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A TRANSIT DEMAND MODEL FOR MEDIUM-SIZED CITIES

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16. Abstract The purpose of the study was to develop a model of bus ridership and do a preliminary study of how the parameters of such a model could be estimated on the basis of the existing bus routes and their usage.

The transit demand (bus ridership) model predicts passenger trip ends for sections of the transit route for an average weekday by time period. At present, the model is applicable only to a central business district route. The model is set out in a series of linear regression equations. A stepwise regression program was used to estimate all equations. In general, the model coefficients seemed reasonable, and during the calibration process all the household coefficients and total employment coefficients exhibited good stability in terms of their values and also consistently high significance levels. The feasibility study shows the model can be successfully calibrated utilizing boarding and exiting data from existing transit routes. The model data requirements and analysis requirements are modest and should encourage its wide usage. The model structure is logical and related to the expected land use variables and the predominant types of transit trip making.

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Messrs. J. Gibson and W. Scott of the Austin Transit System gave valuable assistance and data on ridership on the routes studied. Mr. J. Baldelomar and Mr. D. Brasfield conducted the field work.

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EXECUTIVE SUMMARY

INTRODUCTION

This report is one of a series concerned with the prediction of public transportation patronage. The report provides a model for predicting bus usage in medium-size cities.

PROBLEM STUDIED

The overall concern of the research effort, under which this report was produced, is the determination of the various factors effecting urban mode choice. In particular, the study seeks to answer the following questions:

(1) What attributes--such as ride quality, economy, travel time, flexibility, social image--are considered to be important in the selection of a mode of transportation for various trip purposes?

(2) How important or what weight do specific attributes--such as economy, energy conservation--play in determining mode selection?

(3) Do present public transportation systems possess any of the important determinant attributes, and on which determinant attributes are present public transportation systems deficient?

This report presents the results of one part of this study. The focus of the report is on developing a model, or models, which contain(s) the major relevant variables in predicting urban mode choice. In particular, the model in this report is concerned with predicting bus ridership in medium-sized cities in North America. The objective of this report is to present a relatively simple model which incorporates the known important variables in predicting bus ridership.

RESULTS ACHIEVED

The purpose of this report is to develop a model of bus ridership and to do a preliminary study on how the parameters of such a model may be estimated on the basis of existing bus routes and their usage. The model developed in the study is conceived as empirically based and pragmatic. The approach taken was patterned on the Highway Capacity Manual. This manual provides the framework for a data collection effort as a part of regular operational duties. The model developed in this study attempts to include, however crudely, the effects of all the important variables on bus ridership. The variables included in the model are illustrated in Table 1.

TABLE 1. VARIABLES AFFECTING TRANSIT RIDERSHIP

Population Variables

- Population
- Age
- Income
- Time (historical)
- Car Ownership

Route Variables

- Type of Area
- Potential Destination
- Route Location
- Bus Headways
- Reliability
- Travel Time

Bus Variables

- Fare
- Capacity
- Age, Appearance, and Comfort

Other Variables

- Marketing
- Information Services
- Characteristics of Alternative Modes
- Time of Week and Day
- Other City Factors

Ten objectives underly the development of the model. The model should:

(1) be simple enough to be understood and used on a day-to-day basis,

(2) predict absolute levels of transit ridership,

(3) relate mainly to urban bus transit,

(4) select changes in ridership due to changes in any variable in Table 1,

(5) incorporate realistic limits of ridership levels given extreme values of the variables,

(6) be disaggregated by time of week,

(7) use population data that are available from the census or other readily available sources,

(8) treat each route independently,

(9) divide inputs and outputs consistent with data normally collected by transit properties or data easily obtained with existing procedures, and

(10) avoid network methods because of their high cost in data preparation and computer analysis but try to incorporate in surrogate ways their essential modeling strengths.

Given the model objectives and the basic philosophical approach to the model, this report seeks to accomplish the following aims:

(1) to put forward a model structure and variable definition which meet the objectives,

(2) to review the literature and incorporate any previous research results into the model structure and the preliminary estimates of the parameters, and

(3) to do a pilot survey of a few transit routes in Austin to determine if both the model and the proposed data collection methods for calibration are valid.

The model depends on a series of assumptions. These allow the model to incorporate the main attributes of network (or origin/destination) models in a strictly trip-end model formulation. The assumptions rest heavily on a current structure of bus routes in North America, particularly CBD oriented routes in a suburban growth city. The major assumptions are:

(1) there is no travel from a section to itself in the direction of travel,

(2) there is no travel on a route which continues through the CBD or endpoints of the route,

(3) the movement of bus riders is basically from Household inbound to Attraction and then outbound from Attraction to Household for the predominant trip purpose in each time period only. In other words, the model does not recognize the trips for minor trip purposes and direction in an explicit way. However, as with all these assumptions, since the model parameters are estimated from actual data, these effects are represented indirectly in the parameter estimates although very poorly in a model structural sense,

(4) the model attempts to estimate absolute levels of On and Off by explicit consideration of the downstream destination, when estimating the On's in a section. Conversely, upstream originals are considered when estimating the Off's in a section,

(5) there are three major types of trips: A, Peak Period major direction Work Trips; B, Peak Period minor direction Work Trips; and C, Off-Peak Trips,

(6) the model parameters can be estimated from linear regression analysis using observed data for On's and Off's by section for each time. In the regression analysis all equations are forced to have a zero intercept.

A series of twelve equations comprised the model. A characteristic equation is given below:

A1. On's Inbound, Time Period 1 (going to work)

$$\text{On's in Section} = \left\{ \underset{(.0007)}{.0049}(\text{TGTHH})(\text{SMA}) + \underset{(.0083)}{.0014}(\text{OTRHH})(\text{SMA})(\text{CAR\$}) + 5.0\text{T}^{*} \right\} (\text{HF})(\text{AF})$$

$$\bar{Y} = 26.84(34.3),\ R^2 = .78,\ \text{S.E.} = 16.9$$

where

TGTHH = (Target Households in the Prime Trade Area) + (0.16)(Target Households in the Secondary Trade Area),

$$\text{SMA} = \sum_{\substack{\text{Down}\\ \text{Route}\\ \text{Sections}}} 1.0\ \text{EMP} + 0.08\ \text{COM} + .009\ \text{SCH} + 9.3\ \text{UT}$$

EMP = Total employment in each down route section (in 1000's),

COM = 1000's of feet of commercial frontage in each down route section,

UT = 0 or 1 variable representing The University of Texas student body (40,000),

OTRHH = (Other Households in the Prime Trade Area) + 0.16 (Other Households in the Secondary Trade Area),

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*The coefficient for T, of 5.0, was estimated arbitrarily for all time periods. A special study will be necessary to estimate these coefficients.

