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Bus Route Demand Models

Cleveland Prototype Study

August 1983

Bus Route Demand Models:
Cleveland Prototype Study

Final Report
August 1983

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16. Abstract

The Greater Cleveland Regional Transit Authority's Prototype Bus Patronage Estimation Study was initiated to develop techniques for the estimation of changes in bus service patronage at the individual route level. Specifically, the estimation techniques are intended to be capable of determining changes in patronage resulting from the introduction of new service into a specific service area or as a result of a modification in the route structure of an existing bus route. The techniques are designed to be accurate within acceptable tolerance limits, responsive to local conditions, capable of utilizing existing local data, and operable by the Authority's in-house staff.

The GCRTA, along with three other transit systems in Portland, Los Angeles, and Albuquerque, received special Section 8 grants from the Office of Planning Assistance of the Urban Mass Transportation Administration (UMTA), U.S. Department of Transportation to develop prototype patronage estimation techniques. These prototype efforts have two objectives: 1) to develop improved estimation techniques; and 2) to test and verify that these improved techniques can be effectively used in an operating environment of a transit system.

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FOREWORD

Many transit systems around the country have expressed an interest in improving their patronage estimation techniques. The Greater Cleveland Regional Transit Authority, along with three other transit systems in Portland, Los Angeles and Albuquerque, received special Section 8 grants from the Office of Planning Assistance of the Urban Mass Transportation Administration (UMTA), U.S. Department of Transportation to develop prototype patronage estimation techniques. These prototype efforts have two objectives: 1) to develop improved estimation techniques; and 2) to test and verify that these improved techniques can be effectively used in an operating environment of a transit system.

This report summarizes the results of the Prototype Bus Patronage Estimation Study conducted for the Greater Cleveland Regional Transit Authority. This study was initiated to develop techniques for the estimation of changes in bus service patronage at the individual route level. The report includes a review of existing GCRTA patronage estimation techniques, a review of the procedures and data used to develop the technique, an assessment of the performance of the technique and step-by-step procedures for application. We believe this report will be useful to transit systems in the development and use of new patronage estimation techniques.

Additional copies of this report are available from the National Technical Information Service (NTIS), Springfield, Virginia, 22161.

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A special thanks is extended to Brian E. McCollom, our Project Director in UMTA's Office of Planning Assistance, for his assistance in guiding the project, reviewing the draft report and making thoughtful suggestions for improving the report.

We would also like to thank James McLynn of DTM, Inc. who provided valuable advice and assistance in the model development phase of the project.

TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

STUDY BACKGROUND

The Greater Cleveland Regional Transit Authority's Prototype Bus Patronage Estimation Study was initiated to develop techniques for the estimation of changes in bus service patronage at the individual route level. Specifically, the estimation techniques are intended to be capable of determining changes in patronage resulting from the introduction of new service into a specific service area or from a modification in the route structure of an existing bus route. The techniques are designed to be accurate within acceptable tolerance limits, responsive to local conditions, capable of utilizing existing local data, and operable by the Authority's in-house staff.

Several factors reinforce the need for simplified and accurate techniques for bus route patronage estimation. Most major highway and transit facilities are completed, population growth has slowed or stopped in many locations, and the resources to construct and maintain major facilities are growing increasingly scarce. All of these factors have reduced the emphasis of long-range planning considerations. Simultaneously, scarce operating resources have led to concern for more efficient operation, improved productivity, and the equitable and effective distribution of limited transit resources among the numerous competing interests requesting services within a given community.

Major systems planning procedures and processes utilizing mode-split techniques have not been suitable for the evaluation of short-range low-cost bus route changes. Although some formalized techniques for estimating short-term route-level patronage have been developed, they are generally not used by transit systems. Instead, judgement or rule-of-thumb elasticities are most commonly used. Estimation procedures are also rarely documented. As a result of the informality of existing practices, the accuracy and biases of these methods are not known. Consequently, the extent to which results may be replicated and verified between analysts and over time is not well documented and the transferability of methods among geographical areas is unknown.

The Greater Cleveland Regional Transit Authority (GCRTA) is among many transit systems interested in improving their patronage estimation techniques. The GCRTA, along with three other transit systems in Portland, Los Angeles, and Albuquerque, received special Section 8 grants from the Office of Planning Assistance of the Urban Mass Transportation Administration (UMTA), U.S. Department of Transportation to develop prototype patronage estimation techniques. These prototype efforts have two objectives: 1) to develop improved estimation techniques; and 2) to test and verify that these improved techniques can be effectively used in an operating environment of a transit system.

Before the four prototype studies were initiated, a comprehensive review of estimation techniques currently employed by transit systems was conducted. The findings of this review are detailed in Route-Level Demand Models: A Review[1].

The rest of this report describes the efforts and findings of the GCRTA Prototype Bus Patronage Estimation Study. The report is organized as follows:

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[1] Available from the National Technical Information Service, Springfield, VA 22161, Report Number PB82-1237843

- Chapter 2 presents a description of the GCRTA.
- Chapter 3 summarizes the existing GCRTA estimation techniques and the deficiencies present in the methods used.
- Chapter 4 presents the model development procedure, including review of previous research, guidelines for model development, review of existing data, description of the procedure used and description of the model.
- Chapter 5 provides a assessment of model performance, shortcomings and specific actions to improve the model.
- Appendix A summarizes the step-by-step procedure for model application.
- Appendix B includes a detailed description of the step-by-step procedure for model application
- Appendix C includes a sample estimate for a radial bus route
- Appendix D includes a sample estimate for a crosstown route

CHAPTER 2

DESCRIPTION OF THE GCRTA

The Greater Cleveland Regional Transit Authority (GCRTA) was created to provide mass transit services throughout Cuyahoga County. The primary service area, Cuyahoga County, has a 1980 population of approximately 1.5 million persons inhabiting 450 square miles. The urbanized area centers on the City of Cleveland, which has a population of approximately 572,000 persons living in an area of 77 square miles.

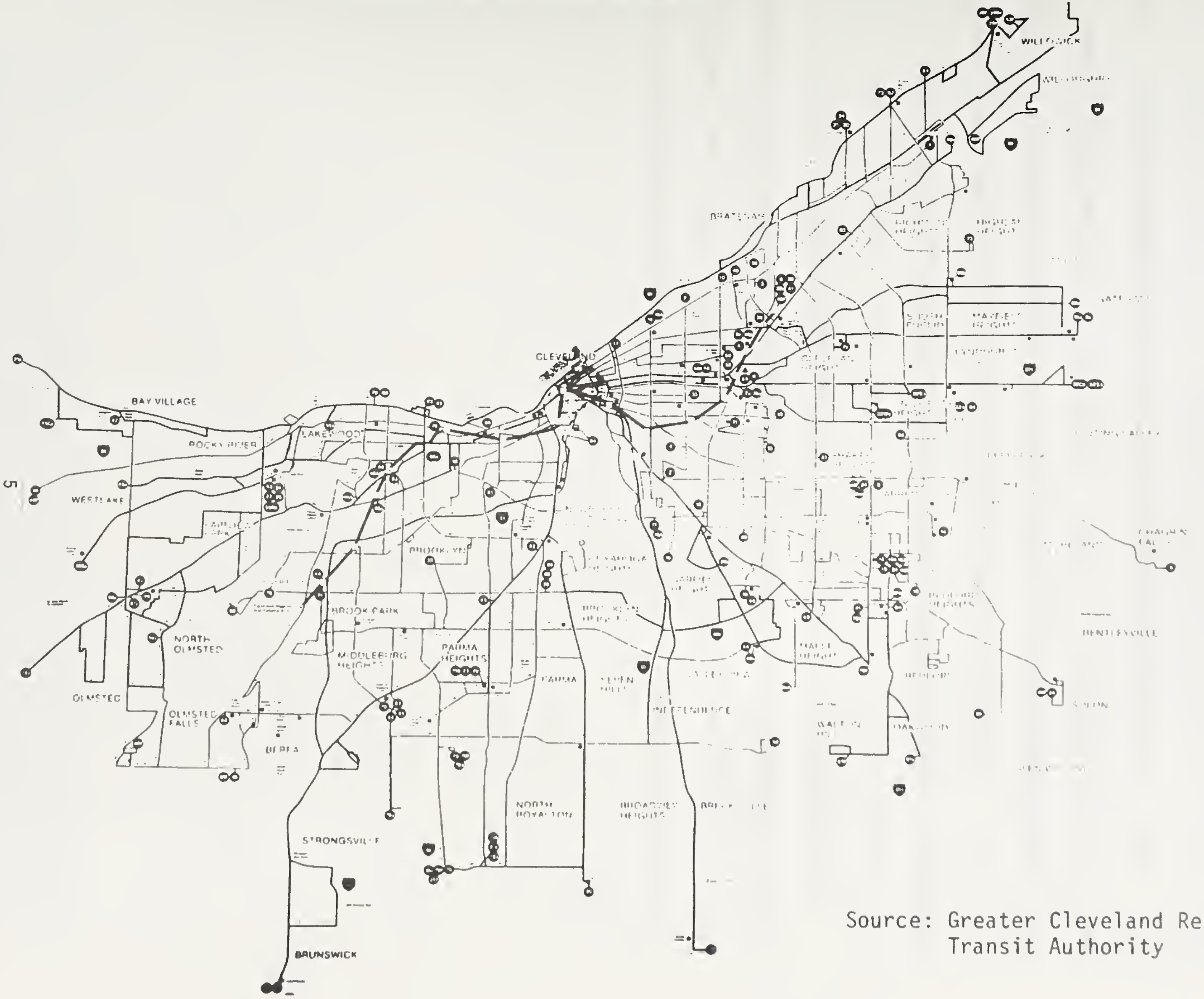
The GCRTA operates a multi-modal system comprised of buses, light rail rapid transit, and paratransit services for the elderly and handicapped. The 1981 system ridership exceeded 120 million unlinked trips with 89% of these trips taken on the fixed-route bus system. A map of the GCRTA service network is provided as Figure 1.

Prior to the creation of the GCRTA in 1975, transit service was provided throughout the urban area by a number of independent public and private transit operators. Transit service had deteriorated steadily to the point where the combined average weekday ridership for all systems in Cuyahoga County had declined to a level of less than 250,000 unlinked trips on an average weekday. Under GCRTA's program of increased service, standardized fares, and coordinated operations, ridership has increased to a level in excess of 450,000 unlinked trips on an average weekday.

One of the major elements of GCRTA's overall improvement program was a 30% expansion of transit service throughout the County. This expansion, expressed in terms of vehicle miles per week, was implemented through a combination of improved frequency on existing routes, expanded hours and days of operation on existing routes, extensions to existing routes, and

FIGURE 1

GCRTA SYSTEM MAP



Source: Greater Cleveland Regional Transit Authority the introduction of new routes into the basic route network service structure. Today, the GCRTA fixed route line-haul bus system encompasses over 90 individual bus routes of all types - radial, crosstown and rapid feeder. The basic responsibility for the planning and implementation of new or modified bus routes to the GCRTA system lies in the Service and Grant Development Department. There are about five planners involved with route planning in the department.

The Northeast Ohio Areawide Coordinating Agency (NOACA) is the designated Metropolitan Planning Organization for the five-county Greater Cleveland area in Northeastern Ohio. NOACA's role in the five-county region includes active involvement in transportation planning and programs.

CHAPTER 3

EXISTING GCRTA ESTIMATION TECHNIQUE

This chapter summarizes the approach used to date by the GCRTA in performing analysis to predict the ridership impacts of service modifications and some of the deficiencies present in the analysis.

The estimation techniques have been a blend of professional judgement and cross-sectional data techniques. The methodology consists of the identification of an area with existing services which contains geographic, socio-economic and demographic characteristics that are judged similar to those in the area for which a service change is proposed. A home based trip generation rate (trips per dwelling unit) is calculated for this similar area and is applied to the proposed new service. This trip generation rate is multiplied by the number of households to be served along the proposed route's service area to estimate the potential ridership for the new service.

The accuracy of this technique has not been tested. While the GCRTA believes that the ridership projection technique has been moderately accurate, there have been instances where projections have been significantly higher than the ridership that occurred after the new service was implemented. The shortcomings of this estimation technique that have been identified by the GCRTA include:

- Informal methodologies were utilized. While there is nothing inherently wrong with using informal techniques, this approach usually results in a lack of documentation and thus makes it difficult for subsequent planners to conduct future follow up to the analysis. It also results in techniques not being consistent from one analysis to another. Thus, different planners using the same data base are likely to produce different patronage estimates.
- Estimation procedures did not include a number of factors exogenous to the transit system that would affect ridership, e.g. changes

in demographic variables. Although exogenous impacts are uncontrollable, being aware of their effects can be beneficial in the planning process, since they give an indication of the changes in patronage that will occur in the absence of policy changes.

CRITERIA FOR THE MODEL DEVELOPMENT EFFORT

The primary emphasis of the GCRTA was to develop a model (techniques) which could project the impact on ridership of modifications to existing bus routes and the ridership potential of new bus routes. Secondary consideration was given to the application of the model in medium range and corridor level planning activities, such as those carried on by the planning group that is part of the GCRTA Service and Grant Development Department or by NOACA transportation planners. Examples of these applications include analysis of patronage impacts of implementing transportation system management-type programs in specific locations.

In light of the planned application of the model, the following criteria were established by the GCRTA to govern the model development process and to respond to the shortcomings of the techniques currently employed by the GCRTA:

1. Accuracy - The model should have the ability to predict ridership accurately within a degree of error that is acceptable for planning purposes. GCRTA set about a 10% deviation from the true ridership figures as constituting a very satisfactory range.
2. Sensitivity to Decision Variables - The model should be able to predict changes in ridership resulting from key modifications made to the system including headway, re-routing or extensions to routes, and transfers.
3. Range of Application - The model should be suitable to be applied for all service types, including local, express, crosstown and feeder.
4. Analyst Independence - Different analysts should achieve the same results given the same set of data.

5. Cost of Application - The model should require only existing data and not new data. Ridership projections should be achieved in less than one hour.

6. Technical Sophistication - The model should be usable by a junior level staff person with a hand or desk top calculator.

CHAPTER 4

MODEL DEVELOPMENT PROCEDURE

The bus route patronage model was developed to specifically meet the needs of the Greater Cleveland Regional Transit Authority (GCRTA) for continuing short range route planning. As a result, the model development analysis and the models which emerged were dependent on, and reflect the conditions present in, the GCRTA service area. These include:

- the data available for model development;
- the data anticipated to be available for application of the models;
- the types of service, route structure and system configuration; and
- the route and service planning issues to be addressed.

The process used in the model development is described in the following sections.

- Review of previous research
- Guidelines for model development
- Review of existing data
- Description of procedure
- Description of model

REVIEW OF PREVIOUS RESEARCH

A review of findings from previous research, model development studies and current transit demand estimation procedures was undertaken to identify explanatory relationships and model structures which had been investigated for transit demand estimation. A considerable body of information was found on factors which explain transit demand and model structures to estimate transit demand. While this information had been developed predominantly for use in longer range transit planning applications, it was based on empirical analysis of transit operations, transit travel demand characteristics and market factors. These findings were considered to be useful as an aid in identifying relationships and model structures which should be pursued.

Review of previous findings was undertaken using the model development specifications as a reference framework. The review covered three major items:

- basic model structure
- variables
- application and service types addressed

Basic Model Structure

Major model structures identified in the review were mode share, pivot point, elasticity and direct demand. Mode share models which "split" person travel demand among various modes (e.g. car, bus, rail, etc.) were judged to be too complex and not sufficiently sensitive for quick response, short range bus route planning. The models required as input, estimates of person travel demand between origins and destinations in the existing or proposed service area. This information is not always available and entails a costly and time consuming effort to develop. Further, this type of model was initially developed for planning of major changes in transit service type or to "skim off" trips for highway planning studies. However, it was felt that such models do not accurately estimate the results of small changes in transit service typical of short range service planning nor do they accurately estimate transit demand in low demand service areas. While not a drawback for regional and major corridor transit planning, this deficiency is of concern in short range service planning. For these reasons, the mode share approach was considered not to be a suitable structure for a simplified, quick response patronage model for transit service planning.

Pivot point models estimate the change in existing transit demand resulting from changes in transit service based on the existing service, the existing demand and the proposed service change. The model explicitly takes into account the demand-transit service relations at both the existing and proposed service levels. This is important because demand-service elasticity can vary over the range of service quality. The model structure requires an estimate of existing travel demand and therefore can only be used to estimate change from a base condition. It cannot be used to estimate demand for a new service where none presently exists. For this reason, this model structure was not considered for the basic model which had to address new service area planning. The pivot point structure, however, was considered as a simplified approach to augment the basic estimation models in estimating some changes in existing routes.

Elasticity models which estimate the rate of change in demand with the rate of change in service parameters were found not to be a suitable approach for this project. One shortcoming of the elasticity structure was that it required a base estimate of transit demand and hence could not estimate transit ridership for new service areas. The second major shortcoming was that an elasticity value is based on a specific level of service. Elasticity values can and do vary as the level of service varies. Hence an elasticity value may be an adequate approximation of change in demand for small service changes from the service level at which the elasticity value was derived, but may not be for large service changes. Since the elasticity value is directly related to a specific service level, that value may not be used to accurately estimate changes from other service levels, except where demand-level of service relationships are linear.

