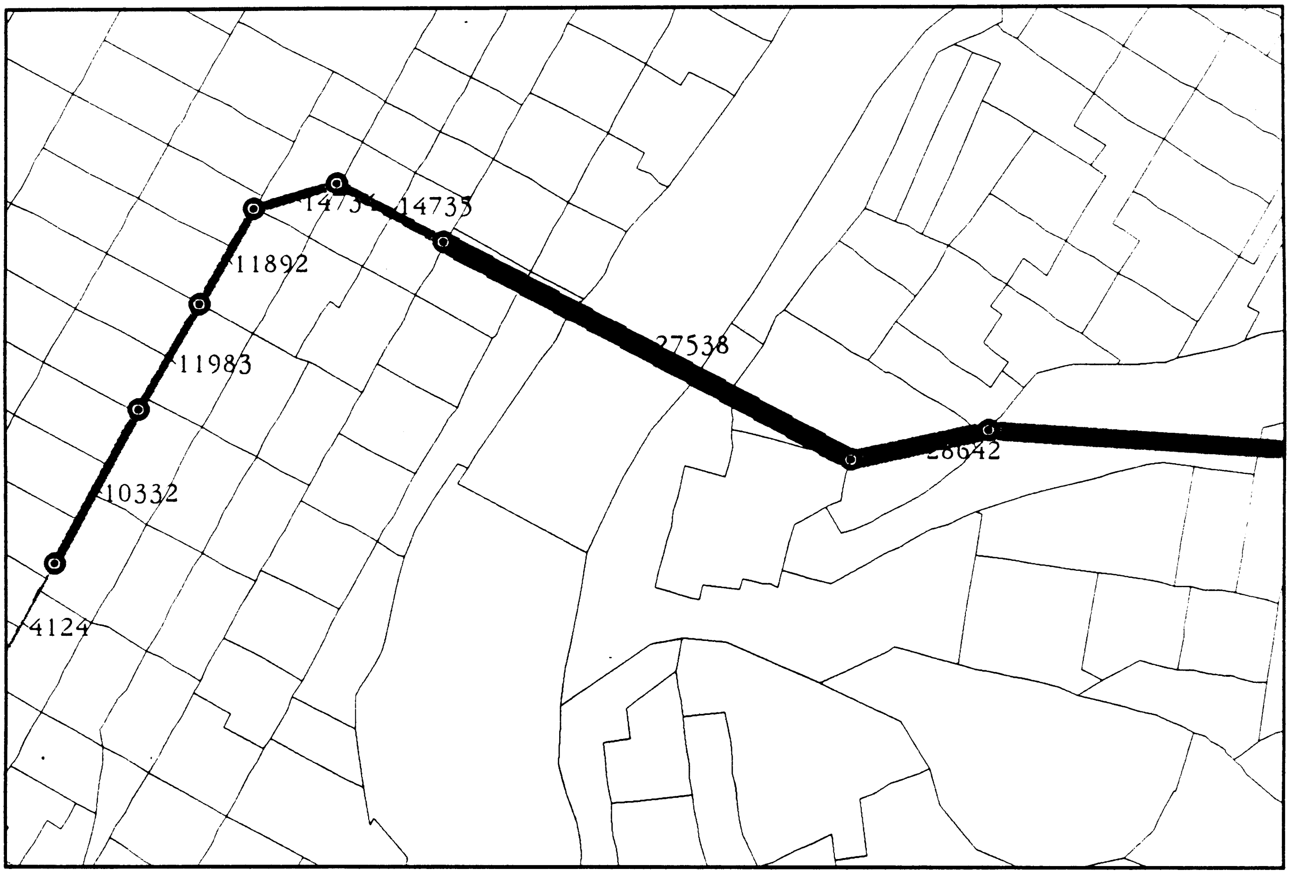


Figure 6-11

Sub 89a-Links: Pie Chart of V/C - Weighted by Pax-Min

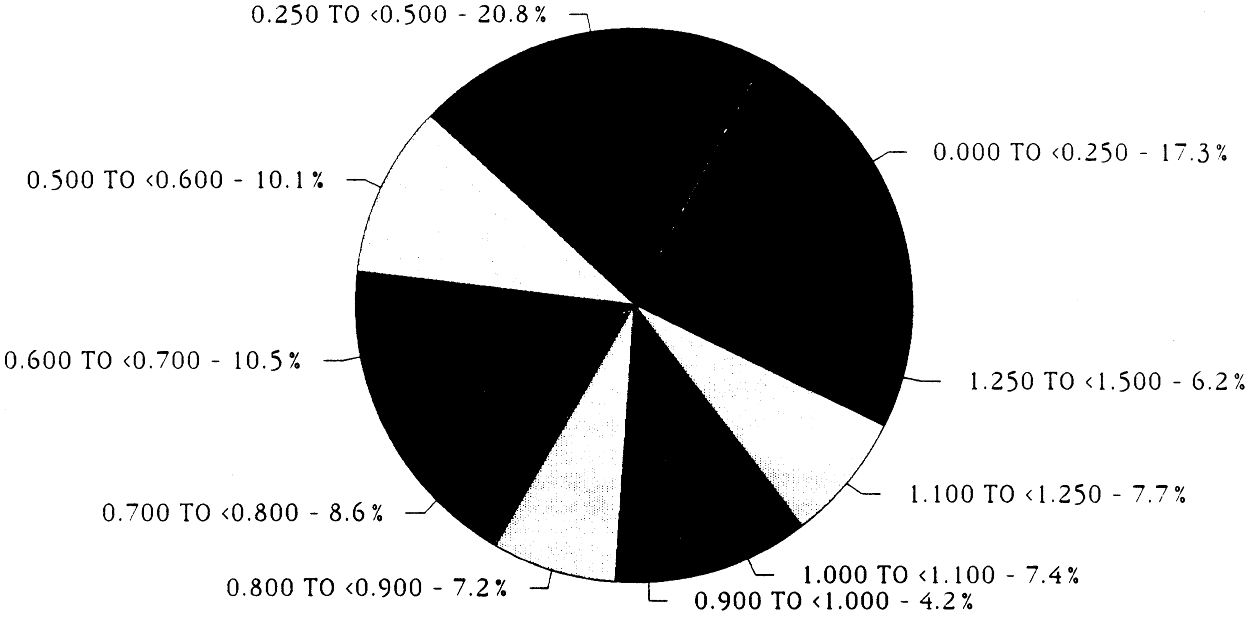


Figure 6-12

DOWNTOWN BROOKLYN NYCTA NETWORK