CAR$ = Car Cost Factor, here set equal to 1.0 for normal conditions,

T^* = Number of transfer points in the section,

HF = Headway Factor - see values in this chapter (also for overlapping routes times a route share factor),

AF = Product of all other Adjustment Factors. Here set equal to 1.0 for all equations for "normal" conditions.

$\overline{Y}$ = Mean of the dependent variable for the four routes (26 sections) studied in Austin,

( ) = Standard deviation for $\overline{Y}$ or the regression coefficients,

R^2 = Multiple correlation coefficient for the regression equation, and

S.E. = The standard error for the regression equation.

The model is calibrated by an iterative procedure until an acceptable correspondence between weights and coefficients was reached. In general, the model coefficient seemed reasonable, and during the calibration process all the household coefficients and total employment coefficients exhibited good stability in terms of values and also consistently high significance levels. Examination of the residuals indicates that the headway factor is reasonable. The car cost factor was tested and appears to be plausible; it really requires further data for its more accurate determination. The fare factor was not applied in the model estimate and thus, the model equations are "normal" for an average fare per boarding passengers. The capacity and condition factors require more detailed study and were not estimated in the model.

While the model equations appear rather formidable, they are in fact quite easy to calculate and would normally be solved by a small computer program. The data requirements and procedure to apply the model are:

(1) identify route location and route sections, noting any adjacent or overlapping route,

(2) mark out the primary and secondary trade areas,

(3) find the number of target and other households for each section and trade areas,

(4) determine the thousands of feet of commercial frontage in each section,

(5) estimate total employment and school enrollments within 750 feet of the route location for all sections,

(6) itemize other special generators (hospitals, CBD, universities, welfare offices, etc.) for each section, and

(7) identify the route characteristics, headways, fares, reliability, equipment, etc., by time.

In short, there is a need for a model of transit to provide a framework for determining the effects for changing transit variables for use in design. The model structure proposed is comprehensive with all important variables included. The feasibility study results show that the model can be successfully calibrated utilizing boarding and exiting data from existing transit routes. The model data requirements and analysis requirements are both modest and should encourage its wide usage. The model structure is logical and related to the expected land use variables and predominant types of transit trip making. The model should be reviewed by the appropriate institutional transit body to ensure compatibility of all definitions of transit usage and land use. Finally, some special studies will be necessary, utilizing origin/destination data to estimate parameters which cannot be estimated by a regression analysis.

UTILIZATION OF RESULTS

A case study within a bus transit property should be carried out utilizing the model as proposed in a route design situation. This would provide input as to its potential usefulness as well as suggestions for improvements. The same study might also design a final delivery form of the design took, as a handbook, a set of designs, a computer program, etc.

CONCLUSIONS

In closing, it is worth remembering that what is proposed is an empirical model. It attempts to predict the demand for transit on a route for a variety of situations utilizing as small a number of input variables as possible. The model is an average, representing considerable variation in the levels of demand, households, etc. Such a model can provide a good basis for design but clearly is not the only input. It is noted that many relationships inherent in any such model can never be tested because of data requirements and will, therefore, always remain as assumptions. It is intended that the model's most important function is to provide a framework of variable definitions and a basic structure that will allow for the collection of data. This will ensure that the results of ongoing demonstrations, route changes, and so forth will be effectively recorded and input into future design procedures to assure more effective transit systems.

CHAPTER 1

INTRODUCTION

The purpose of this study was to develop and put forward a model of bus ridership and to do a preliminary study of how the parameters of such a model could be estimated based on existing bus routes and their usage.

There have been many transit demonstration grants over the past 12 years and they have been made to almost every city in America. While the general results of the demonstrations are quite evident in increased ridership and an improved public image for transit, the results necessary for further detailed improvements in the system have not been forthcoming. The reason is that there is not an accepted model of bus ridership that can be used to document the findings and results of transit demonstrations.

The need for a detailed design model for bus transit ridership is clearly documented.[1] In the day-to-day operation of bus companies there is no way to estimate the ridership effects of changes in headways, route extensions, fare increases, crowding on buses, increasing Central Business District (C.B.D.) parking rates, changes in the cost of gasoline, and so forth. While rules of thumb, such as the 30 percent shrinkage factor for fare increases, are used there is no method for correlating and combining the observed effects of other, more recent, fare changes into these rules.

For example, the City of Atlanta[2] in March 1972 purchased the privately owned Atlanta Transit System. Over the next year or so the system: (a) lowered the fare to fifteen cents, (b) purchased 490 new buses, (c) improved headways, (d) expanded service periods, (e) extended lines, and (f) created five new lines. The result was an overall 30.2 percent increase in transit ridership by June 1973. A study of rider characteristics

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[1]Shortreed, J., Editor, Urban Bus Transit: A Planning Guide (Ontario, Canada: Transport Group, University of Waterloo, 1974).

[2]Metropolitan Atlanta Rapid Transit Authority, The Effects of Fare Reduction on Transit Ridership in the Atlanta Region, Atlanta, 1973, Volumes 1 and 2. See also Kiepper, A.F., et al., "Impact of Immediate-Action Transit Improvements," Highway Research Record 475, Highway Research Board, Washington, D.C. 1973.

was made identifying new and old riders and the characteristics of each. However, information is not available by route and without such a breakdown it is impossible to identify the effect each of the six separate improvements had on transit ridership. Some system-wide analyses have been done in several cities and these are discussed in Chapter 4.

The story is similar for almost every city in America. With new sources of funds, public ownership and so forth, there have been new routes, new buses, new hours, and more passengers. The city of Austin since 1972 has increased route miles by 77 percent and reduced off-peak fares to 15 cents. Ridership has increased from 300,000 per month to 500,000 per month, but again little or no information has been collected to identify what the effect of each change was and, therefore, what further changes should be made to fine tune the system.

The general need for a modeling framework for documenting the effects of design variables on transit ridership was well put by Horton and Louviere.[3]

> One response of those interested in mass transportation issues has been to rely heavily on demonstration projects in order to provide evaluation of alternative systems. Such demonstration projects seem to provide answers in only the narrowest of contexts to the most pressing questions in urban transportation: what is the result of changing the parameters of the various transportation and related systems on mode choice? What are the effects of facility construction and implementation on our urban areas? Although experimentation may seem odious to many social scientists, it appears that the day is here when we must realize that more precise information as to the impact of changes in transportation systems on various urban subsystems is a necessity. One way in which this information can be collected is through a directed program of rigorous experimentation. In this view demonstration projects are not rigorous experiments since too many variables are left uncontrolled and only the "total effects" can be observed. What is really needed is information as to the changes in each of the system parameters which will result from changes in any of the others.