Direct demand models were found to be the most promising for the model structure. Since transit demand was estimated directly, there was no need for involved estimation of total person demand travel markets. Further, the earlier model development efforts and applications indicated that direct demand models could estimate, with acceptable accuracy, transit demand in low volume markets and for the types and small magnitudes of service changes frequently encountered in service planning. Direct demand models could be easily applied on single routes, generally had very simple and easily understandable structures and generally had less demanding requirements on the amount and preparation of input data.

As a result of this review, it was decided that the direct demand model was the most appropriate type of model structure to meet GCRTA's specifications. The pivot point model type was also considered to be useful as a model to estimate the effect of some service changes on existing or base estimate of transit demand. In this case, the pivot point model would be derived from the direct demand models.

Variables

One purpose of the review of variables used to estimate transit demand was to improve the efficiency of the analysis in this project. It was hoped this review would reduce the effort needed to select the proper variables. This review focused on the identification of variables which had been found to best explain and predict transit ridership, the measurement of these variables and the form of the relationships between transit ridership and the variables.

In this review, variables considered were:

- 1) characteristics of the bus trips being made;
- 2) market factor data;
- 3) transit service descriptors which influence persons desiring to to make a transit trip (variables such as bus miles or bus hours of service, which have no meaning to a person making a trip decision, were not considered); and
- 4) ridership count data.

The following variables were found from the literature review to be important:

- Trip Data
  - trips by route
  - origins/destinations
  - purpose of trip
- Market Factor Data
  - population within 1/4 mile of the service
  - households within 1/4 mile of the service
  - employment within 1/4 mile of the service
  - employment within major activity centers served by the bus routes (such as a CBD)
  - income level
  - car ownership/availability level
  - race
  - sex
- Transit Service Data
  - service frequency
  - route travel time (to destinations along the route)
  - route alignment (proximity of the route to major trip attraction locations)
  - number and quality of connections with other routes.
- Ridership Count Data

These variables were used initially in the review of existing NOACA and GCRTA data and subsequently in the formulation of the models.

GUIDELINES FOR MODEL DEVELOPMENT

The next step in the model development process was the establishment of a set of guidelines. These guidelines were prepared using the criteria for model development as a guide.

Range of Application

GCRTA's bus operations consists of four distinctly different types of service - local radial route service, express radial route service, local crosstown route service and feeder bus service to the light and heavy rail systems. The model should be capable of producing accurate estimates for each of these service types.

Sensitivity to Decision Variables

The model should be responsive to service planning needs which included:

- extensions or cutbacks for existing routes;
- increases or decreases in service frequency on existing routes;
- alignment changes along existing routes; and
- introduction of routes into new service areas.

Fare level structure changes were not included by GCRTA as a specification for the model, since it was the belief of GCRTA that service level functions were the prime determinant of route ridership.

Market Factors

The model should be responsive to changes in the size and characteristics of the potential travel market within the service area for an existing or proposed route. Market factors should include measures of:

- population in the route service area;
- socio-economic characteristics of the population which reflect

a propensity to make transit trips; and

- trip attraction within the service area.

Route Demand Characteristics to be Estimated

The model should provide estimates of route ridership characteristics which match the criteria used for route and service planning decisions. Estimates were desired for:

- maximum load point passenger volumes;
- passenger load profiles along the route;
- total daily boardings;
- boardings and alightings along the route; and
- route-to-route transfer volumes.

Use of Existing Data

The model should be developed using existing data. Use of data which would be continuously available was specified to make application of the model as simple as possible. Application of the model was not to involve an extreme effort to develop input data; data were to be drawn directly from data prepared, collected or assembled by NOACA and GCRTA as part of their normal on-going activities. Therefore, the model should be based on data which are both currently available and are expected to be continuously available and kept up to date.

Data available included:

- Ridership on/off counts
- Number of transfers at each transfer point
- Ridership profiles (age, sex, income distributions)
- Regional data (employment densities, land use, number of households)

Simplicity and Quick Response

Models should be structured such that GCRTA could respond to route planning problems and issues quickly, with a minimum cost and without a heavy involvement of senior staff required in use of the model. Explicit guidelines established by GCRTA to meet these quick response and minimum cost and level of effort objectives were that the model should be implemented on a programmable calculator (TI-59) and a junior professional should be able to carry out the estimation for a route in one hour.

Accuracy

Models had to produce estimates at an accuracy to be useful in route planning decisions. The accuracy requirement implied a correct sensitivity to the service changes and a tolerable estimation error. If within the limitation imposed by all the specifications, a model of acceptable accuracy could not be developed, this was to be considered a valid and acceptable finding. While the degree of accuracy necessary for planning varies for different circumstances, a general standard is that a level of error of ± 10% is tolerable.

REVIEW OF EXISTING DATA

As the model had to be developed using existing data, the type and quality of that data was a major factor in determining the initial model structure and developing the final models. It was therefore necessary to conduct a comprehensive review of the data as a prelude to the basic data analysis and the initial model specifications. This review was guided by results of the findings from previous research. The data was evaluated from two viewpoints: 1.) current availability of data to structure and calibrate the model; and 2.) future availability of data to apply the model.

Trip Data

Data describing transit trips by route, origin/ destination and trip market factors were required. An on-board survey conducted in 1976 was the only source of trip data reflecting current operations. The survey had been designed to provide system level, total route and user market segment profiles. The survey was not designed for detailed route level analysis. While the data were statistically accurate and appropriate for the purposes for which they were originally collected, it was not collected in a way to support the more demanding route level analysis requirements of model development.

As was later determined from the review, the data limited the model structure to a single trip purpose, and to a total daily estimate of ridership. Further, the trip end information was defined in such a way that the home end of the trip could not be explicitly identified. Home to destination movement had to be estimated by an adjustment procedure.

Only existing trip data were required for model development; thus future availability of the data was not a consideration in the review of this data.

Market Factor Data

Population, number of households, auto ownership, income, employment density and land use data were available from a number of sources including traffic zone (which were subsets of U.S. Census Zones) data base files developed by NOACA and U.S. Census. To be useful in model development, the data had to be for, or reasonably close to the, same year as the trip data.

NOACA data were for 1975 while Census data were for 1970. Census data were considered too out of date to use.

The NOACA population, number of households, income and car ownership data were estimates of 1975 conditions developed by updating Census, travel survey and land use survey data files. Updating had been done through a combination of trends from the base year of the survey data and some limited inventories from secondary sources. Hence, although the updating had been controlled to minimize errors, it was still subject to problems of estimation accuracy. Even with these potential difficulties it was the best source of market data.

A more detailed review indicated that the number of households appeared to be a more reliable estimate than population. For this reason, households were used as the measure of "home" market size in the route service area.

Income and auto ownership data were found to be strongly correlated. The auto ownership estimates had been developed from income and household size relationships. Therefore, to include both income and auto ownership in this situation would have been statistically incorrect. For this reason, the analysis was limited to only one socio-economic indicator, average household income for the traffic zone. Both income and number of households would be available on a continuing basis from Census and NOACA.

Further, because both the source households and income data were aggregate level estimates (i.e. totals for the U.S. Census Zones), it was not possible to use a disaggregate approach for model development, i.e., data were not available for various population subgroups within each Census Zone.

Review of trip attraction data revealed a number of potential problems. Explicit estimates of employment by location of employment were not available. The only data were traffic zone level (which are subdivisions of Census Zones) estimates of land use area by type and employment density that were estimated using regional travel models. Traffic zone employment therefore had to be estimated by multiplying land use area by employment density.

Land use area data were surface acreage and the data did not specify whether this was gross (total parcel) or net (building) acreage. The broad land use categories were not wholly compatible with trip purpose categories, making it difficult to match land use type to trip purpose. The aggregate form of the traffic zone land use area and employment density data was also not consistent with the need for employment data for smaller areas within the traffic zones corresponding to a bus route service coverage area, since there were often two or more bus route zones contained within a single traffic zone.

This data, however, was the only source of information which could be used as a measure of trip attraction and would also be available for application of the models in future years. Because of the measurement and classification problems, a decision was made to use a single total employment estimate.

Transit Service Data

Data describing route service characteristics could be completely and easily developed from GCRTA's public time tables and driver run sheets. This information included type of service, route alignment, service frequency and travel time between check points along the route. Information was complete, detailed and accurate and did not place any limitation on the model development.

Ridership Count Data

One day on-off counts for each run and quarterly ridership data by route were available. This provided a source of information for use in calibration to check the accuracy of the model estimates of ridership.

Implications for Model Development

Findings from review of the available data resulted in the following implications for model development.

- All socio-economic and demographic data were at an aggregate (U.S. Census Tract) level and could not be broken down into disaggregated (population subgroups) groupings. This precluded use of a disaggregate approach for model development.
- Number of households was the easiest and most reliable factor in measuring the size of the population market within a route service area. This required that trip generation i.e. the point of trip origin (generally riders' homes) had to be based on a household rather than a person rate. However, the use of households does not permit the model to account for any future changes in household size and household trip rate.
- Average income was the only available independent measure of household socio-economic factors. Income data was not available for sub-groups within each area.
- Trip attraction, (i.e. places to which riders are going from their homes) measures were limited to broad traffic zone level estimates of employment. Because of classification problems and broad measures used for these estimates, only total employment could be used. This precluded any stratification by employment type as part of the model structure. Further, because the data was based on total zone averages, estimates of employment within route coverage areas could not be accurately estimated.
- Data describing transit service was comprehensive and complete, and allowed the model to be structured by type of service. All service related factors could be considered in structuring the model.

Thus, trip attraction analysis and model structure were limited to relationships based on total employment. This limitation was further compounded by the weakness of a potential inaccuracy of small area estimates of employment. It can be concluded that this limitation would produce a model more accurate at the route level than bus route segment level.

DESCRIPTION OF PROCEDURE

The first task in the actual development of the model was to assemble, prepare and analyze the data base. The data base included only data items found to be usable in the review of existing data. Preparation of the data base was necessary because data were from several different sources and had to be transformed and combined into the route level data sets. A detailed analysis was undertaken to identify the type and strength of the relationship between the observed transit trips and the market and transit service variables. Findings from this analysis were the basis for formulating the initial model structure.

Data Base Preparation

The data base was organized by transit route and prepared for a total sample of 20 routes representative of each type of service: local radial, express radial, crosstown and feeder. For each route, data was further broken down by route segment. Route segment was a subdivision of the route that had been defined for the on-board survey. Since the survey trip origins and destinations had been coded by route segment, this was the lowest possible level of disaggregation.

The data prepared at the route segment level included:

- number of households in the route segment service area;
- estimated employment in the route segment service area;
- peak and off-peak service frequency;
- number of trips boarding and number of boarding trips by trip purpose;

- total number of trips alighting and number of alighting trips by trip purpose;
- peak and off-peak on-board running time between segments;
- number of board and alighting trips in the peak and off-peak;
- average household income in the route segment service area;
- route segment-to-segment transit trip volumes;
- number of transfers by segment in which the transfer occurred;
- number of transfers by segment of initial boardings; and
- boarding segment to transfer segment trip volumes.

Data preparation involved a number of comparisons and adjustments to the data. These included the following:

1. Survey and On-Off Counts Comparison
A comparison between route segment boardings from the on-board survey and the on-off counts showed a wide discrepancy between the two sources for number of people boarding. Analysis indicated the on-board survey estimate to be incorrect at the route segment level because of the method used to expand the samples to a universe estimate. A single average response rate route expansion factor had been used that did not account for the variation in response rate at the route segment level. This was the cause of the over and under estimation of survey trips at the route segment level. Survey trips were adjusted based on the on-off counts to correct this problem.

2. Home-Based Trip Adjustments
The on-board survey obtained trip information in one direction of travel and did not record which end of the trip was the home location of the trip maker. This required the trip data to be converted into a home based definition so that the trip data could be matched to the service area and attraction characteristics. Adjustments were based on the time of trip and the purpose from - purpose to data recorded for the trip.

3. Service Area Adjustments
An analysis of access distance reported in the on-board survey indicated that almost all trip boardings were from locations within 1/4 mile of the bus route. This distance was used to define the width of the route segment service area. For each route segment, the number of households and employment within a quarter mile of the route were estimated by proportioning traffic zone total households and employment. Proportioning was based on the traffic zone area within a quarter mile of the bus route to the total area of the traffic zone. Uniform household and employment density within a traffic zone had to be assumed as

detailed information could not be developed from the existing secondary sources. The only exception was the CBD segment where total CBD employment was used.

The use of uniform density for households proved to be an adequate approximation. In the later model development, the use of uniform employment density was found to present difficulties in the model structure. Employment land use tends to cluster and uniform density can result in an over or understatement of actual employment within the quarter mile distance from the bus route.

Average income for households in the route segment market area was the average income for the traffic zone. Where portions of two or more traffic zones were included in a route segment service area, a weighted average of the traffic zone incomes was used.

Segment to segment in-vehicle travel times were estimated from the public timetables and driver run sheets. Travel time was defined as being between the midpoints of the segments. Average peak and off-peak period headways were calculated from the route schedules and were assigned to each route segment.

Analysis of Data

The analysis was organized around different components of the transit trip. These were trip generation (places where riders originate their trips), trip attraction (places to which trips are made), and transferring. For each of these components, the initial analysis hypothesis was that the predictive relationships would be different by type of transit service.

One method used for analysis was cross classification tabulation, which entails the determination of a frequency distribution for subgroups of the data. Another technique used was regression analysis, which is a statistical technique that develops an equation that relates a dependent variable to one or more independent (predictor) variables. Data was often graphically displayed to illustrate the correlations that existed between variables.

Trip Generation - The variables which were investigated included trip purpose, income, quality of transit service measured by service frequency and several indices representing the opportunity to make transit trips in the route service area. Trip purpose was quickly eliminated as a variable. Stratification by purpose of the relatively small number of total trip origins in a route segment resulted in data of questionable statistical validity. As a result of this observation, a decision was made to limit the model to a single definition of all purpose home-based trips.

Non-home based trips (those not originating from a person's home) were eliminated because of the difficulty in relating trips to rational predictive factors. These were small in number and represented a fairly constant percentage (about 10%) of total route trips. It was decided that these could be estimated by applying a factor to home-based trips estimated by the model.

A further analysis of the home-based trip data indicated a wide variation in the trip rate for school trips. Variation appeared related more to the public school busing policy than to measurable characteristic factors, i.e. some school systems provide pupil transportation, others do not. For this reason, routes on which a high percentage of the total trips made were to school were eliminated from the model calibration. Thus, the model developed does not account for school trips. On routes where school trips are a significant proportion of the total, the analyst must first estimate non-school trips using the model and then obtain an estimate of school trips from the local school district and add this to the total.

Trip generation, as expected, did vary with income level. In general, regression analysis indicated fairly strong income-trip generation relationships for all service types. For most service types, statistically significant different trip rates were found for different income levels. Another observation was that because of the use of average zonal income, the distribution of zone income levels was not continuous and uniform, but tended to cluster, i.e. although a zone might contain several neighborhoods with widely varying income levels, an average income figure would be calculated that would not really be representative of the different subgroups in the zone. As a result of this finding it was concluded that income should be treated as a stratification rather than as a continuous variable in the model.

Several forms of trip frequency were investigated. These included only A.M. peak frequency and various weighted combinations of A.M. peak and off-peak headways. As expected, strong statistical relationships were found. However, this raised the issue of whether headways are adjusted to demand or does demand respond to service frequency changes. Despite this problem, it was felt service frequency should be included in the model structure.

The trip frequency measure which produced the strongest statistical relationships for all service types except express service was a weighted linear of combination of A.M. peak and off-peak headways with a weight of 0.67 for peak and 0.33 for off-peak. Most express service operated only in peak periods (off peak service was either not provided or provided as local service) and the A.M. peak headway was used for this service. The weight had been developed from a time of day analysis of transit trips. System-wide ratios of A.M. peak to base travel were approximately 2 to 1, and with minor variations this ratio held for each service type (except express service).

Comparison of the trip rate-frequency relationships among service types showed this to be significantly different. This further confirmed the need to structure the models by service type.

Measures of trip opportunity investigated included total work attractions in the route service area and several accessibility indices based on work attractions in individual segments and travel time from the home segment to the attraction segment. No strong relationships were found in both the statistical and graphic analysis of these factors and trip generation rates. This finding appeared intuitively incorrect and may have occurred because of measurement errors in the employment estimates used. Nevertheless, use of a trip potential factor was dropped as a consideration for the model structure.

Trip Attraction - This analysis was undertaken to determine if the number of transit trips to an existing route segment and to new segments resulting from a route extension could be directly estimated from market factors in that segment. Because only total employment was available as a possible measure, this was a limited analysis. Correlation analysis and graphic analysis of total estimated route segment employment and total trips produced no discernible relationships. As a consequence, direct generation of transit trip attractions in a route segment was dropped from further consideration.

Trip Distribution - This analysis proved to be more promising. The initial analysis investigated travel time trip length distributions from the trip origin route to destination segments along the route segment. Several travel time measures were investigated and the strongest relationships were found for a measure which combined running time and headways. All service types exhibited the same basic relationship. A direct relationship between percent of ridership and time/headway measures existed throughout most of the function - with the curve first rising gradually, then more sharply. For the higher time/headway measures, an inverse relationship became apparent, as higher measures were associated with gradually decreasing percentages of ridership.

This analysis was then expanded to include a measure of the relative attraction in the destination segments along the route. An expression similar to a gravity model formulation was analyzed. This expression estimated the proportion of trips from an origin segment to a destination segment and was of the form:

$$P_{ij} = \frac{A_j \; t_i}{\text{Sum } A_k \; t_{ik}}$$

where: P_{ij} = proportion of trips which originate in segment i which are destinated to segment j

A_j = measure of employment in segment j

t_{ij} = measure of travel time from origin segment i to destination segment j (minutes)

$A_{ki} \; t_{ik}$ = as defined above but for each destination segment in the route service area.