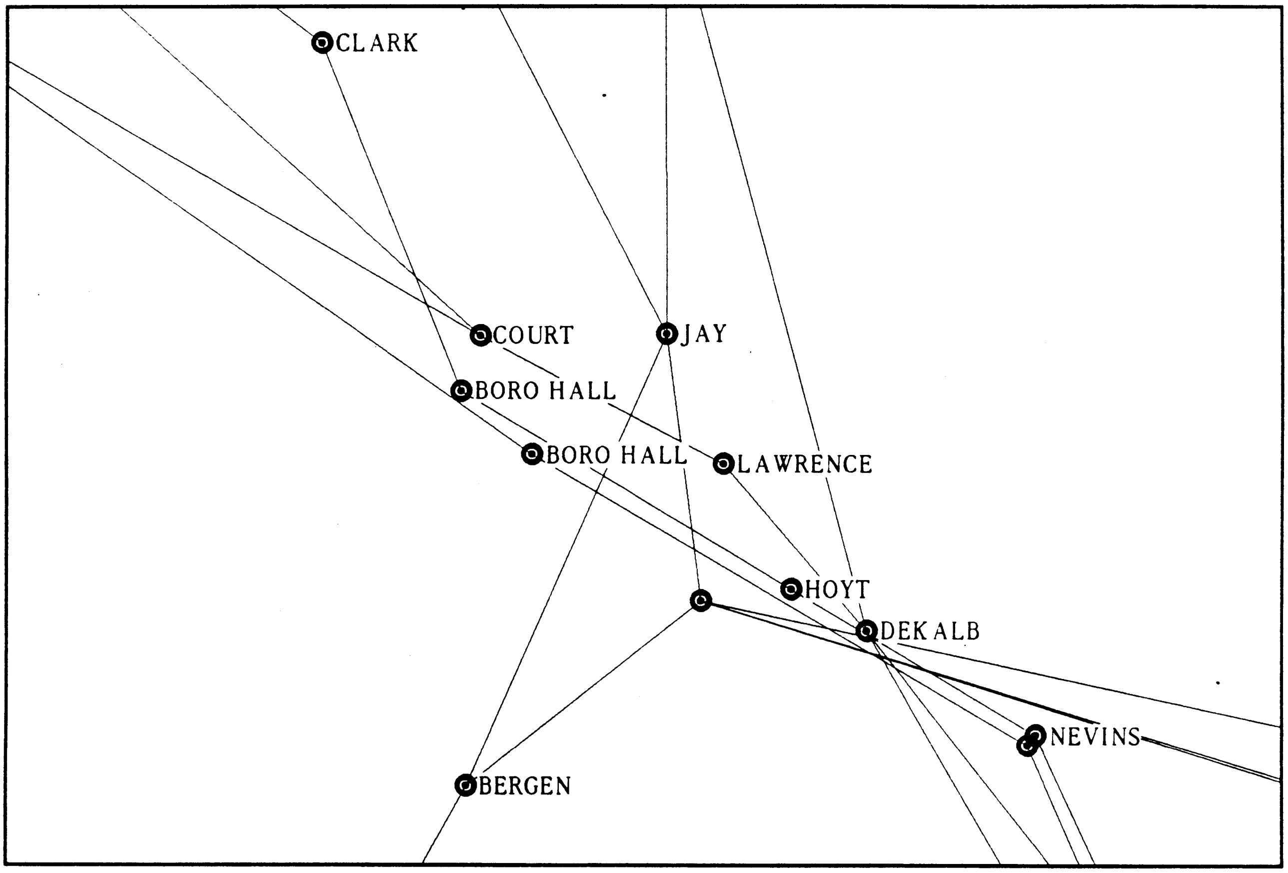
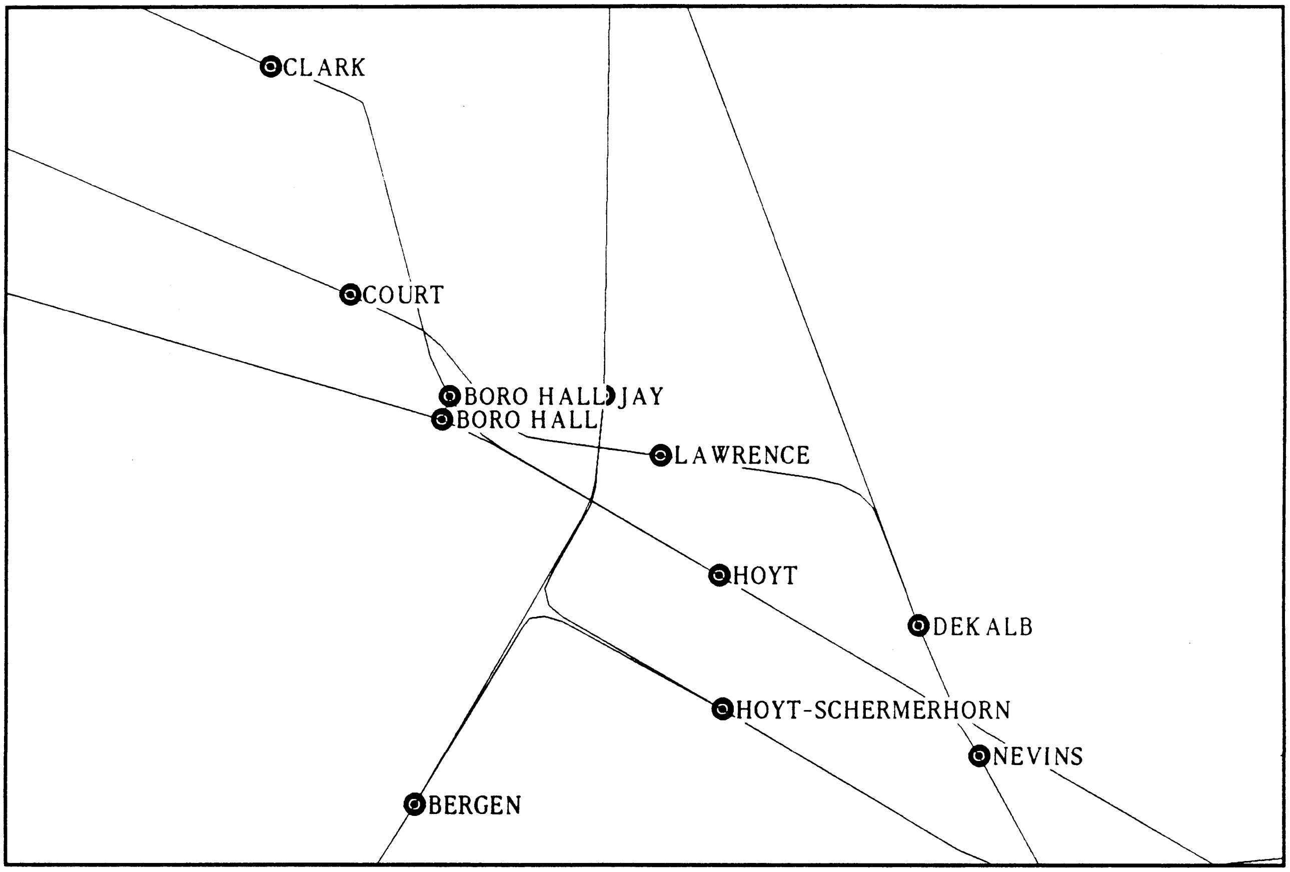


Figure 6-13

Figure 6-14

DOWNTOWN BROOKLYN NYCTA NETWORK (REVISED)



Only one method, stochastic user equilibrium, was found to provide a reasonable portrayal of traveler behavior. In addition, the work performed in this study indicated that the method is computationally tractable.