The Basic Modelling Approach

The model developed in this study was conceived as empirically based and pragmatic. Its form and structure will not please most theoretical model

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[3] Horton, F.E., and J.J. Louviere, "Behavioural Analysis and Transportation Planning: Inputs to Transit Planning," Transportation, Vol. 3, Elsevier, Amsterdam, 1974.

builders. It is felt that this approach is appropriate given the lack of existing data and results in the literature of analyses which have effectively determined the effect of one factor while accurately controlling for all the other factors.

The approach taken was patterned on the Highway Capacity Manual which was first presented as a very rough empirical model in 1950.[4] This model provided the framework for a data collection effort as a part of regular operational duties, which made possible a much more advanced and useful approach to determining road capacity - the 1965 manual.[5] This latter manual is providing good basic guidelines for determining the effects of design details based on a broad empirical data base. It is hoped that the model prepared here may be the start of a similar process for developing a method for ridership on urban transit routes.

Another attribute of the model is that it attempts to include, however crudely, the effects of all the important variables. The variables of concern are illustarted in Figure 1.1 and listed more fully in Table 1.1. The model must take into account the effects of these factors on ridership.

There are currently a number of different types of models available for estimating transit ridership, none of which is suitable for operational planning for one reason or another. They are

(1) Urban Transportation Planning Models, incorporating modal split procedures.[6,7] These models are for planning system wide and are generally too expensive for day-to-day use.

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[4]The Highway Research Board, Highway Capacity Manual, Washington, D.C., 1950.

[5]Highway Capacity Manual, Special Report 87, Highway Research Board, Washington, D.C., 1965.

[6]Weiner, E., "Modal Split Revisited," Traffic Quarterly, Saugatuck, Connecticut, January 1969.

[7]Shortreed, op. cit., Chapter 2, "Transit Demand."

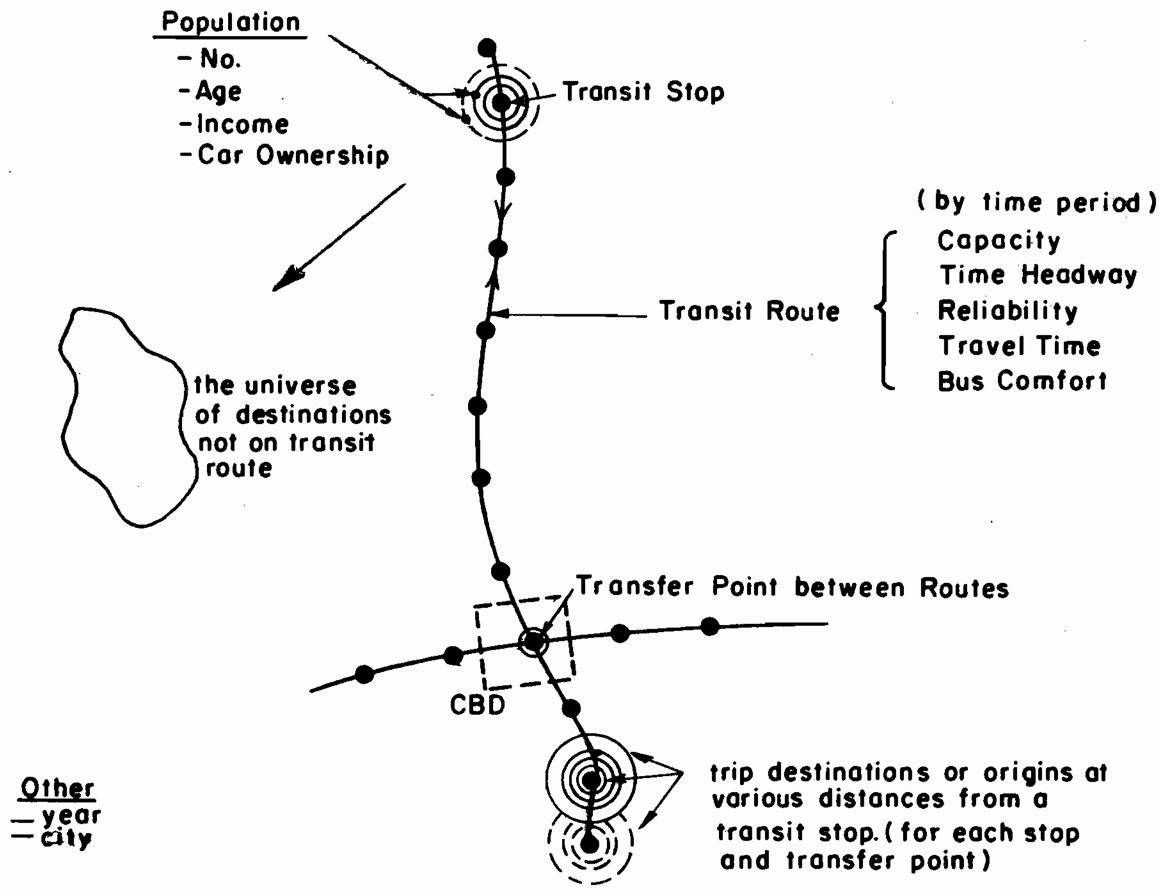

Figure 1.1. TRANSIT TRIPMAKING

TABLE 1.1. VARIABLES AFFECTING TRANSIT RIDERSHIP

Population Variables

- Population
- Age
- Income
- Time (historical)
- Car ownership

Route Variables

- Type of area
- Potential destinations
- Route location
- Bus headways
- Reliability
- Travel time

Bus Variables

- Fare
- Capacity
- Age, appearance and comfort

Other Variables

- Marketing
- Information Services
- Characteristics of alternative modes
- Time of the week, and of the day
- Other city factors

(2) Changes in Ridership Models. Changes in existing ridership are predicted based on elasticities.[8,9] These models are useful but limited in scope and do not provide an overall comprehensive framework.

(3) Detailed Rule of Thumb Methods. Typically used by Transit properties, these involve house counts on routes and local rides per capita standards. These are useful and, in fact, the model in this study is an extension of these methods.

(4) Direct Demand Models.[10,11] Using cross-section data, elasticity type models are developed which predict the level of ridership as a function of population and systems factors.