Relationships appeared reasonably strong, and based on this, a decision was made to pursue a similar approach for the model structure.

Transfers - Investigation of trip transfer relationships was carried out for crosstown and feeder services for bus to bus and bus to rail transfers. A preliminary analysis of the on-board trip survey data indicated that transfers from local radial and express to crosstown for a trip originating at the trip makers home were minimal. This result was not unexpected since data for local and radial lines represented only one way travel in the direction of the CBD, and the CBD is the destination of the largest number of transit riders. Persons transferring to a crosstown route would have a destination other than the CBD.

GCRTA feeder bus service is designed specifically to support the light and heavy rail rapid transit lines. Routes tend to be short and all end at a rapid transit station. Most riders boarding the route transfer to the rapid transit service. Analysis of the percentage of total riders who transferred to the rail service indicated that as the length of the feeder route increased, the percentage of riders who transferred decreased. This suggested that: 1) feeder service transferring was related to travel time from the rail service; and 2) that as the feeder route increased in length the route also tended to function as a local service.

Crosstown service and non-radial service which did not terminate at a rail station, also offered an opportunity to transfer to the rapid transit service. Since not all crosstown routes had rail station connections and the main purpose of these routes was to provide non-radial local service, the rail transfer relationship for crosstown routes were investigated separately from the feeder service. The analysis indicated that, like feeder bus service, the proportion of riders transferring to rail service was related to travel time from the boarding segment to the rail station. However the transferring rate was significantly lower than for the feeder service.

Initially, bus to bus transfers were analyzed separately for feeder and crosstown service. Owing to limitations in the on-board survey data, the bus route transferred to could not be easily identified. Segment to segment travel time relationships, therefore, could not be investigated. However, the number of riders who boarded in a segment and then transferred to another bus and the number of transfers which occurred in a segment could be estimated. Analysis of this information indicated the number of boarding riders in a segment who transferred and the number of transfers which occurred in the segment were almost the same. The percentage of boarding trips in a segment which transferred was also compared to the proximity of intersecting radial routes. This showed that the transferring percentage was very low when there were no intersecting routes in the segment. From this it was inferred that the crosstown or feeder portion of a transferring trip was very short, with both the origin and transfer location in the same segment. This was observed for both feeder and crosstown lines.

Using the simplification that all riders who transferred in a segment originated in that segment, an investigation of possible relationships to predict the amount of transfer activity was undertaken. The only variables available were the service frequency on the crosstown or feeder service and the intersecting radial service. Several combinations of the crossing route frequencies in the segment were investigated. The strongest relationships were found between percent of crosstown or feeder trips originating in the segment which transferred to bus and a linear combination of the headways of the crosstown or feeder service and the intersecting radial service. The general relationship was that the rate of transferring increased as the combined value of the headways decreased. No significant difference was found in the relationships for crosstown and feeder bus.

As a result of this analysis, it was concluded that the model structure should explicitly address transferring. Further, bus to rail and bus to bus transfers would need to be treated separately. The analysis strongly suggested that crosstown and feeder bus service to rail transfer relationships were significantly different and would require separate model specification. Bus to bus relationships appear to be the same for both crosstown and feeder service and did not appear to warrant separate model specification.

Trip Attractions - Relationships were investigated to estimate increases in transit route ridership for extensions of routes to major attractions and for new major attraction centers along existing routes. The trip generation relationships addressed extensions of routes into new residential areas and increases in existing residential service areas.

A number of factors were investigated. The two factors which resulted in the best relationships were employment and the weighted linear combination of A.M. peak and off-peak headways. The analysis also indicated that the relationship should be based on the transit percentage, rather than the actual number, of total attractions. The effect of the size of the population market which could take transit to the attraction site was investigated. Route length, in minutes, was used as the factor to represent residential market access. Results of this analysis indicated that the transit potential to the new major attraction site appeared to vary with length of route. Short routes served a small residential market area and therefore could provide fewer trips to the major attraction than a longer route which served a larger residential market area.

Overall, very strong relationships were not found for transit trip potential of new generators. Nevertheless, it appeared that usable predictive relationships could be developed which would address GCRTA's route extension planning specification.

DESCRIPTION OF MODEL

This section describes the formulation of the initial model structure, which was based upon an analysis of the relevant variables; the calibration analysis performed, which determined the functional relationships for the model; and a description of the model validation process, which tests the accuracy of the calibrated equations.

Formulate Initial Model Structure

It was concluded that the model structure would best be approached as a series of models rather than as a single model. The analysis indicated that transit route ridership patterns were a function of service type, transfer conditions, service frequency, trip maker characteristics, size of the residential (trip origin) market and the transit time distribution of trip attraction opportunities. A single model that took all these factors into account would have resulted in a complex model structure. Such a model structure would be difficult to calibrate, and more importantly, difficult to use. Also, since most applications would be for an individual route of a specific service type, it would be most appropriate to tailor different model structures to the different route types.

Two general types of models were developed. One was for analysis of bus routes, while the other was for assessing transit activity centers. This approach was desirable because transit use is a function of: 1) the type and availability of service; and 2) places that will generate the demand for transportation service. A third model type, the Headway Elasticity Model, was developed as an alternative to the bus route models for use when the only modification is a change in service frequency.

A. Bus Route Models - The proposed model structure contained two features:

- separate models for each type of service;
- use of a chain model approach for each service type model.

The chain model approach would address trip generation, transferring, and segment to segment distribution of transit trips as a sequence of individual models. This is similar to the trip generation, trip distribution, mode split and assignment model sequence commonly used for regional planning. The advantage of the chain model approach is that the model could be broken down into less complex components which would simplify both calibration and application.

A three-step chain model structure for each service type was proposed (Figure 2).

1. Trip generation model to estimate one-way home-based ridership originating in a route segment.
2. Transfer model to estimate the number of trip transfers for feeder and crosstown service. Two submodels are used;

   a. Bus to rail transfer model to estimate the number of trips generated in a segment that transfer to rapid transit and the segment to segment bus volumes;

   b. Bus to bus transfer model to estimate the number of trips generated in each segment that transfer to an intersecting bus route;
3. A trip distribution model to estimate the segment to segment volumes for non-transfer trips generated in each origin segment.

The structure is based on one-way trip movement for total home-based trips, since the trip origin is the home location of the trip maker. A procedure was needed to estimate the return trip, since the on-board survey did not provide information to determine the relationship between a home to non-home trip and a return non-home to home trip. A relationship was derived from a 1963 home interview survey transit trip data. This data indicated

Figure 2

Service Type Model

- Trip Generation Model

  Home Base Trip Origin/Household = function of income and service frequency

  1.) income is used as a stratification variable (low, medium, high)

  2.) service frequency is a combination of A.M. peak and off-peak headway

- Transfer Model

  1.) Bus to Rail

  Percent of Trip Origins Transferring to Rail = function of in-vehicle travel time from origin segment to the rail station

  2.) Bus to Bus

  Percent of Trip Origins in Segment Transferring to Bus = function of the service frequency on trip origin bus route and service frequency on the bus route transferred to

- Trip Origin Segment to Trip Destination Segment

  Non-Tranfer Trip Route Origin to Destination Segment to Segment Movement = function of in-vehicle travel time between segments, A.M. peak and off-peak headway of service between segments, the employment attractions in the destination segment and the one-way trip origins in the origin segment home to non-home and non-home to home trips between traffic zone pairs were approximately equal; a home to non-home trip almost always generated a return non-home to home trip. Thus it was assumed that total two-way direction home based trip movement along the route could be estimated by combining the home to non-home and non-home to home segment to segment trip tables. This procedure would be applied to trips where both ends of the trip journey were in the route service area and for home based trips which transferred to rail service and to intersecting radial bus routes.

In addition to a return trip procedure, a procedure was also needed to account for non-home based trips. Since non-home based trips had been found to be almost a constant percentage of total transit trips, a simple procedure based on factoring the home based trips was proposed.

B. Activity Center Model - For estimation of transit trips on a route to a new major activity center, a chain model structure was proposed. As with the service type model, the chain model structure was chosen because it would simplify both calibration and use of the model.

An initial three model chain was proposed, as shown in Figure 3.

1. Transit trip potential to the activity center by a route bus.
2. Total transit trips generated to the activity center on the bus route.
3. Trip distribution to estimate the distribution of activity center trips to trip origin route segments.

C. Headway Elasticity Model - The headway elasticity model uses graphs developed for the trip generation model to predict ridership changes resulting from increased or reduced service on a route. Predicting the impact of frequency changes on ridership, based on historic patterns is difficult. Relationships between service frequency and ridership levels have developed

Figure 3

Activity Center Type Model

- Transit Trip Potential

  Potential Percentage of Total Trips to the Activity Center by a Route Bus = function of the employment in the activity center and the bus route A.M. peak and off-peak service frequency to the center

- Total Transit Trips Generated

  Total Transit Trips to the Activity Center on the Bus Route = function of the transit trip potential, the size of the residential market served by the bus route and the length (in-vehicle travel time) of the bus route

- Trip Distribution

  Distribution of Activity Center Transit Trips to Trip Origin Route Segments = function of the number of households in each route segment, the in-vehicle travel time from the origin segment to the activity center and the A.M. peak and off-peak service frequency gradually over time in a circular manner. Riders respond to frequency changes but transit properties also adjust service frequencies to reflect changes in ridership.

Calibration Analysis

The purpose of calibration analysis is to find the relationships which produce the best fit for the data used in the analysis. Validation analysis, the next major step in the model development process, is performed to check the estimation accuracy of the models developed in calibration. The validation analysis described in the following section was done using data which were not included in the data used for calibration.

Procedures used included regression analysis, cross-classification analysis, analysis of graphic data displays and iterative trials. Iterative trial procedures are the type of procedures frequently used for calibration of gravity trip distribution models. They were employed for calibration by adjusting the exponent to fit the data of the observed distributions, i.e. a curve had been developed from actual data and different exponents were used in the equation until a close approximation of this curve was achieved.

The hypothesis used in calibration was that the models would be different for each service type. Therefore, models for each service type were initially addressed separately. Data for calibration were the observation sets prepared in an earlier step for the sampled routes selected for calibration. These data observations were separated into four data sets corresponding to the four types of bus service.

Calibration analysis was conducted in parallel for the corresponding models in the model chain. That is, the trip generation models for each service type were analyzed simultaneously, then the transfer models and finally the trip distribution models.

Then, the calibration analysis of the separate service type models were compared. Models of the same type (trip generation, trip distribution, transfer) for different service types and for different stratifications within a service type (low, medium and high income) were combined into a single model when either the individual service type models were not statistically different from each other or when the data was "too thin" to statistically support separate models.

A. Service Type Models

1. Trip Generation Models - Three average household income level stratifications were defined: low - under $10,000; middle - between $10,000 and $14,000; and high - over $14,000. Separate income level models based on trips per household versus service frequency for each service type were analyzed. The basic analysis indicated a non-linear relationship between trip rate and service frequency measures.

As shown in Figure 4, five trip rate generation equations were calibrated. Separate models were developed for low-income and middle-income radial local service. For crosstown and feeder service, a single model was calibrated for both the low and middle income levels. A single trip generation model for the high income level was developed for local radial, crosstown and feeder service, because there was a limited number of observations in high income zones. With the small number of observations, it was not possible to calibrate models for each service type which were statistically reliable. Only a single model could be specified for express

Figure 4

Trip Rate Generation Equations

Local Radial Routes

Low-Income

$$TGR = .440\ e^{-.002(CH^2)} \qquad R^2 = .619$$

(t= 5.55)

Middle-Income

$$TGR = .586\ e^{-.0034\ (CH^2)} \qquad R^2 = .826$$

(t = 6.88)

Local Radial, Crosstown and Feeder Routes

High Income

$$TGR = .101e^{-.004(CH^2)} \qquad R^2 = .355$$

(t = 2.14)

Crosstown and Feeder Routes

Low and Middle Income

$$TGR = .624 - .17\ (\mathrm{Ln}\ CH) \qquad R^2 = .498$$

(t = 4.88)

Express Routes

$$TGR = .311\ e^{-.0013\ (PH^2)} \qquad R^2 = .572$$

where:

TGR = number of home-based trips generated per household
CH = (.67 PH) + (.33 OPH)
PH = peak headway
OPH = off-peak headway

service. Express service was provided only in middle and high income areas, thereby limiting the model to middle and high income user markets. This model, therefore cannot be used in low income areas. Such desired applications would be infrequent, though, since express service is generally provided to suburban communities inhabited by middle and high income households.

2. Trip Distribution Models - Separate trip distribution models for each service type were considered. While the preferred approach would have been to develop separate equations for each service type and income, as was done for the trip generation model, the number of data observations were not enough to provide a statistically stable base at that detail of analysis. Thus one functional form was hand fit for all service types. This was as shown in Figure 5.

3. Transfer Models

a. Bus-to-Bus Transfer Models - Separate bus-to-bus transfer models were investigated for feeder and crosstown service. No significant difference was found in the models for each type of service. Therefore, as shown in Figure 6, a single model was calibrated which applied to both feeder and crosstown service.

b. Bus-to-Rail Transfer Models - Two separate equations were calibrated for feeder to rail and crosstown to rail transferring. As shown in Figure 7, while one functional form is used in both equations, each equation had different constants and coefficients. When a segment is less than 4 minutes travel time from the station, it is assumed that rail-bound passengers can reach the station by walking. Therefore, no transfers are assigned. For feeder routes travel time from the origin segment to the rail station is constrained to 50 minutes; for crosstown routes a 28 minute con-

Figure 5

Trip Distribution Equations

$$PTij = \frac{Empj / TIij}{Sum(Emp_j / TI_{ij})}$$

$$TI_{ij} = (TT_{ij} + CH_{ij})1.8$$

where:

PTij = Proportion of home-based riders boarding in segment i who alight in segment j

Emp_j = Employment accessible to bus route in segment j

TI_{ij} = Travel Impedance between segments i and j

Sum(Empj / TIij) = Sum of Employment / Travel impedance for all segments (j) accessible by the bus route from (i)

TT_{ij} = Travel Time between segment i and j by transit

CHij = Combined Headway (minutes) along the route between segments i and j (if combined headways in i and j differ, CHij equals the larger of the two combined headways

Figure 6

Bus-to-Bus Transfer Model

$$PT_{ab} = .498 - .1242\,[\log\,(CHa + CHb)]^{*} \qquad R^{2} = .55$$

$$(t = 4.68)$$

where:

PT_{ab} = percentage of passengers on crosstown bus route "a" transferring to radial bus route "b"

CH_{a} = combined headway (minutes) for crosstown route "a"

CH_{b} = combined headway (minutes) for radial bus route "b"

* $(CH_{a} + CH_{b})$ must be less than 55. If greater than 55, transfer rate = 0.

Figure 7

Rail/Light Rail Transfer Equations

Feeder Routes

$$PT_{ij} = 98.6 - 1.97\ RD_{ij} \qquad R^2 = .64$$

$$(t = 5.18)$$

For Feeder Routes, RD_{ij} must be between 4 and 50.

Crosstown Routes

$$PT_{ij} = 33.6 - 1.20\ RDij \qquad R^2 = .49$$

$$(t = 3.81)$$

For Crosstown Routes, RD_{ij} must be between 4 and 28.

PT_{ij} = percentage of riders boarding in segment i who transfer at rail station j

RD_{ij} = travel time in minutes between segment i and rail station j straint is imposed. These constraints are based upon the limitations of the data used to develop the model.

B. New Activity Center Model - A single model was calibrated for all service types, as shown in Figure 8. Because the constant is negative, a value of less than zero can be obtained for the market rate. If this occurs a default of zero is used and it is assumed that no new trips are attracted. The adjustment factor is used to modify the estimate based on the length of the route. If the route is very short, then a higher percentage of accessible households will be close to the new segment. If the route is long, more of the households will be farther away. Thus a new segment at the end of a short route with 5000 households in the market area will attract more trips than a segment with the same employment and number of accessible households at the end of a long route. The adjustment factors were developed from trip length distribution data.

Problems were experienced in using the available employment data to calibrate this model. Some comparisons were made between the traffic zone employment data and other data which were available on major employment centers. In a number of cases, the traffic zone employment data clearly underestimated or overestimated employment in the traffic zone. The further division of traffic zone employment data to the bus segment level increased the potential error. The R^2 of this model (.50) indicates a data fit equal to or better than some of the other models. Because of inaccurate input data, however, this model can only be relied upon for a very rough estimate of new ridership.

C. Headway Elasticity Model - The model is not actually calibrated. Rather the ridership procedure entails use of any one of Figures 9 to 13. As a

Figure 8

Activity Center Service Extension Model

$$RR^{*}_{ai} = -.0238 + .0094 \text{ Ln}(Emp_i) - .0104 \text{ Ln}(CH_i)$$

$$(t = 5.50) \qquad (t = 3.54) \qquad R^2 = .50$$

$$NR_{ai} = (RR_{ai}) (HH_i) (F_a)$$

where:

RR_{ai} = percentage of potential market along route "a" attracted to new route segment i

Emp_i = employment accessible to transit in segment i

CH_i = combined headway of service to route segment i

NR_{ai} = number of new transit riders in market area of route "a" attracted to new route segment i

HH_i = number of households in transit market area of route "a"

F_a = route length adjustment factor

* If RR_{ai} is zero or less, new ridership to segment is zero.