As an interactive spatial database system with extensive query capabilities, GIS provides a dramatically enhanced level of information access to planners, managers, and other potential users. For example, a user can retrieve a history of station boardings simply by pointing to the subway station icon on the screen. The travel time and transfers for routes between an origin and a destination can be computed in a matter of seconds.

Nor is data retrieval and manipulation limited to numerical information in a modern GIS. Maps, schematics, photographs, engineering drawings, and other types of images can be geographically referenced and retrieved by anyone, irrespective of their degree of training in using computers.

These capabilities greatly reduce the burden of accessing and manipulating all types of transportation data, including data pertaining to operations and the environment within which the transit system functions.

Modeling within a GIS Framework

Computerized systems that integrate planning models and GIS are relatively new and offer many advantages over separate planning software packages. Among the principal benefits that we see are greater accuracy, transparency, flexibility, pertinence, and validity.

A GIS offers the means to increase the accuracy of data inputs through direct calculation of spatial quantities from geographic data. This can be as simple as obtaining more accurate travel distances or times for a mode choice model, or may involve making use of polygon overlay to estimate the socioeconomic characteristics of traffic analysis zones. In the latter case, more timely data may be available for non congruent reporting units such as ZIP Codes; TransCAD's polygon overlay function allows new traffic analysis zone characteristics to be derived from these other sources.

An important aspect of GIS utilization in planning model development is in the visualization of model inputs and outputs. Errors in input data and irregularities in model generated outputs are more easily spotted, corrected, or comprehended. Indeed, it appears that the increased transparency of planning model application afforded by GIS helps the technician and manager alike in placing the models and their forecasts in appropriate perspective.

Use of a GIS in planning enhances the empirical content of the modeling process. This can be vital in a field in which conceptual formalism may obscure flaws in forecast accuracy and model validity. Clearly, a GIS can assist planners in making use of more pertinent data in model building. The most striking example is, perhaps, the opportunity to pursue analysis at various spatial scales. For example, trip generation may be examined at the parcel or land use level within zones rather than just for aggregate units. GIS technology makes it easy to manipulate the large amount of data that may exist at a detailed spatial scale and to aggregate results with minimal effort. Similarly, intersection data and simulated behavior can be linked with trip assignment methods to capture traffic flow characteristics more accurately. In these and in other ways, a GIS can resolve some of the difficulties with planning models by reducing undesirable aggregation and aggregation bias.

Model linkage, synthesis, and integration are facilitated and fostered by the GIS environment making it possible to use more appropriate modeling components and protocols. An extremely important byproduct is the accessibility that the GIS affords in making demand data available for other applications and analyses. It is hoped that in the future, this may close the undesirable gap between planning tools and operations management.

As suggested previously, it appears that a GIS can improve the efficiency of planning model development. Application of planning models involves a large number of data items and numerical calculations. TransCAD makes it easy to organize the necessary data files and perform the transformations needed to estimate, apply, and link the models in a forecasting procedure. Of perhaps equal or greater importance, the model inputs can be easily generated or modified, and the model outputs can be analyzed and presented geographically as well as graphically.

A GIS is not a substitute for effective and pertinent demand models. Another finding of this project is that standard algorithms and even specialized ones may perform poorly in the face of different application contexts. They must be evaluated and, if need be, modified to achieve reasonable results and to provide a suitable basis for planning.

Future Activities

The combined GIS/forecasting system provides a platform for additional data and model development which should take place in the future. As noted earlier, the specific demand models that were estimated in this project can be greatly enhanced as new data become available from travel surveys and from the 1990 Census.

Specific examples include improved trip production and attraction models which could be constructed from improved zone-level estimates of population and employment, and improved mode choice and distribution models that could be developed with more detailed information on travel patterns and trip characteristics. Future directions for improved model building include the development of disaggregate models of mode and destination choice. While data collection efforts targeted specifically at the development of improved models would be most helpful, some of this work may be feasible with recent travel survey data and 1990 Census data.

As new data become available, there will also be opportunities to enhance the modeling methodology through elimination of some of the other limitations and deficiencies of the four-step modeling process. This has always been a motivation for the development and evolution of TransCAD, and is expected to be a fruitful area for future research.

The models and GIS capability provided in the system have numerous applications beyond those which were utilized in this study. TransCAD is already in use at the MTA for analysis of capital projects, and for analyzing and displaying results of travel survey data. The system can also generate efficient paths through the subway network and produce directions for subway riders. Applications to operations planning and facility management are particularly promising and are among the numerous areas in which GIS technology offers significant benefits.