(5) Attitudinal Approaches to Demand.[12,13] Psychometric methods are used to determine the most appropriate factors for design improvements.

(6) Other approaches, including the systems approach.[14]

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[8] Boyd, J.H., et al., Demand for Urban Bus Transit: Two Studies of Fare and Service Elasticities, Institute for Defense Analysis, Arlington, Va., 1973, (NTIS-BP224-943).

[9] Carstens, R.L., "A Model for Estimating Transit Usage in Cities in Iowa," Highway Research Record 213, Highway Research Board, Washington, D.C., 1968.

[10] Domencich, T.A., G. Kraft, and J. Valette, "Estimation of Urban Passenger Travel Behavior: An Economic Demand Model," Highway Research Record 238, Highway Research Board, Washington, D.C., 1968.

[11] Aldana, E., R. de Neufville, and J. Stafford, "Microanalysis of Urban Transportation Demand," Highway Research Record 446, Highway Research Board, Washington, D.C., 1973.

[12] Hartgen, D.T. and G.H. Tanner, "Investigations of the Effect of Traveler Attitudes in a Model of Mode-Choice Behavior," Highway Research Record 369, Highway Research Board, Washington, D.C., 1971.

[13] Keller, W.F., "Method for Development of a Mass Transit Evaluation Model Based on Social System Values," Highway Research Record 427, Highway Research Board, Washington, D.C., 1973.

[14] Tomazinis, A.R., "Forecasting Travel Demand for New Urban Transportation Systems," Highway Research Record 392, Highway Research Board, Washington, D.C., 1972.

Each of these methods produces reasonable estimates for specific planning tasks yet each has some disadvantages. For instance, the direct demand models do not incorporate the absolute limits on demand which are implied in the trip generation models of Urban Transportation Planning. The latter incorporate route structure in only a very general way and the coverage of a route within a traffic zone is not defined. Methods using elasticity methods generally do not allow for changing elasticities with levels of the variables which Boyd has shown to exist. House count methods do not deal satisfactorily with the number of destinations that are available for trips. These and many more disadvantages can be incorporated into a set of objectives for the model. The model should:

(1) be simple enough to be understood and used on a day-to-day basis,

(2) predict absolute levels of transit ridership,

(3) relate mainly to urban bus transit,

(4) select changes in ridership due to changes in any variable in Table 1.1,

(5) incorporate realistic limits of ridership levels given extreme values of the variables,

(6) be disaggregated by time of the week,

(7) use population data that are available from the census or other readily available sources,

(8) treat each route independently,

(9) provide inputs and outputs consistent with data normally collected by transit properties or data easily obtained with existing procedures, and

(10) avoid network methods because of their high cost in data preparation and computer analysis, but try to incorporate in surrogate ways their essential modeling strengths.

In developing a model, it is clear that not all objectives can be met with the same degree of satisfaction. When a choice had to be made the viewpoint of a medium-size city (50,000 - 300,000 pop.) bus transit system was adopted, on the basis that such a model would be useful, in a simpler form, to smaller cities, while larger cities would have access to more individually tailored methods and techniques, including network methods.

Aims of the Study

Given the model objectives and the basic philosophical approach to the model this study tried to accomplish the following aims:

(1) to put forward a model structure and variable definitions which would meet the objectives,

(2) to review the literature and incorporate any previous research results into the model structure and the preliminary estimates of the parameters, and

(3) to do a pilot survey of a few transit routes in Austin to determine if both the model and the proposed data collection methods for calibration were valid.

Outline of the Report

The next chapter presents the model definitions, the preliminary model structure, and most parameter values and contains the main conclusions.

Chapter 3 describes the field work and provides details and findings of the calibration process.

Chapter 4 provides a selective literature review and a discussion of the various factors affecting transit ridership.

Finally, Chapter 5 contains more detailed discussions of the model and makes recommendations for further work.

CHAPTER 2

THE PRELIMINARY MODEL AND CONCLUSIONS

Given the limitations of earlier modeling efforts and the philosophical basis of this work--as outlined previously--this chapter presents the definitions, preliminary structure, and parameter values for a new transit demand (bus ridership) model. This model predicts passenger trip ends for sections of a transit route for an average week day by time period. It is presently necessary to utilize additional local factors and indices[1] for

(1) seasonal variations,

(2) daily variations and peaks,

(3) revenue passengers given boarding passengers, and

(4) Saturday, Sunday, and evening service.

The model predictions of boarding and exiting passengers are adequate to determine maximum load point and expected revenue for an average day.

At present, the model is only applicable to a Central Business District (C.B.D.) route.

Definitions

Route. A transit route which follows a fixed path that either (a) leaves from and returns to the C.B.D. area or (b) is a self-contained crosstown route. A route is considered to start and terminate in the central business district even though it operationally continues through the C.B.D. Figure 2.1 illustrates the route definition.

C.B.D. Route. A transit route with a starting and ending point in the central business district or a route that operationally continues through the C.B.D. Note that the model at present pertains only

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[1] See, for example, Figures 2.1 and 2.2 in O'Brien, W., "Transit Demand," in Urban Bus Transit, A Planning Guide, Transport Group, University of Waterloo, Waterloo, Ontario, Canada, 1974.