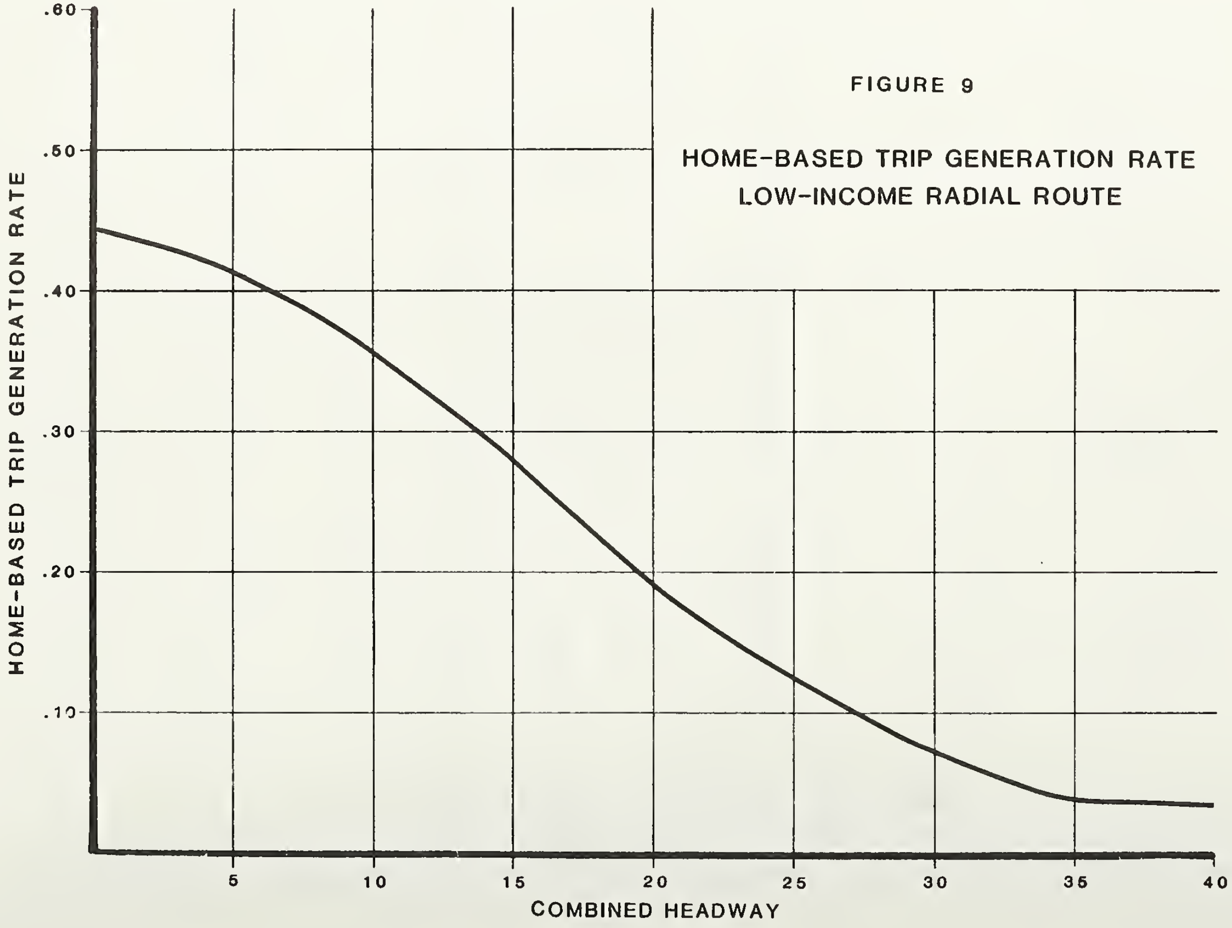


FIGURE 9

HOME-BASED TRIP GENERATION RATE
LOW-INCOME RADIAL ROUTE

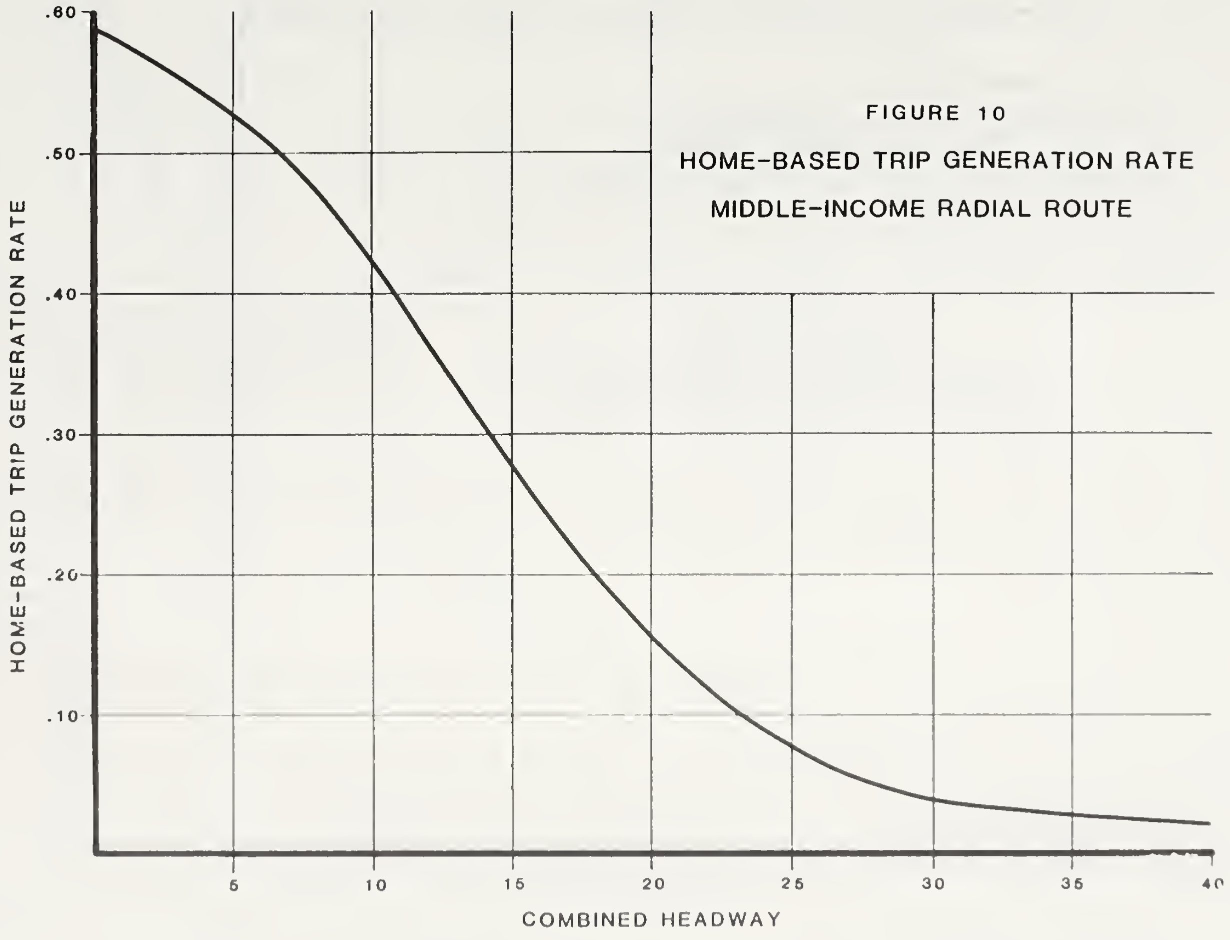


FIGURE 10

HOME-BASED TRIP GENERATION RATE

MIDDLE-INCOME RADIAL ROUTE

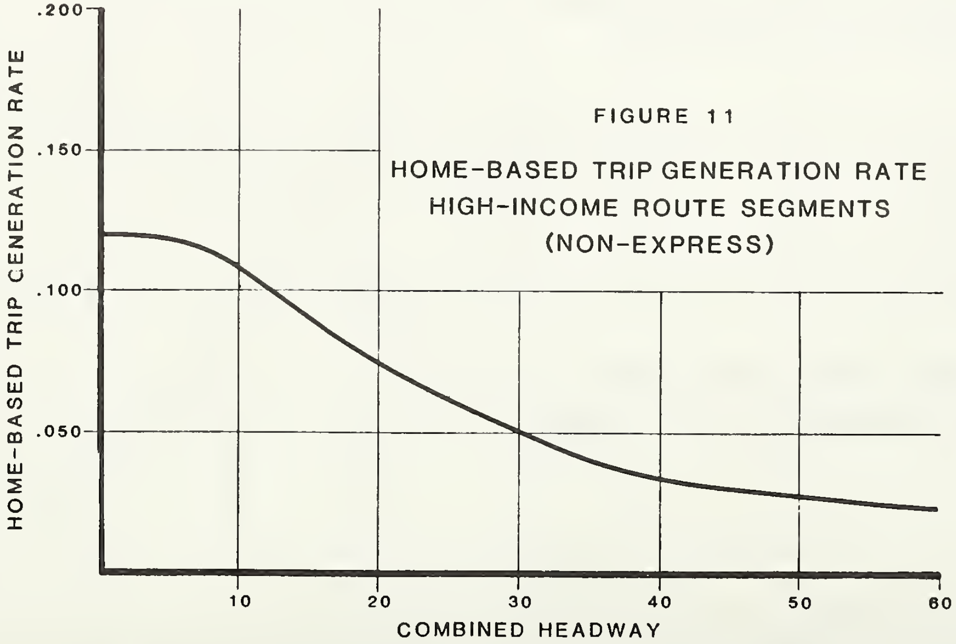


FIGURE 11

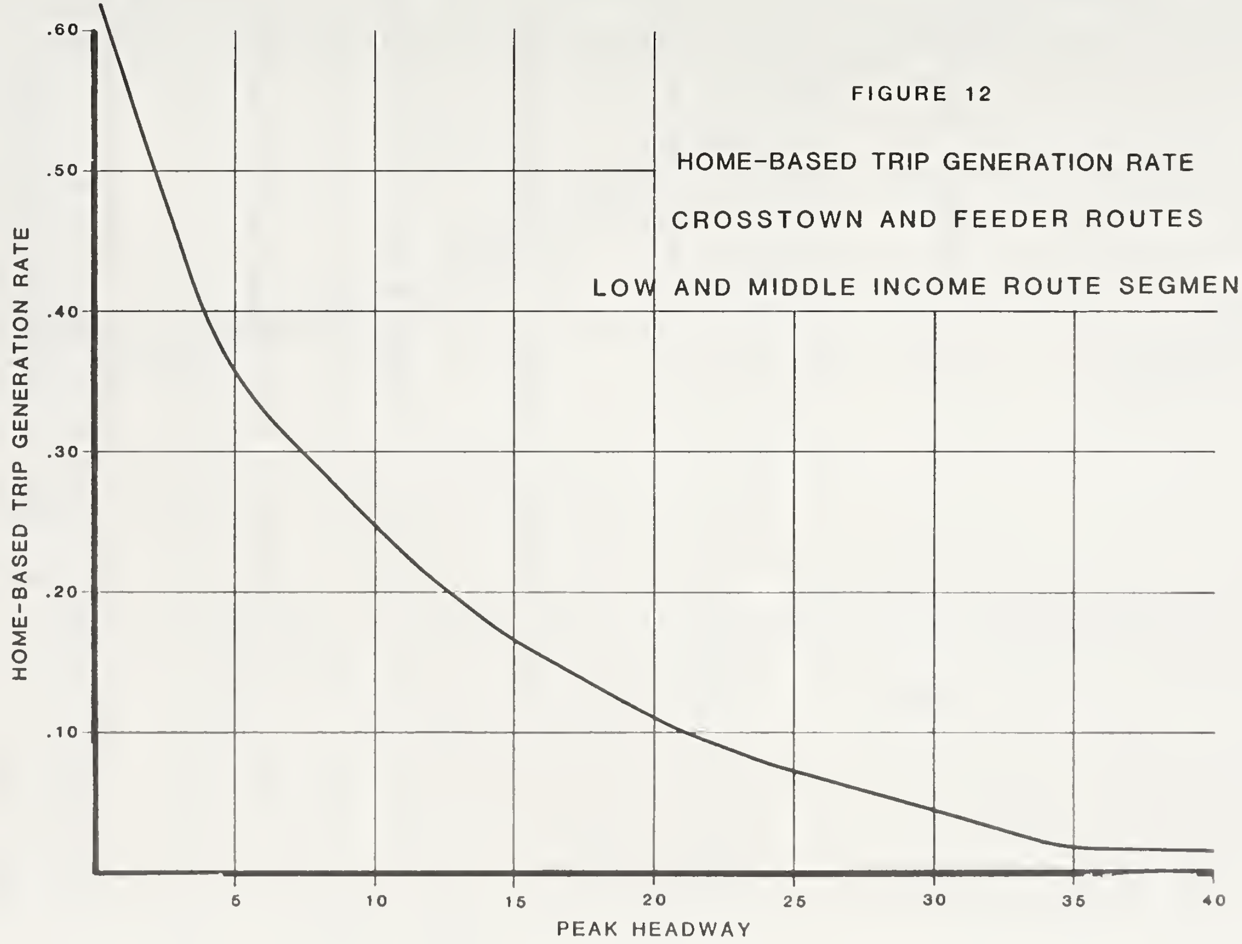
HOME-BASED TRIP GENERATION RATE
HIGH-INCOME ROUTE SEGMENTS
(NON-EXPRESS)

FIGURE 12

HOME-BASED TRIP GENERATION RATE

CROSSTOWN AND FEEDER ROUTES

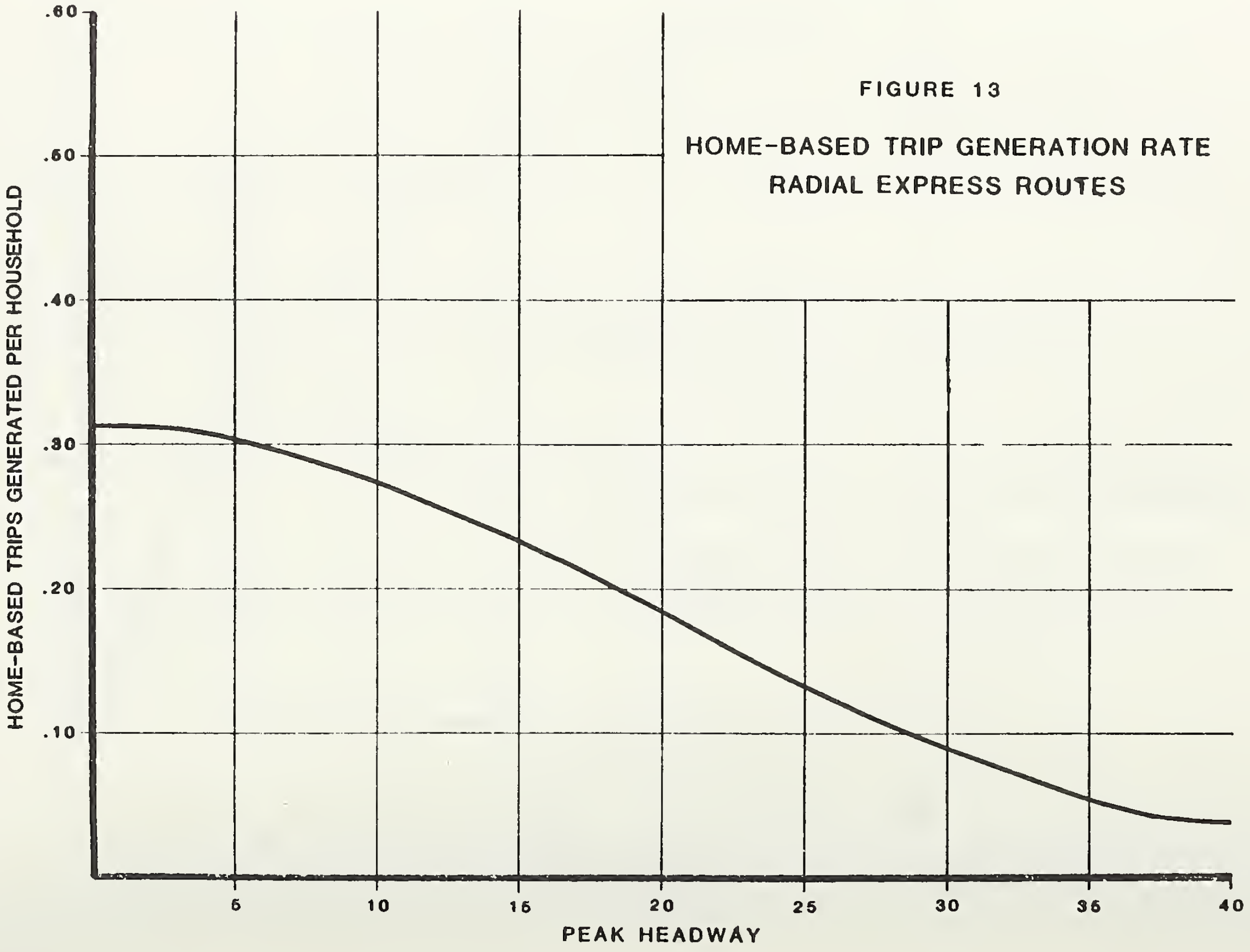
LOW AND MIDDLE INCOME ROUTE SEGMENTS



SG Associates, Inc

FIGURE 13

HOME-BASED TRIP GENERATION RATE
RADIAL EXPRESS ROUTES



change in headway is implemented, movement along the "x" axis will result in new home-based trip per household rate on the "y" axis.