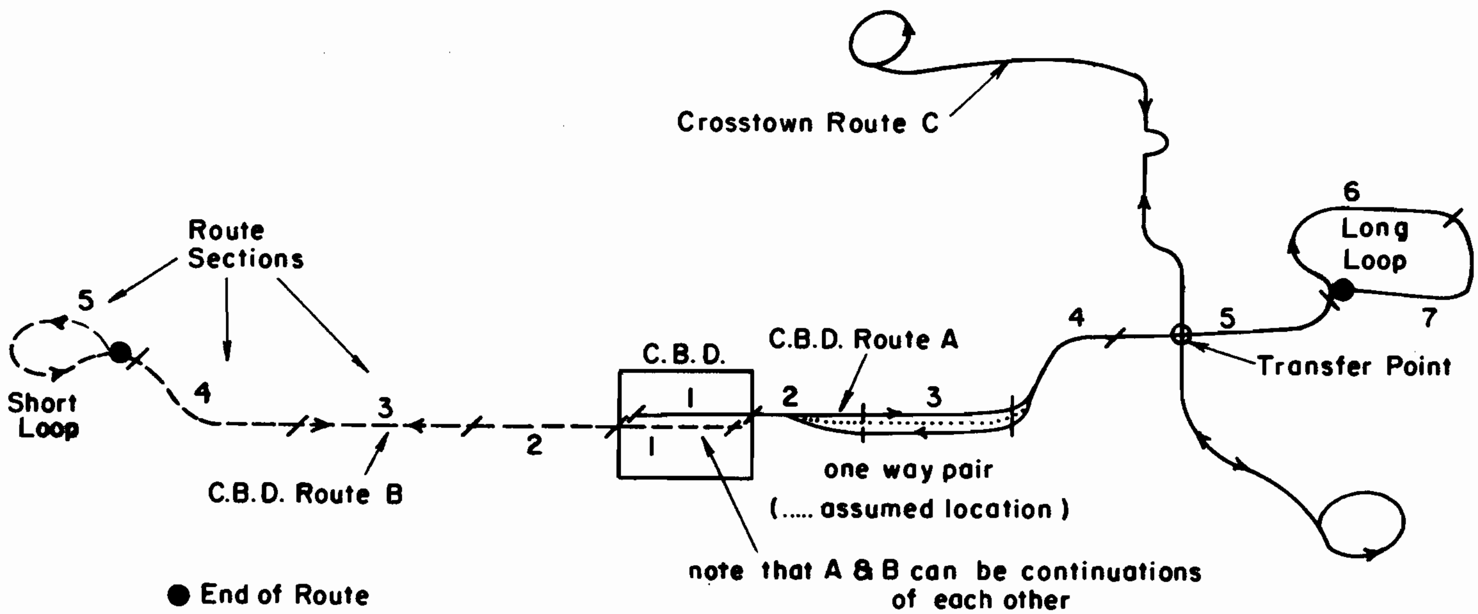

Figure 2.1. ROUTES AND SECTIONS

to that type of route.[2]

Crosstown Route. A route not connected to the C.B.D.

Section. Each route is divided into sections, usually four to eight sections per route. A section is generally one-half mile to two miles long (or a maximum of 10 minutes travel time). A section is homogeneous with respect to headways, overlapping routes, and general service characteristics. It is not necessary that it be homogeneous with respect to land use.

The maximum load point for the route should be at or near a section boundary; generally, this will be at the edge of section 1, which is at the C.B.D. boundary.

The number of sections should be kept as small in number as possible and should be compatible with data availability.

C.B.D. Boundary. For purposes of the model, the C.B.D. boundary defines the edge of the first section. In practice it was found quite easy to define. It is determined subjectively from the following factors:

(1) the location of the maximum load point,

(2) the limit of walk trips to the C.B.D., usually 2000 to 2500 feet,

(3) the dividing line between few residential land uses and predominant residential land uses, and

(4) the "grey" area of warehousing, light industrial use, and land use in transition, which generally circles a C.B.D. area.

Overlapping Route. Two C.B.D. routes are said to be overlapping if they are parallel and within 500 feet of each other.

Adjacent Route. Two C.B.D. routes are said to be adjacent if they are parallel to each other and more than 500 feet but less than 2000 feet apart. For purposes of the model the route trade areas are considered only up to the midpoint between adjacent routes.

Transfer Point. For this model, a transfer point is any point outside the C.B.D. route section where a transfer between a C.B.D. route and a crosstown route is possible. Transfers between routes within the C.B.D. are considered elsewhere in the model.

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[2] A review of routes for Atlanta in 1974 indicated that all 123 separately designated routes were C.B.D. routes. In Austin, 22 of the 24 routes (1975) are C.B.D. routes.

One-Way Pair. When a route utilizes a one-way street pair not on a route loop, the route is considered to be located at the midpoint of the two streets for purposes of defining the trade areas.

Short Loop. A one-way route location at the end of a route and less than ten minutes long. The area within the loop is assigned to the closest route for defining the trade area. Short loops are assigned to one section.

Long Loop. A one-way loop more than ten minutes long. It is divided into two sections and each section is treated as a separate route section; the distance to the C.B.D., etc., is taken along the route direction.

Route Location. The actual path of the route or, for one-way street pairs, the midpoint path.

Prime Trade Area[3]. The area within 500 feet of the route location.

Secondary Trade Area[3]. The area from 500 feet to 1000 feet of the route location.

Land Use. A general term to denote population location and characteristics and employment location and type as well as other land use variables such as commercial frontage and square feet of retail floor area.

Household Land Use. Land use variables associated with home-based trip ends.

Attraction Land Use. Land use variables associated with non-home-based trip ends.

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[3]The break points of 500 feet and 1000 feet were selected because (a) they generally correspond to two blocks and four blocks and (b) many studies have shown that the majority of bus riders walk less than 500 feet, and very few walk more than 1000 feet. C. W. Barnes (Crosstown Line 9 - An Evaluation of a New Route, Sacramento Transit Authority, 1971 NTIS-PB 198-138) found that 95 percent of all bus trips origins and destinations were less than one eighth mile from the route. The Austin Transit Study (City of Austin, 1972) found that 78 percent of all bus riders walkes less than 500 feet.

Target Households[4]. The number of households residing in dwellings with a census definition value in 1971 of $13,000 or less or, alternatively, paying a census definition contract rent of $105 per month or less in 1971. These dollar limits are to be adjusted over time according to a constant dollar value.

Other Households[4]. The number of households residing in dwelling units with value greater than $13,000 or paying contract rent greater than $105 per month, in 1971 dollars.

Total Employment. The total number of jobs in 1000's within 750 feet of the route location. This does not vary in situations of overlapping or adjacent routes; all jobs within 750 feet are included.

Retail Employment. The number of retail jobs within 750 feet of the route location, without qualification. Note that in this study such a measure was not available and a surrogate measure of 1000's of linear feet of commercial land use was used.

School Enrollment. The student enrollment for all schools within 750 feet of the route location that have students who can use the bus. In this study all junior and senior high schools were included.

The C.B.D. Attractor. In some equations the C.B.D. is used as a 0 or 1 variable. It is used as a surrogate variable to represent all the C.B.D. transfers from other routes in the city for the time period.

Other Attractors. This refers to special traffic generators for transit such as hospitals, medical centers, universities, and welfare offices. In this study a 0 or 1 variable was used to represent The University of Texas' 40,000 students. Its employees were treated in the normal way.

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[4]Appendix A gives the background for this definition of target and other population groups.

[5]See, for example, Barnes, op. cit.

Time periods. There is a separate model for each of the following weekday time periods:

(1) 6:00 a.m. to 9:00 a.m.

(2) 9:00 a.m. to 3:00 p.m.

(3) 3:00 p.m. to 6:00 p.m.

At some future time the evening off-peak period and the Saturday and Sunday periods could be added.

Inbound. When a route direction is toward the C.B.D. it is inbound. See Figure 2.2.