The model was programmed to run on the TI-59 calculator. Peak and off-peak headways are entered along with the current level of ridership. The program converts these headways into a combined headway and determines the trip rate on the appropriate frequency elasticity curve. The trip rate is then divided into the current ridership to obtain the number of households in the market area. The new peak and off-peak headways are entered and a new combined headway is calculated. A new trip rate is found along the curve and multiplied by the number of households to obtain the new level of ridership.

Integration of Models for Ridership Estimation

For most bus routes, route level analysis of the impacts of service changes on ridership will entail use of the trip generation, trip distribution and transfer models as a chain. The integration of these components produces the generalized service type patronage estimation model.

Use of the trip generation model produces bus route ridership by segment that originates along the route. However, since many bus routes have at least one transfer point, the transfer model is also often used to estimate the number of riders who begin their trips from points along other bus routes. Transfer totals are added to home-based trips to produce an estimate of one-way boardings.

With the above information total route ridership can be calculated simply by multiplying one-way boardings by two. To obtain segment boardings the trip distribution model is used.

The headway elasticity model is actually a cruder version of the service type model and can be used when only headways are changed. This model would generally be used instead of , rather than in conjunction with, the generalized service type model.

The activity center service extension is also a special application model. It would be used to supplement the service type model, which is not as well structured for use where routes are extended. For example, in a situation where service modification entailed: 1) extension of a route to an industrial park; 2) changing peak headways from 30 to 20 minutes; and 3) reducing travel time between segments by operating a portion of the route as express service, the activity center service extension model would be used for estimation of the first component of service modification and the service type model would be used for the latter two.

CHAPTER 5

ASSESSMENT OF MODEL PERFORMANCE AND POTENTIAL APPLICATIONS

RESULTS OF VALIDATION

Validation of the models was undertaken to "test" the accuracy of the calibrated models. The models were used to estimate the impact of six service changes which were made to existing GCRTA routes. To judge "accuracy", estimates of transit ridership were made and compared to the on-off count data for the routes.

The service changes included typical modifications that are made by GCRTA planners. Two service modifications entailed extension of routes into employment/activity centers, two involved route deviations into employment/activity and residential areas respectively; and two covered service cutbacks, one involving a truncation and the other entailing reduced frequency of service.

For two routes, Garfield (extension into employment/activity center) and Snow-Rockside (reduced service frequency), the model produces estimates well within the desired error range of+-10% (Figure 14). For two routes, State Express (deviation to residential area) and E. 250 - Richmond (truncation), the percent error of the estimates fall just outside of the target range. For the other two routes, Clifton-Wooster (extension into employment/activity center) and Northfield-Aurora (deviation into employment/activity center), the model produces a substantial overestimate of patronage.

For two of the routes tested, model estimates had percentage errors in the 12%-13% range. These estimates thus fall just outside the desired

Figure 14

Results of Validation Tests

Rte	Service Change	Base Ridership	Model Prediction After Service Change	Actual Ridership	% Error
20A-21x State Exp	Deviation of route to residential area	1854	6268	5565	+12.6%
94 E.250-Richmond	Route truncation	767	122	139	-12.2%
55s Clifton - Wooster	Extension of express route to employment/activity center	1894	2614	1649	+58.5%
29 Garfield Exp	Extension of radial route to employment/activity center	924	1378	1285	+7.2%
24 Northfield - Aurora	Deviation of crosstown/feeder route to employment/activity center	1272	1741	1197	+45.4%
44 Snow-Rockside	Eliminate off-peak service and change peak headway on crosstown/feeder route	728	254	247	+2.8%

accuracy of 10%. One of these two routes (94-E.250/Richmond) was a low ridership route and thus the estimation error of 12.2% translated to only 17 riders per day.

For the two routes for which the model significantly overestimated ridership, it would appear that non-service related influences dominated the impacts of service changes. Examination of patronage indicates downward trends on both routes, even after the service improvements were implemented. The indication is that the 1981-1982 recession reduced the number of attraction trips to employment/activity centers. Thus, the model, calibrated on base employment figures (1980), overestimated the impacts of the service improvements.

SHORTCOMINGS AND POTENTIAL MODEL IMPROVEMENTS

The validation tests tend to support the model's effectiveness as a short range tool for estimation of the impact of service modifications on total route ridership. Given a number of model structural and resource development improvements, a wider range of application and lower degree of error in estimates can be achieved. These improvements are summarized below.

Stuctural Model Improvements

- Data were not available for examining the impact of fare changes. The most recent increase occurred during the project. A fare elasticity component would increase potential usefulness of the overall model.

- The trip generation model could be improved by separating transit and non-transit trip-making households and applying a trip rate to transit trip-making households. Characteristics distinguishing the two types of households (income, auto ownership), would be identified. This would be an improvement over the use of aggregate zonal incomes or auto ownership rates, particularly in zones where incomes and/or auto ownership rates vary widely.

- Another model refinement involves the introduction of trip purpose and peak/off-peak ridership analysis into the model. Better relationships are needed between types of employment and trip generation rates. Trip purposes also vary between peak and off-peak periods. Improved employment data is required to better establish these relationships. These improvements would make the model more sensitive to changes in employment along a route and to changes resulting from service modifications at different times of day.

- Reliability of service is another variable which could enhance the model. Consistent reliability problems along a route or route segment will impact the level of ridership over time. A separate study of reliability over the system would be required as input to this effort.

- Passenger response to changes in service or socio-economic conditions will take place over a period of time. This "time lag" factor could not be established in this model development effort, but can be important, particularly in estimating revenue impacts. As changes are implemented in the system, response over time should be measured.

Model Development Resource Improvements

- Greater consistency in input data is needed. The use of different year base data (1976 and 1980) was undoubtedly a source of variability in model estimates. This is particularly true for an area such as Cleveland, which has experienced significant economic structural changes during the past several years.

- A higher level of accuracy in data collection is needed at the bus route segment level, including households, employment and income. Because transit market areas cut across the boundaries of traditional analysis units such as traffic zones and Census Tracts, a method for disaggregating household and employment data to small units is needed. Inaccuracy in measurement primarily involved assignment of data to the wrong segment, rather than failure to include the data anywhere along the route. Thus, these errors did not affect total route ridership model estimates, but resulted in a high level of error at the route segment level.

Continuous Model Refinement

- The model developed is based on a point-in-time and the relationships established will only hold for a short time span (estimated maximum of five years, but probably less in a dynamic economy). Thus monitoring of changing socio-economic conditions will be required to adjust the model parameters as behavioral responses change.
- Changing ridership patterns over time will also require adjustment of frequency elasticity relationships. Changes in real income, for example, may require a readjustment of income categories or a refinement of the elasticity curves. Thus changes in ridership, trip rates, service frequency and socio-economic characteristics must be monitored over time.

Applications

- The bus route patronage estimation model can be used in development of marketing strategies. A more detailed description of potential transit markets, however, is needed in order to effectively target areas where potential for increased ridership is greatest.

- The primary use of the model in the short term is to help transit agencies to maximize increasingly scarce resources. Specific services such as park-and-ride service, downtown loop service and late night service could not be analyzed with the available data in this project. Efforts should be directed toward widening the scope of the model to conduct service rationalization studies for the total range of services provided.

APPENDIX A

PROCEDURE FOR MODEL APPLICATION

The usefulness of the model set for short range transit planning is a function of the estimation accuracy of the model and the ease of application. Case examples are presented, which illustrate model components in the chain model series (Appendix B provides a more detailed description and Appendicies C and D illustrate examples based on actual GCRTA routes).

Procedures are presented for the following applications:

- Estimation of radial route patronage;
- Estimation of crosstown or feeder route patronage;
- Use of activity center extension model; and
- Use of a headway elasticity model.

PROCEDURE FOR ESTIMATION OF RADIAL ROUTE PATRONAGE

A seven step process is involved in estimating radial route patronage. Figure A1 lists these steps and Figure A2 presents the data required for the procedure.

Step 1 - Divide Route into Segments

The route is divided into logical segments based on major intersections and transfer points. There should be consistency in assigning intersection segment divisions to the lower of the two adjacent segments for all routes.

Step 2 - Determine the Market Area for Each Route Segment

For determining route segment market areas, NOACA Socio-econonic data, or U.S. Census data at the block or tract level can be used. The market area for the bus route is defined as the area within 1/4 mile from the route.

Figure A1

Radial Route Patronage Estimation Procedure

Steps for Use of Model

1 - Divide Route into Segments

2 - Determine Market Area for Route Segments

3 - Determine Mean Income for Route Segment Market Areas

4 - Determine Home-Based Transit Trip Generation Rate

5 - Calculate Home-Based Transit Trip Generations

6 - Calculate Transfer Trips

7 - Distribute Trips Between Segments

Figure A2

Data Required for Estimation of Radial Route Travel

1 - Route Map with Crossing Routes

2 - Income Data at Traffic Zone or Census Tract Level

3 - USGS or Land Use Maps

4 - Bus Route Travel Times

5 - Land Use and/or Employment Data at Traffic Zone or Census Tract Level

6 - Schedules and Ridership Data for Crossing Routes

Step 3 - Determine Average Income for Route Segments

The income of residents in the bus route market area will affect the rate of transit tripmaking. If data on average income at the traffic zone level is available, the average income for each route segment can be determined.

Step 4 - Determine Home-based Transit Trip Rate

The number of home-based transit trips for each segment of the route is based on the average income of the segment and the frequency of service provided.

Step 5 - Determine the Number of Home-based Trips

For each segment, the trip rate is multiplied by the number of households in the market to obtain the number of home-based trips in each segment.

Step 6 - Determine the Number of Passengers Transferring on to the Route

In calculating transfers, it is assumed that passengers will transfer from crosstown routes to radial routes only, not from a radial to a radial. The number of passengers transferring is a function of (1) the total number of passengers on the crosstown bus at the transfer point and (2) the combined frequencies of the two routes. When a transfer point is located at the intersection of two route segments, the transferring passengers are loaded onto the segment closest to the CBD.

Step 7 - Distribute Trips to Other Segments

We must now determine where the boarding passengers are going. This will enable us to eventually obtain total two-way boardings by route segment. The distribution is a function of the distance between segments, the combined headway on the route and the level of employment in each route segment market area.

PROCEDURE FOR ESTIMATION OF CROSSTOWN OR FEEDER ROUTE PATRONAGE

The technique for crosstown or feeder route ridership estimation is similar to that used for the radial route, with several exceptions (Figures A3 and A4). This description refers to the radial route estimation procedure for those steps which are the same in both procedures.

Step 1

Divide the route into segments. Since the CBD is Segment 1, as explained earlier, and crosstown routes do not go the CBD, the numbering starts with Segment 2. Where segments are in small units (e.g. only a few blocks and resulting in a low ridership figure for the segment, perhaps less than 100 riders), adjacent segments can be combined to permit a more accurate measurement of ridership.

Step 2

Determine the market area for each segment. This involves counting residential units within 1/4 mile of the route, as described in Step 2 of the radial route estimation procedure.

Step 3

Determine average income for route segments. For crosstown routes average income is calculated in a manner similar to that described in Step 3 for radial routes.

Step 4

Determine the home-based transit trip rate. As with radial route estimation, combined headway is the variable used to predict the home-based trip generation rate.

Step 5

Multiply the trip rate by the number of households in the market to obtain the number of home-based transit trips.

Step 6

Distribution of transfer trips is completed before trips are distributed to other segments. First, trips are distributed to rail stations.

Step 7

The next step involves the distribution of bus transfer trips. Each segment generally is bounded by radial bus routes on both sides. Some have crossing radial bus routes within the segment. Generally, the transfer trips are distributed to the nearest bus route. If two bus routes are equally close (as is usually the case) trips are distributed to the one with the most frequent service. Only non rail trips are distributed.

Step 8

The remainder of the trips (non-transfer trips) are distributed to other segments in the same way which non-CBD trips are in the radial route procedure, with use of the trip distribution model. The proportion of employment over travel impedance is calculated for each segment on the route and trips are distributed.

Figure A3

Crosstown/Feeder Route Estimation Procedure

Steps for Use of the Model

1 - Divide Route into Segments
2 - Determine Market Area for Each Segment
3 - Determine Mean Income for Route Segment Market Areas
4 - Calculate Home-Based Trip Generation Rate
5 - Determine Number of Home-Based Transit Trips
6 - Distribute Rail Transfer Trips
7 - Distribute Bus Transfer Trips
8 - Distribute Non-Transfer Trips

Figure A4

Data Required for Estimation of Crosstown/Feeder Route Travel

1 - Route Map with Crossing Routes

2 - Income Data at Traffic Zone or Census Tract Level

3 - USGS or Land Use Maps

4 - Land Use and/or Employment Data at Traffic Zone or Census Level

5 - Running Times Between Bus Route Segments and Rail Stations

6 - Running Times Between Bus Route Segments

7 - Schedules for Intersecting Radial Routes

PROCEDURE FOR USE OF A HEADWAY ELASTICITY MODEL

The headway elasticity model uses the relationships developed between service frequency and ridership rates to predict changes in ridership which will occur with changes in the level of service. Graphs are used to define the relationships between various frequency levels. Movement along the curve resulting from service (headway) changes results in a new estimate of trip rate.

PROCEDURE FOR USE OF AN ACTIVITY CENTER SERVICE EXTENSION MODEL

Because trips are generated on the basis of residential household characteristics (household income and number of transit units), the number of new transit trips generated by an extension into a residential area can easily be estimated. A methodology was needed, however, for estimating new trips generated by the extension of a route into an employment center.

The technique developed is designed primarily for extensions into major activity centers such as shopping malls or industrial parks but can be used for new segments with strip development as well. The model can also be used to evaluate the impact on ridership of major increases in activity along existing portions of the route. This model should only be used where a base route estimate already exists and service is either being extended or major new development occurs along the route. It should not be used on an entirely new route.

The model has been designed for operation on the TI-59 calculator.

APPENDIX B

DETAILED PROCEDURE FOR MODEL APPLICATION

PROCEDURE FOR ESTIMATION OF RADIAL ROUTE PATRONAGE

A seven step process in involved in estimating radial route patronage. Figure B1 lists these steps and Figure B2 presents the data required for the procedure.

Step 1 - Divide Route into Segments

The route is divided into logical segments based on major intersections and transfer points. There should be consistency in assigning intersection segment divisions to the lower of the two adjacent segments for all routes.

Step 2 - Determine the Market Area for Each Route Segment

For determining route segment market areas, NOACA Socio-econonic data, or U.S. Census data at the block or tract level can be used. The market area for the bus route is defined as the area within 1/4 mile from the route. The number of households within the 1/2 mile band centered in the route is determined by the following procedure:

a) Determine the traffic zones which are located within 1/4 mile of each route segment.

b) If some of the zone is within 1/4 mile of the route and some of the zone is not, determine the percentage of the zone which is within the market area.

c) If a zone is partly in one route segment and partly in another, determine the percentage of the zone which is in each segment.

d) Determine the percentage of the zone within each segment by multiplying the two percentages from steps b and c. That is, if 40% of the traffic zone 1 is within the route market area (within 1/4 mile) and 50% of that portion of the zone is within the segment

Figure B1

Radial Route Patronage Estimation Procedure

Steps for Use of Model

1 - Divide Route into Segments

2 - Determine Market Area for Route Segments

3 - Determine Mean Income for Route Segment Market Areas

4 - Determine Home-Based Transit Trip Generation Rate

5 - Calculate Home-Based Transit Trip Generations

6 - Calculate Transfer Trips

7 - Distribute Trips Between Segments

Figure B2

Data Required for Estimation of Radial Route Travel

1 - Route Map with Crossing Routes

2 - Income Data at Traffic Zone or Census Tract Level

3 - USGS or Land Use Maps

4 - Bus Route Travel Times

5 - Land Use and/or Employment Data at Traffic Zone or Census Tract Level

6 - Schedules and Ridership Data for Crossing Routes

A market area, then:

Proportion of traffic zone i
households in market area of = (.5) x (.4) = .2 or 20%
segment A

Figure B3 shows this process graphically.

e) Utilize USGS maps to make sure that the percentage of residences in the route segment market area is accurate. Empty land, industrial land or major barriers such as highways or railroad tracks might require a revision of the percentage derived in step d. This type of problem is illustrated in Figure B4. In zone 1, 25% of the land area consists of industrial land use. Therefore, the division of residential land between the two segments must be modified. 50% of the residential area is within the market area, but due to the location of the industrial park, 75% of that 50% is in segment A, while 25% is in segment B. The calculation is therefore:

segment A = (.75) (.50) = .375 or 37.5% of households in zone i

segment B = (.25) (.50) = .125 or 12.5% of households in zone i

In the case of zone j, 75% of the residential land in the zone is within the market area for segment B. However, 20% of that 75% is located beyond a railroad embankment and is inaccessible to the route. The percent of zone j actually accessible to the route is:

(.80) (.75) = (.60) or 60% of zone j is in the bus route market area.

f) Residential market areas are calculated for all route segments outside of the CBD. The CBD is designated as route segment 1 (which is logical, since radial route ridership is oriented toward the CBD) and residential market areas are not calculated for the CBD area. This is because the CBD has little residential land use and also has its own circulation system, the loop bus.