Outbound. When a route direction is away from the C.B.D. it is outbound.

On's. The number of boarding (not revenue) passengers entering the route buses in a section for a given route direction and time period.

Off's. The number of exiting passengers leaving the route buses in a section for a given direction and time period.

Up Route Sections. All sections up-stream (for the route direction) of the given section, not including the given section, up to and including the C.B.D. or the End of Route Section. See Figure 2.2.

Down Route Sections. All sections down stream (for the route direction) of the given section, excluding it, down to and including the C.B.D. or the End of Route Section.

Fare. The average fare per time period per boarding passenger.

Headway. The scheduled time headway for a route and section in a time period. In the case of overlapping routes the headway for a section is the combined time headway for all routes. The resulting On's and Off's are, of course, allocated proportionally to each of the overlapping routes.

Reliability. The degree of adherence to the schedule. No definition of this variable is included. See Chapter 4 for some suggestions.

Capacity. The probability of not having a seat in a time period, for a section of a route.

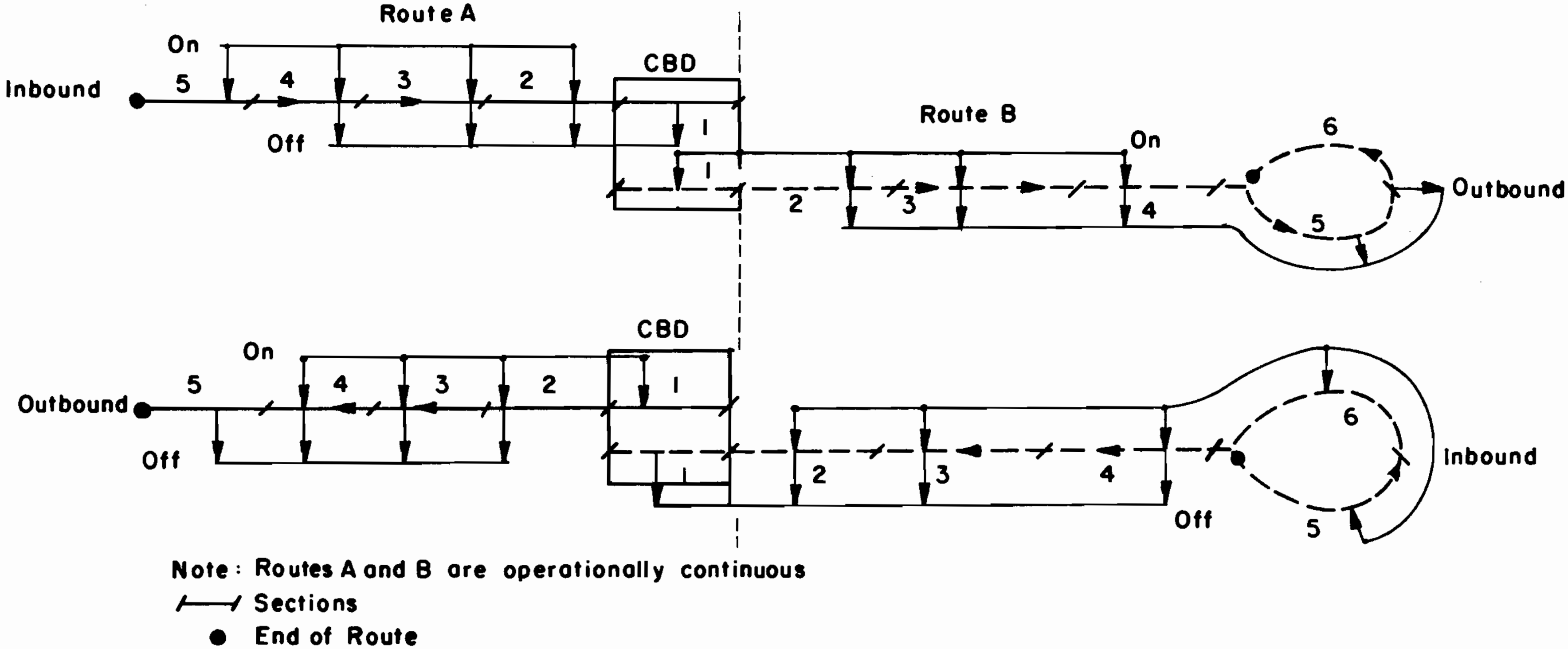


Figure 2.2 DEFINITION OF RIDERSHIP VARIABLES

Bus Condition. A measure of:

(1) bus age,

(2) bus condition,

(3) air conditioning, and

(4) marketing program (image).

Currently no measure of this variable is available.

Normal Conditions. The average level of Reliability, Fare, Headway, Capacity, and Bus Condition over all bus routes in North America. For these conditions no adjustment factors are necessary.

Adjustment Factors. A series of multiplicative adjustment factors for non-normal levels of Reliability, Fare, Headway, Capacity and Bus Conditions, one factor for each variable.

Car Cost. A variable (along with its associated adjustment factor) which is the generalized cost difference for a trip from a section to the C.B.D. by transit and by car. This is the variable which would respond to changes in parking charges, gasoline price increases, and so forth. The associated factor is used only with another population.

City Factor. A city-by-city factor to reflect differences in local habits, types of employment, working times, store hours, and so forth. It would be estimated locally for each time period.

Major Model Assumptions

The model depends on a series of assumptions which are mainly true but are violated by a small percentage of cases. These assumptions allowed the model to incorporate the main attributes of network (or origin/destination) models in a strictly trip-end model formulation. The assumptions rest heavily on the current structure of bus routes in North America as C.B.D. oriented routes in a suburban growth city. The major underlying philosophy of the model is discussed in Chapters 3 and 5.

1. There is no travel from a section to itself in the direction of travel.

2. There is no travel on a route which continues through the C.B.D. or the end point of a route. On the same route where a loop is composed of two or more sections the route end point is defined as in Figure 2.2, so that in fact the whole loop acts as the last section. Thus in effect there is no travel wholly within the loop itself.

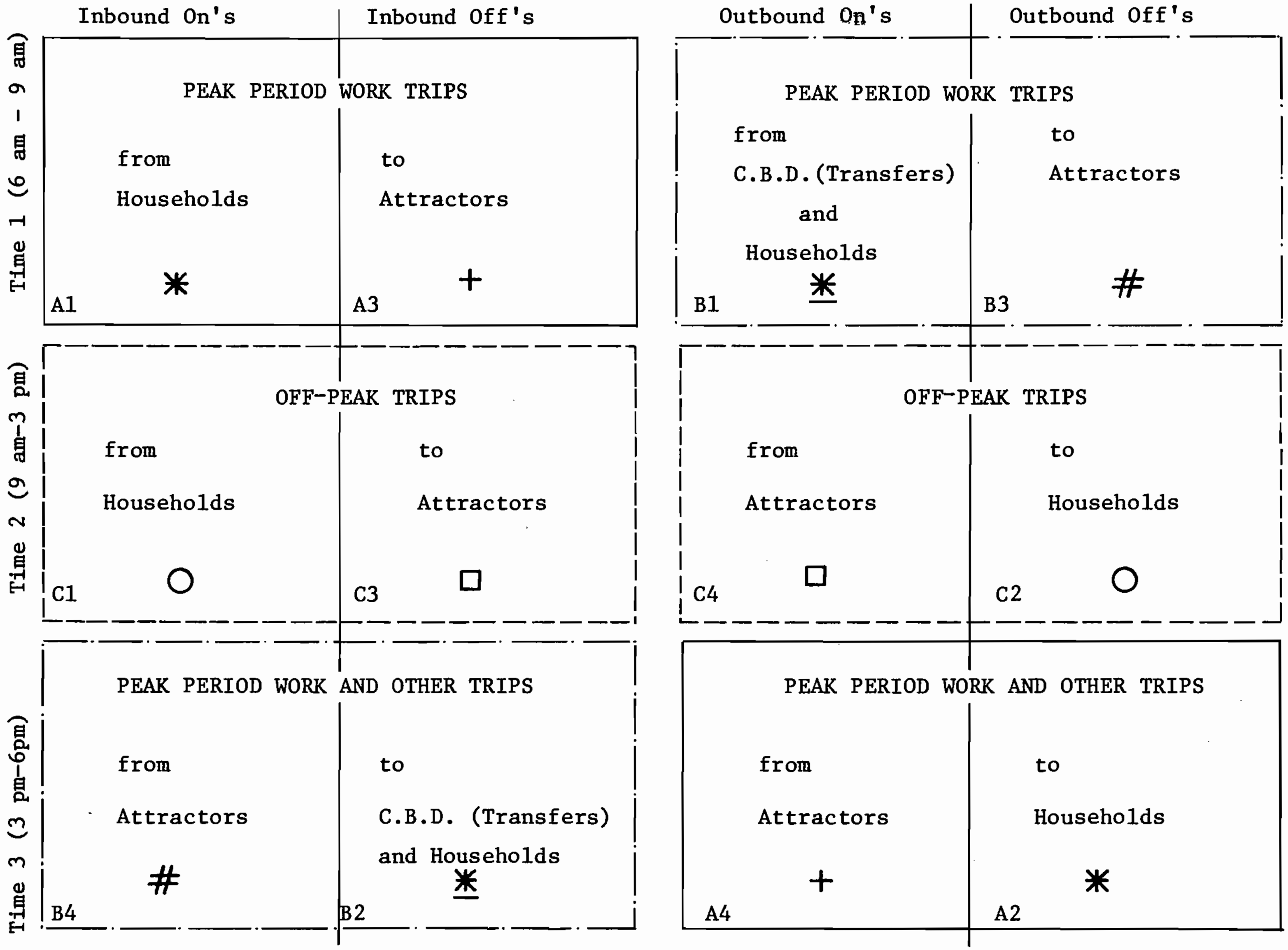
3. The movement of bus riders is basically from Households inbound to Attractions and then outbound from Attractions to Households for the predominant trip purpose in each time period only. In other words, the model does not recognize the trips for minor trip purposes and direction in an explicit way. However, as with all these assumptions, since the model parameters are estimated from actual data, these effects are represented indirectly in the parameter estimates, although very poorly in a model structural sense.

4. The model attempts to estimate absolute levels of On's and Off's by explicit consideration of the downstream destination, when estimating the On's in a section. Conversely, upstream origins are considered when estimating the Off's in a section.

5. Figure 2.3 shows in a graphical manner the assumed major land use determinants of On's and Off's, for the different time periods and inbound and outbound directions. There are three major types of trips indicated by the heavy outlined boxes: A, Peak Period major direction Work Trips; B, Peak Period minor direction Work Trips; and C, Off-Peak Trips. The symbols in the boxes indicate where similarity of the coefficients can be expected. The letters in the boxes correspond to the model equations.

6. The model parameters can be estimated from linear regression analysis using observed data for On's and Off's by section for each time period. In the regression analysis all equations were forced to have a zero intercept. See Chapter 3 for a further discussion of the calibration procedure and findings.

FIGURE 2.3. BASIC MODEL STRUCTURE



The Model Equations[6]

A. Peak Period Major Direction

A1. On's Inbound, Time Period 1 (going to work)

$$\text{On's in Section} = \left\{ \underset{(.0007)}{.0049}(\text{TGTHH})(\text{SMA}) + \underset{(.0083)}{.0014}(\text{OTRHH})(\text{SMA})(\text{CAR\$}) + 5.0\text{T}^{7} \right\} (\text{HF})(\text{AF})$$

$$\overline{Y} = 26.84(34.3),\ R^2 = .78,\ \text{S.E.} = 16.9.$$

where

TGTHH = (Target Households in the Prime Trade Area) + (0.16)(Target Households in the Secondary Trade Area),

$$\text{SMA} = \sum_{\substack{\text{Down}\\ \text{Route}\\ \text{Sections}}} 1.0\ \text{EMP} + 0.08\ \text{COM} + .009\ \text{SCH} + 9.3\ \text{UT}$$

EMP = Total employment in each down route section, (in 1000's),

COM = 1000's of feet of commercial frontage in each down route section,

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[6]The California Biomedical Statistical Package stepwise regression program was used to estimate all equations. When a zero intercept is forced by the program user, the standard deviation for $\overline{Y}$ is taken about 0 and the resulting R^2 is higher than normal. All other statistical indicators are as usual. The corresponding R^2 for equation A1 calculated in the usual way is about .6 or .65. R^2's shown here, of .85 to .90, correspond to actual R^2's of about .75 to .80. This should be kept in mind when reviewing the equations. The standard error provides a good value for comparing equation fit.

In considering the partial regression coefficients the test t value for all equations for a one-tailed test t at the 5 percent level is t = 1.73. No equation was estimated where the sign is incorrect. This holds control for multicollinearity problems in a situation of prototype models and interdependent variables.

The coefficients in SMA are inputs and should correspond to the coefficients in Equation A3.

All model estimates are based on 26 sections.