Step 3 - Determine Average Income for Route Segments

The income of residents in the bus route market area will affect the rate of transit tripmaking. If data on average income at the traffic zone level is available, the average income for each route segment can be determined.

a. Find average income from the tables for each traffic zone.

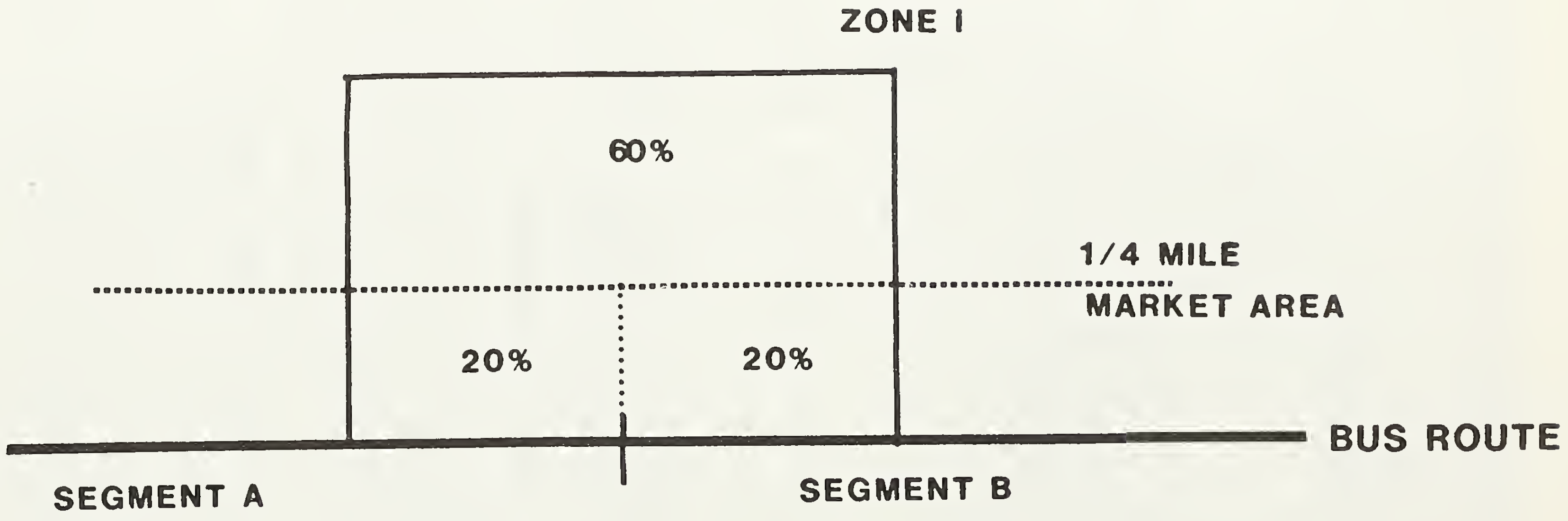


FIGURE B3

TRAFFIC ZONE SEGMENTATION

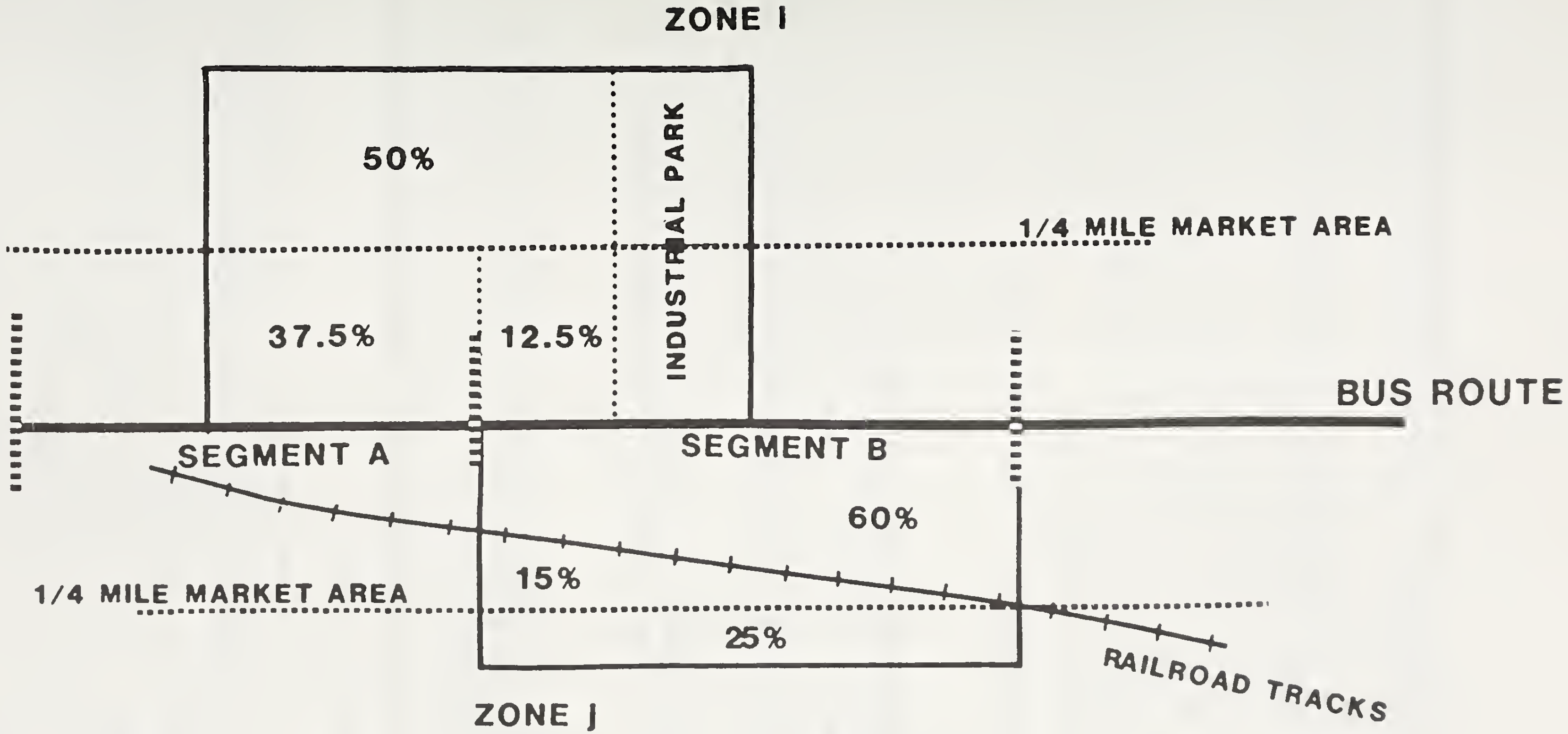


FIGURE B4

PARTITIONING OF ZONAL LAND USES

b. Calculate a weighted average for the segment based on the number of households in each zone.

The formula used is:

$$\frac{(I \times HH)_1 + (I \times HH)_2 + \ldots. + (I \times HH)_N}{HH_{1-N}}$$

where:

I = average income for traffic zone

HH = number of households in zone 1,2,3 ... N

Step 4 - Determine Home-based Transit Trip Rate

The number of home-based transit trips for each segment of the route is based on the average income of the segment and the frequency of service provided.

a. Determine the income category of each segment, based on the following breakdown:

LOW = under $10,000
MIDDLE = $10,000 - $14,000
HIGH = over $14,000

b. Determine the combined peak and off-peak headway for each route segment using the following formula:

Combined Headway = (.67 x peak headway) + (.33 x off-peak headway)

c. Home-based trip generation rates can be obtained in one of three ways. The first method is to use the data cards which have been prepared for the TI-59 calculator. Data cards are available to determine trip generation rates for the following route segment types:

- low-income radial
- middle-income radial

- high-income radial and crosstown
- express route

Instructions for determining the home-based trip rate on the TI-59 are as follows:

1) Use Math and Utilities Module #10
2) Insert appropriate data card in calculator bank No. 3
3) Call Program 14
4) Enter 30 and press key A
5) Enter 10 and press key A'
6) Enter combined headway for segment and press key D

Trip rates can also be calculated with the equations in Figure 4, or estimated from the graphs in Figures 5 to 8 (since the graphic form of the model incorporates adjustment, the graphs are preferable to use of the equation).

Step 5 - Determine the Number of Home-based Trips

For each segment, the trip rate is multiplied by the number of households in the market to obtain the number of home-based trips in each segment.

Step 6 - Determine the Number of Passengers Transferring on to the Route

In calculating transfers, it is assumed that passengers will transfer from crosstown routes to radial routes only, not from a radial to a radial. The number of passengers transferring is a function of (1) the total number of passengers on the crosstown bus at the transfer point and (2) the combined frequencies of the two routes. When a transfer point is located at the intersection of two route segments, the transferring passengers are loaded onto the segment closest to the CBD.

a. Calculate the number of passengers on crosstown route at transfer point.

b. Calculate the combined headway of the radial and crosstown routes as:

$$[(.67 \times PH_R) + (.33 \times OPH_R)] + [(.67 \times PH_C) + (.33 \times OPH_C)]$$

The sum of the combined headways is used with the calibrated equation for transfer rate as follows:

$$\text{Transfer Rate} = 0.498 - [.1242 \times \text{Ln}\ (CH)]$$

By multiplying the resulting transfer rate by the number of passengers on the bus at the transfer point (step a.), the number of transferring passengers is obtained.

c. Transferring passengers are added to home-based boardings for each segment to obtain one-way boardings.

Step 7 - Distribute Trips to Other Segments

We must now determine where the boarding passengers are going. This will enable us to eventually obtain total two-way boardings by route segment. The distribution is a function of the distance between segments, the combined headway on the route and the level of employment in each route segment market area.

a. To determine the distribution of trips along the route, the level of employment in each route segment market area must be determined. For the CBD, the employment figure used is 64,000, which was the figure determined for the 1970 U.S. Census. For non-CBD segments, the procedure used is similar to that used in step 2 to estimate the route segment residential market area. The NOACA data base included a breakdown of commercial, industrial and retail land use acreage for each traffic zone. NOACA also had data on employment densities for each zone and for different land uses.

Traffic zone and USGS maps were used to determine the acreage within the bus route market area. With the data available, it was not possible to separate retail and commercial land uses. Therefore, two categories, industrial and retail/commercial, were used. USGS maps were used to locate industrial areas. Employment densities for the zone were then multiplied by land use acreage to determine the number of employees in the segment market area.

In some cases, more specific information may be obtained. If a traffic zone includes only a major shopping mall, for example, specific employment data may be available from the Mall. Where specific land uses can be identified, NOACA data on land-use specific employment densities can be used. Strip commercial development, for example, is estimated to have 25-30 employees per acre, a measure which can be used instead of zone-specific densities.

b. The travel time between each segment on the route can be easily determined from the GCRTA schedules. For each segment, determine the travel time to all other segments.

Travel within a segment is generally not estimated unless the segment is unusually large (over ten minute travel time from end to end) because walking is competitive with transit for short trips.

c. For each segment, divide employment in all other segments by travel impedance to those segments. Travel impedance is defined as:

$$TI_{ij} = (TT_{ij} + CH_{ij})^{1.8}$$

where:

TI_{ij} = travel impedance for passengers in going from segment i to segment j
TT_{ij} = travel time in minutes from segment i to segment j
CH_{ij} = combined headway along route

When there are two different combined headways in a segment pair, the higher of the two should be used.

d. Trips are distributed by dividing the Employment/Travel Impedance for each segment by the sum of Employment/Travel for all segments. This fraction is then multiplied by the number of one-way boardings in the originating segment. This provides the distribution of one-way trips from one route segment to all other segments on the route. These trips will be reversed later in the day. Thus once the one-way distribution table is developed, reverse trips are added in to obtain the overall trip distribution table. This is done by adding paired cells.

Example: 100 trips are made from segment i to segment j and 50 trips made from segment j to segment i. Since all trips will be reversed later in the day, the two cells should be added together, for a total of 150 trips.

Once boardings have been estimated by the model for each route segment, the difference between the predicted and actual ridership should be calculated and divided by the actual ridership to calculate the percent error in the estimates for each route segment.

PROCEDURE FOR ESTIMATION OF CROSSTOWN OR FEEDER ROUTE PATRONAGE

The technique for crosstown or feeder route ridership estimation is similar to that used for the radial route, with several exceptions. This description refers to the radial route estimation procedure for those steps which are the same in both procedures.

Step 1

Divide the route into segments. Since the CBD is Segment 1, as explained earlier, and crosstown routes do not go the CBD, the numbering starts with Segment 2. Where segments are in small units (e.g. only a few blocks and resulting in a low ridership figure for the segment, perhaps less than 100 riders), adjacent segments can be combined to permit a more accurate measurement of ridership.

Step 2

Determine the market area for each segment. This involves counting residential units within 1/4 mile of the route, as described in Step 2 of the radial route estimation procedure.

Step 3

Determine average income for route segments. For crosstown routes average income is calculated in a manner similar to that described in Step 3 for radial routes. Only two income categories are used for crosstown routes, however, under $14,000 or over $14,000 (using NOACA 1980 income estimates). In most cases, the category can be determined without actually calculating the average income, if all or most zones in a segment have average incomes above or below $14,000.

Step 4

Determine the home-based transit trip rate. As with radial route estimation, combined headway is the variable used to predict the home-based trip generation rate. It should be emphasized that these equations can be used only on crosstown or feeder routes which tie into the rest of the GCRTA system. There are two separate equations, one for crosstown/feeder segments with under \$14,000 mean household income and one for segments with over \$14,000.

The estimating equations for the under \$14,000 segment are:

Home-based trip rate = .624 - [.17(Ln CH)]

where: CH = combined headway

For the high-income segments, combined headway can be used with the high-income data base and the TI-59 interpolation program (as described in the radial route example) to obtain the home-based trip generation rate. Alternatively, graphs may be developed and used for estimation, as was illustrated earlier.

Step 5

Multiply the trip rate by the number of households in the market to obtain the number of home-based transit trips.

Step 6

Distribution of transfer trips is completed before trips are distributed to other segments. First, trips are distributed to rail stations. Using the transfer model for crosstown routes, the following equation is used to distribute trips to the nearest rapid station:

% of home-based trips in
segment transferring to rapid = 33.6 - (1.2 x travel time to station)

(Note that a crosstown route is defined as a route which goes in a direction perpendicular to radial routes, not toward the CBD. A feeder route is defined as a route which terminates at a rail station which is the closest point on the route to the CBD. Separate distribution equations are used for feeder routes.)

Figure B5

Crosstown/Feeder Route Estimation Procedure

Steps for Use of the Model

1 - Divide Route into Segments

2 - Determine Market Area for Each Segment

3 - Determine Mean Income for Route Segment Market Areas

4 - Calculate Home-Based Trip Generation Rate

5 - Determine Number of Home-Based Transit Trips

6 - Distribute Rail Transfer Trips

7 - Distribute Bus Transfer Trips

8 - Distribute Non-Transfer Trips

Figure B6

Data Required for Estimation of Crosstown/Feeder Route Travel

1 - Route Map with Crossing Routes

2 - Income Data at Traffic Zone or Census Tract Level

3 - USGS or Land Use Maps

4 - Land Use and/or Employment Data at Traffic Zone or Census Level

5 - Running Times Between Bus Route Segments and Rail Stations

6 - Running Times Between Bus Route Segments

7 - Schedules for Intersecting Radial Routes

Step 7

The next step involves the distribution of bus transfer trips. Each segment generally is bounded by radial bus routes on both sides. Some have crossing radial bus routes within the segment. Generally, the transfer trips are distributed to the nearest bus route. If two bus routes are equally close (as is usually the case) trips are distributed to the one with the most frequent service. Only non-rail passengers are distributed (from crosstown to radial routes) with the equation:

Proportion of non-rail
passengers transferring = .498 - [.1242(Ln CH of crossing routes)]
to bus

A special procedure is used where a segment is large and contains two major radial routes with roughly equal service. In this situation, transfer proportions are calculated for both routes and the totals added together.

Step 8

The remainder of the trips (non-transfer trips) are distributed to other segments in the same way which non-CBD trips are in the radial route procedure, with use of the trip distribution model. The proportion of employment over travel impedance is calculated for each segment on the route and trips are distributed with the following equations:

$$PT_{ij} = \frac{E_j/TI_{ij}}{\text{Sum}\,(E_j/TI_{ij})}$$

$$NT_{ij} = (PT_{ij})\,(NTGR)$$

where:

PT_{ij} = proportion of trips generated in segment i going to segment j

E_j = employment accessible to the bus route in segment j

TI_{ij} = travel impedance for transit trip between segment i and segment j

NT_{ij} = number of trips originating in segment i going to segment j

NTGR = total number of non-transfer trips generated from segment i

In the radial route model, it was mentioned that travel within segments was ignored unless the segment was large. However, where segments are combined and result in over 10 minutes in travel time in the combined segment, it can be assumed that the combined segment will generate significant intra-segment travel. The segment is thus considered as an attraction for trips generated within it, and half the end-to-end travel time is used in the calculation of travel impedance. The equation used to determine employment/travel impedance is the same as that used in the radial route estimation procedure.

The rail transfers are calculated by station and the bus transfers are added to the appropriate segment. Total one-way trips generated from home are shown in a trip generation summary table. As described in the radial route procedure, these trips are reversed to account for the trip home later in the day. Thus total daily boardings are summarized in a total boardings table.

PROCEDURE FOR USE OF A HEADWAY ELASTICITY MODEL

The headway elasticity model uses the relationships developed between service frequency and ridership rates to predict changes in ridership which will occur with changes in the level of service. The graphs shown in Figures 9-13 define the relationships between various frequency levels.

Movement along the curve resulting from service (headway) changes results in a new estimate of trip rate.

The estimates can also be obtained by using the program cards that have been developed for use on the TI-59 calculator. The attached instruction sheet describes how the program is used. The current number of riders impacted by the change in frequency is entered into the calculator. Current headways (peak and off-peak) and new headways (peak and off-peak) are entered. The program then prints out the new ridership level, the change in ridership and the percentage change in ridership. The current ridership must be entered to start the program, but the printer will prompt for the headway entries. It is emphasized that this technique should only be applied to an existing route service base. It should not be used to make an initial ridership estimate for a new route or a new extension to an existing route.

PROCEDURE FOR USE OF AN ACTIVITY CENTER SERVICE EXTENSION MODEL

Because trips are generated on the basis of residential household characteristics (household income and number of transit units), the number of new transit trips generated by an extension into a residential area can easily be estimated. A methodology was needed, however, for estimating new trips generated by the extension of a route into an employment center.

The technique developed is designed primarily for extensions into major activity centers such as shopping malls or industrial parks but can be used for new segments with strip development as well. The model can also be used to evaluate the impact on ridership of major increases in activity along existing portions of the route. This model should only be used where a base route estimate already exists and service is either being extended or major new development occurs along the route. It should not be used on an entirely new route.

The model has been designed for operation on the TI-59 calculator. The user enters:

- employment accessible to the bus route in the new segment
- peak headway of service to the segment
- off-peak headway of service to the segment
- number of households within 1/4 mile of the route, or potential market
- length of the route in minutes (if the estimate is being made for a new activity center along an existing part of the route the distance in minutes from the farthest end of the route should be used instead).

The calculator will then print the number of new riders who will be attracted to the extension. The trip distribution model can be used to distribute the new trips back to their origin segment along the line.

This would be accomplished by using the following formula:

$$PT_{ji} = \frac{HH_i / TI_{ji}}{\text{Sum } (HH_i / TI_{ji})}$$

where:

PT_{ji} = proportion of new trips attracted to activity center segment j which originate in segment i

HH_i = number of households in segment i

TI_{ji} = travel impedance between segments i and j

Travel impedance is determined by the same formula used in the trip distribution model. A redistribution of existing trips along the route

TITLE Activity Center Service Extension PAGE ____ OF ____

PROGRAMMER SG Associates, Inc. DATE 5-18-82

TI Programmable Program Record

Partitioning (Op 17) 7 2 9.2 9 Library Module None Required Printer Yes Cards 3

PROGRAM DESCRIPTION

This program predicts the number of new riders who will be attracted to a bus route by an extension of the route into an activity center. The user must enter employment in the new segment, peak and off-peak headways, the number of households along the route and route length in minutes. The program is on two cards and must be entered in Banks 1,2, and 3.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS			DISPLAY
1	Partition Storage Area	3	2nd	Op	17	729.29
2	Enter program cards in Banks 1,2 and 3					
3	Start Program - Press R/S Key twice		R/S			-2.38
			R/S			Printer Prompt
4	Enter New Segment Employment	Emp.	A			Printer Prompt
5	Enter Peak Headway	Pk. HW	B			Printer Prompt
6	Enter Off-Peak Headway	Off-Pk Hw	C			Printer Prompt
7	Enter Households in Route Market Area	HH	D			Printer Prompt
8	Enter Route Length in Minutes*	Rte.Len	E			New Ridership
9	Press Reset Key to Start Again		RST			
	* If activity center is not at the end of the route, enter the distance from the activity center to the farthest end of the route.					

USER DEFINED KEYS	DATA REGISTERS (INV LIST)	
A Employment	0	0
B Peak HW	1	1
C Off-Peak HW	2	2
D Households	3	3
E Rte. Length	4	4
A'	5	5
B'	6	6
C'	7	7
D'	8	8
E'	9	9

LABELS (Op 08)

INV	lnx	CE	CLR	x⇌t	x^2
√x	1/x	STO	RCL	SUM	y^x
EE	(	)	÷	GTO	×
SBR	−	RST	+	R/S	.
+/−	=	CLR	INV	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]				

FLAGS	0	1	2	3	4	5	6	7	8	9

should also be completed, since the new activity center will probably divert some trips which currently go to other locations. The model should be used only on routes which are similar to those in the system. If, for example, a route is extended through a large undeveloped area to an activity center, the model will probably overestimate new ridership. The attached sheet provides instructions for using the model on the TI-59 calculator.

TI Programmable Program Record

TITLE Headway Elasticity Program PAGE ___ OF ___

PROGRAMMER SG Associates, Inc. DATE ___

Partitioning (Op 17) 4 7 9 . 5 9 Library Module #2 - Math - Utilities Printer ___ Cards ___

PROGRAM DESCRIPTION

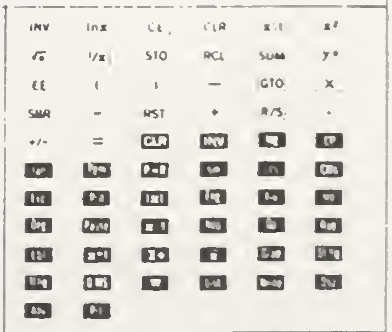
Headway Elasticity Program - Estimates change in ridership resulting from change in headway for low, middle and high-income groups and express service. Uses data cards inserted into Bank 3. Prints out estimate of new ridership. Use data cards - LR1 for low-income radial route segments, C1 for crosstown, MR1 for middle-income radial, H1 for high-income and E1 for express service.

USER INSTRUCTIONS

STEP	PROCEDURE	ENTER	PRESS	DISPLAY
1	Insert Appropriate Data Card in Bank 3	3	Insert Card	3
2	Insert Program Card in Banks 1 & 2	1	Insert Card	1- 2
3	Insert R_0 - Ridership impacted by headway change	R_0	B'	Printer Prompt
4	Enter CPH - Current peak headway	CPH	C'	Printer Prompt
5	Enter COH - Current off-peak headway*	COH	E'	Printer Prompt
6	Enter NPH - New Peak Headway	NPH	D'	Printer Prompt
7	Enter NOH - New Off-Peak Headway*	NOH	E	Trip Rate
8	Press R/S To Continue		R/S	Trip Rate
9	Press R/S To Continue		R/S	New Ridership on Printout
10	Press RST to start again		RST	
	* Enter peak headway again for express service-model can be used only for peak analysis of express routes.			

USER DEFINED KEYS	DATA REGISTERS (INV [list])	
A	0	0
B	1	1
C	2	2
D	3	3
E New Off-Pk Headway	4	4
A'	5	5
B' Current Ridership	6	6
C' Current Pk Headway	7	7
D' New Pk Headway	8	8
E' Current Off-Pk Headway	9	9

LABELS (Op 08)



FLAGS	0	1	2	3		5	6	7	8	9

APPENDIX C

RADIAL ROUTE PATRONAGE ESTIMATE: ROUTE 19 - BROADWAY MILES

Step 1 - Divide Route into Logical Segments

Segment divisions for Broadway are as follows (see Figure C1).

Segment No.	Boundaries
1	Public Square to E. 55th St.
2	E. 55th St. to E. 93rd St.
3	E. 93rd St. to E. 116th St.
4	E. 116th St. to E. 131st St.
5	E. 131st St. to Lee Rd.
6	Lee Rd. to Warrensville Ctr. Rd.
7	Warrensville Ctr. Rd. to Banbury Cir.

Step 2 - Determine Market Area for Each Route Segment

Determination of the traffic zones, number of households in each zone and the percentage of zone households in each route segment market area resulted in the following number of households in each route segment market area for bus route segments 2 through 7:

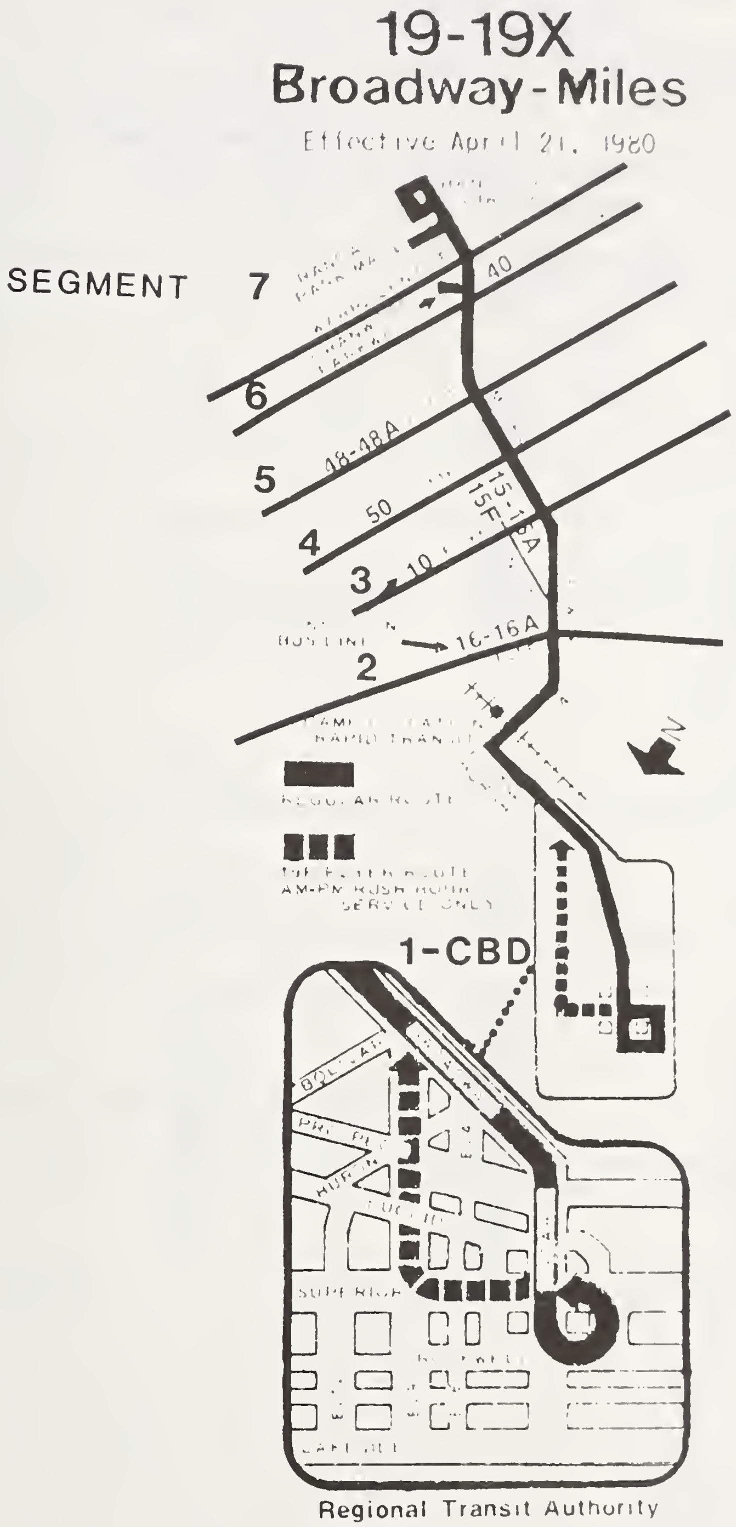


FIGURE C1

ROUTE SEGMENTATION SCHEME

Calculation of Transit Route Market Area

1 Route Segment	2 Traffic Zone	3 No. of Households in Traffic Zone	4 Percent of Zone Households in Route Segment Market Area	5 No. of Households in Route Segment Market Area (3) x (4)
7	655	509	100%	509
6	656	511	75%	383
	525	692	48%	332
	661	1142	42%	+ 480
				1195
5	660	564	33%	186
	524	106	0%	0
	620	1010	40%	404
	521	309	22%	68
	629	661	85%	+ 562
				1220
4	628	0	0%	0
	630	1072	100%	+1072
				1072
3	503	682	85%	580
	502	1287	83%	+1068
				1648
2	501	425	85%	361
	507	1656	40%	662
	500	105	100%	105
	499	877	40%	351
	491	1483	25%	371
	492	1138	10%	114
	493	719	90%	647
	508	960	15%	144
	494	797	15%	+ 120
				2875

Step 3 - Determine Average Income for Route Segments

a. Find average income from the NOACA tables for each traffic zone. For bus route Segment 6, the figures would be:

Segment 6

Traffic Zone	Mean Income
656	14010
525	14314
661	14607

b. Calculate a weighted average for the segment based on the number of households in each traffic zone, as shown below for Segment 6.

Traffic Zone	Mean Income	Households in Bus Route Market Area
656	14010	383
525	14314	332
661	14607	480

Using the Step 3 formula described earlier for calculating average income, for Route 19, segment 6, the calculation would be:

$$\frac{(383 \text{ x } 14010) + (332 \text{ x } 14314) + (480 \text{ x } 14607)}{383 + 332 + 480} = \$14,334$$

Step 4: Determine Home-based Transit Trip Rate

a. For Route 19, the average income and income category for each segment is:

Segment	Average Income	Category
7	11,414	Middle
6	14,334	High
5	10,945	Middle
4	10,164	Middle
3	10,126	Middle
2	9,085	Low

b. Determine the combined peak and off-peak headway for each route segment using the following formula:

Combined Headway - (.67 x peak headway) + (.33 x off-peak headway)

For segments 2 through 4, the average peak headway is 13 minutes and the average off-peak headway is 14 minutes. Segments 5 through 7 have less frequent service in the peak period (22 minutes) but run at 14-minute headways in the off-peak. This unusual service pattern on segments 5-7 exists because the route serves a major suburban mall.

For segments 1-4, the combined headway is:

13.3 = (.67 x 13) + (.33 x 14)

For segments 5-7, the combined headway is:

19.4 = (.67 x 22) + (.33 x 14)

c. Using data cards which have been programmed for the TI-59 calculator, the following trip generation rates are calculated for the Broadway route:

Segment	Income Category	Combined Headway	Trip Rate
2	Low	13.3	.304
3	Middle	13.3	.327
4	Middle	13.3	.327
5	Middle	19.4	.162
6	High	19.4	.080
7	Middle	19.4	.162

(These trip rates can be alternatively calculated from the equations in Figure 4 or estimated from the graphs in Figures 5-8).

Step 5: Determine the Number of Home-based Trips

For each segment, the trip rate is multiplied by the number of households in the market to obtain the number of home-based trips in each segment.

Segment	Trip Rate	No. of Households	No. of Home-Based Trips
2	.309	2875	888
3	.327	1648	539
4	.327	1072	351
5	.162	1220	198
6	.078	1195	93
7	.162	509	82

Step 6: Determine Number of Passengers Transferring onto Route in Segment

To demonstrate this technique, the transfers from Route 16-16A to Route 19 (boarding in segment 1) will be calculated.

a. Calculate the number of passengers on crosstown route at transfer point.

Route 16 Northbound	370
Route 16/16A Southbound	680
Route 16A Northbound	192
Total On-Board	1242

b. The combined headway for Route 19, segment 1 was already determined in Step 4b (13.3). The combined headway for Routes 16-16A can be determined from RTA schedules. At Broadway the peak headway is 12 minutes and the off-peak headway is 15 minutes. The combined headway is therefore:

(.67 x 12) + (.33 x 15) = 13

The sum of the combined headways is 26.3, and is used in the following equation to determine the transfer rate.

Transfer Rate = 0.498 - (.1242 x natural log Combined Headways)

Transfer Rate = 0.498 - (.1242 x natural log 26.3) or:

.092 = 0.498 - (.1242 x 3.27)

By taking the transfer rate (.092) and multiplying by the number of passengers on the bus (1242), the number of transferring passengers is obtained:

.092 x 1242 = 114

114 passengers will transfer from Route 16-16A and board the Broadway bus. The following table shows the number of transfers for each of the transfer points along Route 19.

Segment	Crossing Route	Crossing Route Headway	Combined Headway	Passengers on Bus	Transfer Rate	Transferring Passengers
2	10	18	31.3	635	.070	45
3	50	18	31.3	335	.070	24
4	48-48A	13.67	27.0	1548	.089	137
5	40	16.3	32.6	267	.065	17
6	41	25.0	41.3	466	.036	17

c. Transferring passengers are added to home-based boardings for each segment to obtain total one-way boardings.

	Home-Based	Transfers	Total One-Way Baordings
Segment 1 =	0	114	114
2	888	45	933
3	539	24	563
4	351	137	488
5	198	17	215
6	93	17	110
7	82	0	82

Step 7: Distribute Trips to othe Segments

a. An example of the determination of the level of employment is shown below for Segment 3 on Route 19:

Traffic Zone	Industrial Acreage	Retail/Commercial Acreage
503	9.5	9.9
502	43.2	13.8

Traffic Zone	% Industrial Acreage in Market Area	% of Retail Acreage in Market Area
503	100%	100%
502	50%	50%

Traffic Zone	Industrial Acreage in Market Area	Retail/Commercial Acreage in Market Area
503	9.5	9.9
502	21.6	6.9

Traffic Zone	Total Acreage	Traffic Zone Employees/Acre	Employees in Segment Market Area
503	19.4	23.6	458
502	28.5	26.1	744
			1202

For Route 19, the following estimates of employment for each route segment are made:

Segment	(1) Industrial Acreage	(2) Retail/Commercial Acreage	(1)+(2)	Employees/ Acre	Number of Employees
7	23	403	426	12.9	5495
6	183	91	274	7.3	2000
5	55	45	100	15.3	1530
4	7	59	66	20.6	1360
3	31	17	48	25.0	1200
2	117	154	271	21.7	5881
1	---	---	---	---	64,000

c. The travel time between each segment on the route can easily be determined from the GCRTA schedules. For each segment, determine the travel time to all other segments. For segment 2, these times are as follows, in minutes:

	Segment						
Segment 2 to	1	2	3	4	5	6	7
	16	---	6	10	14	19	26

c. For each segment, divide employment in all other segments by travel impedance to those segments, using the previously defined formula.

When there are two diffeent combined headways in a segment pair, the higher of the two should be used. For example, the combined headway for segment 2 is 13.3 and the combined headway for segment 7 is 19.4. Thus the travel impedance for the trip from segment 2 to segment 7 should use 19.4 as the combined headway:

Combined Headway = 19.4
Travel Time Segment 2 to 7 = 26

$$960.9 = (19.4 + 26)^{1.8}$$

Travel impedance can be rounded to the nearest integer or 961. The calculation of employment/travel impedance for passengers traveling from segment 2 to all other segments is shown here:

	Segment						
Segment 2 to:	1	2	3	4	5	6	7
Employment	64000	---	1200	1360	1530	2000	5495
Travel Impedance	445		206	289	553	711	961
Employment/Travel Impedance	144		6	5	3	3	6

Sum of (Employment/Travel Impedance) = 167

d. Trips are distributed by dividing the Employment/Travel Impedance for each segment by the sum of Employment/Travel for all segments. This fraction is then multiplied by the number of one-way boardings in the originating segment.

The number of one-way boardings in Segment 2 is estimated at 933. The distribution of these trips is calculated as follows:

From Segment 2 to:	Employment/ Travel Impedance		Sum of Employment/ Travel Impedance		One-Way Boardings		Number Of Trips
Segment 1	144	/	167	= .862 x	933	=	804
Segment 2	---		---	---	---		---
Segment 3	6	/	167	= .036 x	933	=	34
Segment 4	5	/	167	= .030 x	933	=	27
Segment 5	3	/	167	= .018 x	933	=	17
Segment 6	3	/	167	= .018 x	933	=	17
Segment 7	6	/	167	= .036 x	933	=	34

This means that 804 passengers boarding in Segment 2 will go to Segment 1, 27 will go to Segment 4, etc. These trips will be reversed later in the day. The 804 passengers going from Segment 2 to Segment 1 will reverse their trip later in the day, boarding in Segment 1 and returning to Segment 2. First, the one-way trip distribution table is developed, and then reverse trips are added in to obtain the overall trip distribution table:

One-Way Distribution Table

From Segment:	To Segment 1	2	3	4	5	6	7
1	99	8	1	2	1	1	2
2	804	---	34	27	17	17	34
3	383	104	---	30	15	15	26
4	298	70	25	---	32	16	32
5	132	25	7	12	---	14	25
6	65	11	3	4	7	---	20
7	55	8	3	3	4	9	---

e. The Trip Distribution Table is completed by adding in reverse trips. This is accomplished by adding paired cells. For example, Segment 3 to Segment 2 has 104 trips and Segment 2 to Segment 3 has 34 trips. Since these trips are reversed later in the dcay, the two cells should be added together with both cells having atotal of 138 trips. The final distribution is shown below:

Trip Distribution Table

From Segment:	To Segment 1	2	3	4	5	6	7	Total
1	198	812	384	300	133	66	57	1950
2	812	---	138	97	42	28	42	1159
3	384	138	---	55	22	18	29	646
4	300	97	55	---	44	20	35	551
5	133	42	22	44	---	21	29	291
6	66	28	18	20	21	---	29	184
7	57	42	29	35	29	29	---	221

Finally, boardings estimated by the model are compared with actual passenger counts, to determine the percent error in the estimates that occurs.

Comparison With 1980 Ridership Count

Segment	Boardings Estimated by Model	Ridership Count	% of Error
1	1950	2084	-6.4%
2	1159	1124	+3.1%
3	646	649	-0.5%
4	551	838	-34.3%
5	291	457	-36.4%
6	184	156	+17.9%
7	221	469	-53.2%
Total	5002	5777	-13.4%

APPENDIX D

CROSSTOWN/FEEDER ROUTE PATRONAGE ESTIMATE: ROUTE 40 - LEE RD.

Step 1

Figure D1 shows the original layout for Route 40. Because several of the segments were small, segments 2 and 3, 8 and 9, and 11 and 12 were combined into single segments.

Step 2

Determine market area for each segment. For Lee Rd., the household market area for the segments were:

Segment	No. of Households
2/3	6246
4	1466
5	1804
6	1591
7	1533
8/9	1792
10	906
11/12	1673

Step 3 and Step 4

Determine home-based transit trip rate. There are two separate equations, one for crosstown/feeder segments with under $14,000 mean household income and one for segments with over $14,000 mean household income. Household Income ranges can be easily identified.

The estimating equations for the under $14,000 segments are:

Home-based trip rate = .624 - (.17(Ln CH))

where: CH = combined headway

Ln = natural log

All segments except 6 and 7 are in this category. For segment 2/3,

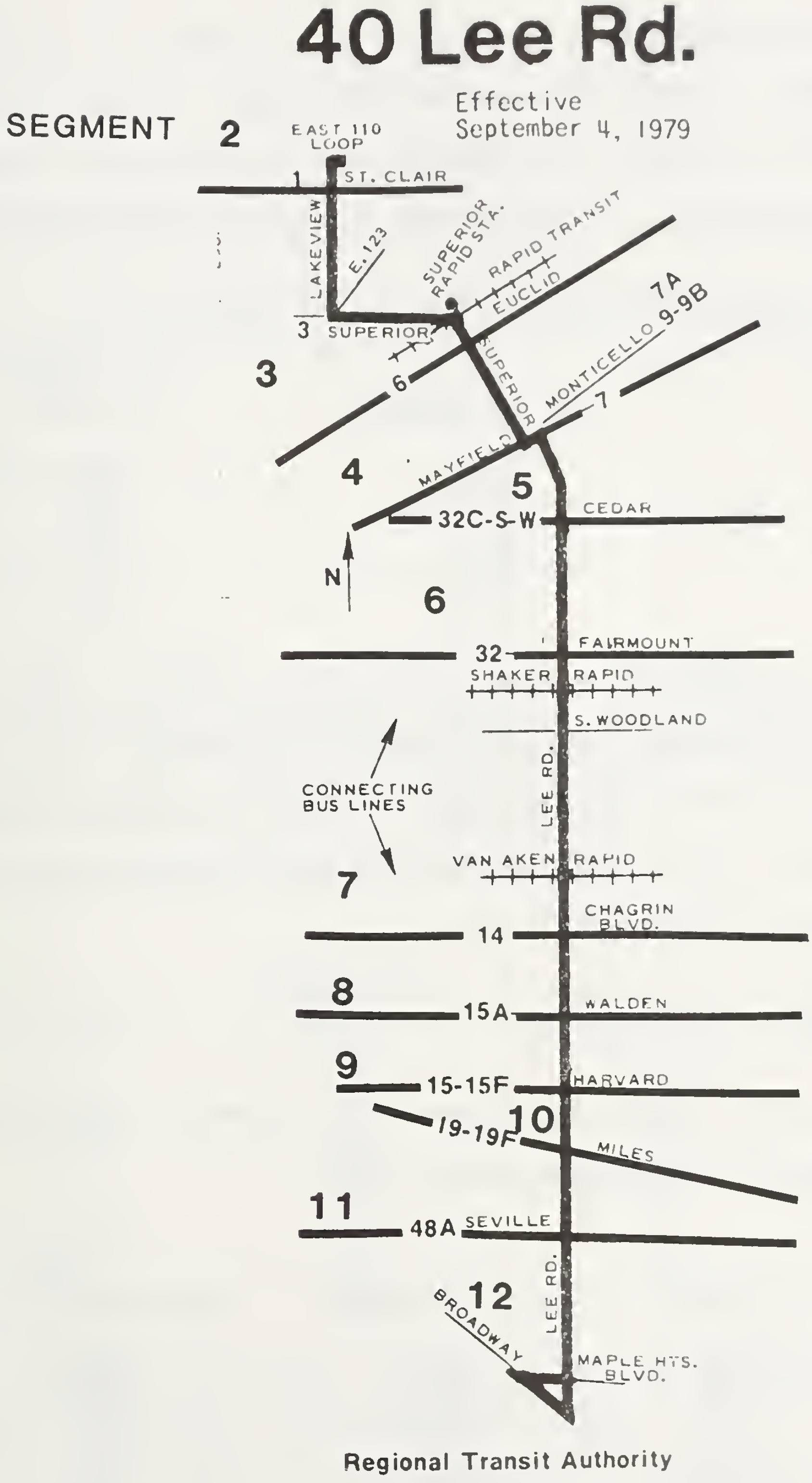


FIGURE D1

ROUTE SEGMENTATION SCHEME

the calculation would be:

Trip Rate = .624 - (.17 x natural log 12.2) =

.624 - (.17 x 2.50) = .199

Combined Headway = (.67 x 9 (peak headway)) + (.33 x 18.6 (off-peak headway)) = 13.2

For the other under $14,000 segments, the trip rates are:

Segment	Combined Headway	Home-Based Trip Rate
2/3	12.2	.199
4	12.2	.199
5	12.2	.199
8/9	16.3	.150
10	16.3	.150
11/12	16.3	.150

For the two high-income segments (6 and 7), combined headway can be used with the high-income data base and the TI-59 interpolation program (as described in the radial route example) to obtain the home-based trip generation rate. Using combined headway of 12.2, the home-based trip generation rate is estimated at .100.

Step 5

Multiply the trip rate by the number of households in the market to obtain the number of home-based transit trips.

Segment	Trip Rate	No. of Households	Home-Based Trips
2/3	.199	6246	1243
4	.199	1466	292
5	.199	1804	359
6	.100	1591	159
7	.100	1533	153
8/9	.150	1792	269
10	.150	906	136
11/12	.150	1673	252

Step 6

Distribution of transfer trips is completed before trips are distributed to other segments. First trips are distributed to rail stations. In this example, the Shaker and Van Aken lines are treated as one because they are in the same segment. The Superior station on the Rapid Red line is treated separately. Using the transfer model for crosstown routes, the following equation is used to distribute trips to the nearest rapid station:

% of home-based trips in
segment transferring to rapid = 33.6 - (1.2 x travel time to station)

For segments 2 and 3, the calculation would be:

27.6 = 33.6 - (1.2 x 5)

(Note that a crosstown route is defined as a route which goes in a direction perpendicular to radial routes, not toward the CBD. A feeder route is defined as a route which terminates at a rail station which is the closest point on the route to the CBD. Separate distribution equations are used for feeder routes.)

For all segments, calculations are as follows:

Segment	% of Trips to Rail	(1) Number of Home-Based Trips	(2) Number of Trips to Rail	(3) Number of Non-Rail Trips
2/3	27.6	1243	343	900
4	28.8	292	84	208
5	21.6	359	78	281
6	26.4	159	42	117
7*	0.0*	153	0	153
8/9	28.8	269	77	192
10	26.4	136	36	100
11/12	12.0	252	30	222

* When a segment is less than 4 minutes travel time from the station, it is assumed that rail-bound passengers can reach the station by walking. Therefore, no transfers are assigned.

Rail trips from segments 2-5 are distributed to Superior and trips from 6-12 are distributed to Shaker and Van Aken lines, since these are the closest stations.

Step 7

The next step involves the distribution of bus transfer trips. Each segment generally is bounded by radial bus routes on both sides. Some have crossing radial bus routes within the segment. Generally, the transfer trips are distributed to the nearest bus route. If two bus routes are equally close (as is usually the case) trips are distributed to the one with the most frequent service. Only non-rail passengers are distributed (from crosstown to radial routes) with the equation:

Proportion of non-rail passengers transferring to bus = .498 - (.1242 x natural log Combined Headways of crossing routes)

For segment 7, there are two adjacent radial routes, 15A and 14. Route 14 has the most frequent service and thus receives bus transfers from segment 7. The sum of combined headways is:

18.4 = 12.2 (Route 40) + 6.2 (Route 14)

The proportion of transferring passengers from segment 7 is:

.136 = .498 - (.1242 x natural log 18.4)

This proportion is multiplied by the number of non-rail passengers to obtain the number of bus transfer passengers, as for segment 7:

(.136) x 153 = 21 bus transfer passengers

Because the intersection of two segments is assigned to the lowest segment number, transferring passengers may be distributed either within the same segment or to an adjacent one.

For segment 2/3, a special procedure is used. This segment is large and contains two major radial routes with roughly equal service (Route 1- St. Clair and Route 3 - Superior). In this situation, transfer proportions are calculated for both routes and the totals added together. The table summarizes bus transfer assignments for Route 40.

Segment	Crossing Route	(1) Non-Rail Passengers	(2) Transfer Proportion	(3) Transfers	(1)-(3) Passengers
2/3	1,3	900	.225	203	697
4	6	208	.147	31	177
5	32C-S-W	281	.107	31	250
6	32C-S-W	117	.107	13	104
7	14	153	.136	21	132
8/9	14	192	.113	22	170
10	15-15F	100	.098	10	90
11/12	19	222	.053	12	210

Step 8

An example of the use of the trip distribution model to distribute the remainder (non-transfer) trips to other segments is shown below for trips originating in segment 2/3. In the radial route model, it was mentioned that travel within segments was ignored unless the segment was large. In this example, segment 2/3 is large (over 10 minute travel time within the segment) and could be expected to generate significant intra-segment travel. The segment is thus considered as an attraction for trips generated within it, and half the end-to-end travel time is used in the calculation of travel impedance.

From Segment 2/3

To Segment	Travel Time	Combined Headway	Employment	Employment Travel/Impedance
2/3	5	12.2	3989	23.8
4	12	12.2	1169	3.7
5	18	12.2	2470	5.4
6	24	12.2	1097	1.7
7	29	12.2	1765	2.2
8/9	33	16.3	1586	1.4
10	37	16.3	687	0.5
11/12	43	16.3	1643	1.1

From Segment 2/3

To Segment	Employment/ Travel Impedance	/Employment Travel Impedance	Proportion of Trips	Non-Transfer Trips	One-way Trips
2/3	23.8	39.8	.60	697	417
4	3.7	39.8	.09	697	63
5	5.4	39.8	.14	697	98
6	1.7	39.8	.04	697	28
7	2.2	39.8	.06	697	42
8/9	1.4	39.8	.03	697	21
10	0.5	39.8	.01	697	7
11/12	1.1	39.8	.03	697	21

A similar procedure is used for all other segments, except that travel within those segments is considered to be zero except for calculated bus transfers.

The rail transfers are calculated by station and the bus transfers are added to the appropriate segment according to the routes shown in Bus Transfer Table in Step 7. For example, there are 27 bus transfer passengers boarding in segment 5 who transfer to bus route 32-C-S-W. Since route 32C-S-W is located in segment 4, these 27 trips are added into the cell "segment 5 to segment 4". Segment 7 has 19 passengers who board in segment 7 and transfer to Route 14. Since Route 14 is also in segment 7, these trips are placed in the cell "segment 7 to segment 7". Thus all one-way trips generated from home are shown in the table "Trip Generation Summary." As described in the radial route procedure, these trips are reversed to account for the trip home later in the day. Thus total daily boardings are summarized in the table "Total Boardings."

TRIP GENERATION SUMMARY

From Segment	To Segment 2/3	Superior	4	5	6	7	Lt. Rail	8/9	10	11/12
2/3	620	343	63	98	28	42	--	21	1	21
Sup										
4	85	84	--	59	16	13	--	13	4	8
5	62	78	45	31	42	44	--	30	10	17
6	14	--	9	43	--	23	42	15	5	8
7	16	--	9	28	21	21	--	33	10	15
Lt. Rail	--	--	--	--	--	--	--	--	--	--
8/9	21	--	10	29	19	68	77	--	18	27
10	10	--	4	12	8	18	36	32	--	16
11/12	29	--	12	33	20	42	30	49	37	--

TOTAL BOARDINGS

From Segment	2/3	Sup.	4	5	6	7	Lt. Rail	8/9	10	11/12	Total
2/3	1240	343	148	160	42	58	--	42	17	50	2100
Superior	343	--	84	78	--	--	--	--	--	--	505
4	148	84	--	104	25	22	--	23	8	20	434
5	160	78	104	62	85	72	--	59	22	50	692
6	42	--	25	35		44	42	34	13	28	313
7	58	--	22	72	44	42	--	101	28	57	424
Lt. Rail	--	--	--	--	42	--	--	77	36	30	181
8/9	42	--	23	59	34	101	77	--	50	76	462
10	17	--	8	22	13	28	36	50	--	53	227
11/12	50	--	20	50	28	57	30	76	53	--	364

Segment	Boardings Estimated From Model	1980 Ridership Count	% Error
2/3	2100	2068	+1.5%
Superior	505	438	+15.2%
4	434	659	-24.1%
5	692	657	+5.3%
6	313	245	+27.8%
7	424	374	+13.4%
Lt. Rail	181	292	-38.0%
8/9	462	478	-3.3%
10	227	265	-14.3%
11/12	364	360	+1.1%
Total	5702	5836	-2.3%

DOT-I-83-34

TECHNOLOGY SHARING

SPECIAL STUDIES IN TRANSPORTATION PLANNING (SSTP)

PROGRAMS OF THE U.S. DEPARTMENT OF TRANSPORTATION

19