[7]The coefficient for T, of 5.0, was estimated arbitrarily for all time periods. A special study will be necessary to estimate these coefficients.

UT = 0 or 1 variable representing The University of Texas student body (40,000),

OTRHH = (Other Households in the Prime Trade Area) + 0.16 (Other Households in the Secondary Trade Area),

CAR$ = Car Cost Factor, here set equal to 1.0 for normal conditions,

T = Number of transfer points in the section,

HF = Headway Factor - see values in this chapter (also for overlapping routes times a route share factor),

AF = Product of all other Adjustment Factors. Here set = 1.0 for all equations for "normal" conditions,

$\overline{Y}$ = Mean of the dependent variable for the four routes (26 sections) studied in Austin,

( ) = Standard deviation for $\overline{Y}$ or the regression coefficients,

R^2 = Multiple correlation coefficient for the regression equation, and

S.E. = The standard error for the regression equation.

A2. Off's Outbound, Time Period 3 (arriving home from work)

$$\text{Off's in Section} = \left\{ \underset{(.00093)}{.0059}(TGTHH)(SMA) + \underset{(.00011)}{.0018}(OTRHH)(SMA)(CAR\$) + 5.0\,T \right\} HF.AF$$

$$\overline{Y} = 36.11(47.01),\ R^2 = .74,\ S.E. = 25.36$$

where

$$SMA = \sum_{\substack{\text{Up Route}\\ \text{Sections}}} 1.0\ EMP + 0.44\ COM + .012\ SCH + 4.85\ UT$$

and all other variables were previously defined.

A3. Off's Inbound, Time Period 1 (arriving at work)

$$\text{Off's in Section} = \left\{ \underset{(.043)}{.26(EMP)(SMH)} + \underset{(.277)}{.199(COM)(SMH)} + \underset{(.0009)}{.005\ (SCH)(SMH)} + \underset{(3.01)}{2.11\ (UT)(SMH)} \right\} AF$$

$$\overline{Y} = 17.96(31.18),\ R^2 = .72,\ S.E. = 18.44$$

where

$$SMH = \sum_{\substack{\text{Up Route}\\ \text{Sections}}} \left[.00489\ TGTHH + .0014(OTRHH)(CAR\$) + 5.0T \right] HF$$

and all other variables were previously defined.

A4. On's Outbound, Time Period 3 (leaving work)

$$\text{On's in Section} = \left\{ \underset{(.027)}{.556(EMP)(SMH)} + \underset{(.170)}{.164(COM)(SMH)} + \underset{(.004)}{.0042(SCH)(SMH)} + \underset{(1.79)}{2.66(UT)(SMH)} \right\} AF$$

$$\overline{Y} = 36.26(61.90),\ R^2 = .94,\ S.E. = 15.28$$

where

$$SMH = \sum_{\substack{\text{Down Route}\\ \text{Sections}}} \left[.0059\ TGTHH + .0018\ (OTRHH)(CAR\$) + 5.0T \right] HF$$

B. Peak Periods Minor Direction

B1. On's Outbound, Time Period 1 (leaving for work, reverse flow)

$$\text{On's in Section} = \left\{ \underset{(9.95)}{34.4(CBD)} + 5.0T + \underset{(.0017)}{.0034(TGTHH)(SMA)} + \underset{(.0020)}{.0015(OTRHH)(SMA)} \right\} HF.AF$$

$$\overline{Y} = 18.89(29.3),\ R^2 = .73,\ S.E. = 16.55$$

where

CBD = 1 for the CBD section and 0 for all other sections; this represents transfers from all other routes. Note that CBD is not weighted by SMA.

$$SMA = \sum_{\substack{\text{Down Route} \\ \text{Sections}}} 1.0\ EMP + .08\ COM + .007\ SCH + 9.3\ UT$$

B2. Off's Inbound, Time Period 3 (arriving home from work)

$$\text{Off's in Section} = \left\{ \underset{(5.67)}{40.0(CBD)} + 5.0T + \underset{(.00053)}{.0010(TGTHH)(SMA)} + \underset{(.00062)}{.00141(OTRHH)(SMA)} \right\} HF.AF$$

$$\bar{Y} = 18.17(26.66),\ R^2 = .89,\ S.E. = 9.73$$

and

$$SMA = \sum_{\substack{\text{Up Route} \\ \text{Sections}}} 1.0\ EMP + .44\ COM + .013\ SCH + 4.85\ UT$$

B3. Off's Outbound, Time Period 1 (arriving at work, reverse flow)

$$\text{Off's in Section} = \left\{ \underset{(.066)}{.198(EMP)(SMH)} + \underset{(.00013)}{.0005(SCH)(SMH)} \right\} AF$$

$$\bar{Y} = 17.88(23.43),\ R^2 = .57,\ S.E. = 16.18$$

and,

$$SMH = \sum_{\substack{\text{Up Route} \\ \text{Sections}}} \left[.0049\ TGTHH + .0014(OTRHH)(CAR\$) + 5.0T \right] HF + 34.4\ CBD$$

B4. On's Inbound, Time Period 3 (leaving work, reverse flow)

$$\text{On's in Section} = \left\{ \underset{(.06)}{.051(EMP)(SMH)} + \underset{(.0096)}{.022(COM)(SMH)} + \underset{(.00008)}{.00012(SCH)(SMH)} \right\} AF$$

$$\bar{Y} = 14.2(17.74),\ R^2 = .55,\ S.E. = 12.7$$

and

$$SMH = \sum_{\substack{\text{Down Route}\\ \text{Sections}}} \left[.0060\ TGTHH + .0018(OTRHH)(CAR\$) + 5.0T \right] HF + 40.0\ CBD$$

C. Off Peak Period

C1. On's Inbound, Time Period 2 (leave home to shop, etc.)

$$\text{On's in Section} = \left\{ \underset{(.00053)}{.0049}(TGTHH)(SMA) + \underset{(.00051)}{.00098}(OTRHH)(SMA)(CAR\$) + 5.0T \right\} HF.AF$$

$$\bar{Y} = 32.09(38.6),\ R^2 = .85,\ S.E. = 15.74$$

and

$$SMA = \sum_{\substack{\text{Down Route}\\ \text{Sections}}} 1.0\ EMP + 1.0\ COM + .01\ SCH$$

C2. Off's Outbound, Time Period 2 (home from shops, etc.)

$$\text{Off's in Section} = \left\{ \underset{(.0006)}{.0049}(TGTHH)(SMA) + \underset{(.00077)}{.0018}(OTRHH)(SMA)(CAR\$) + 5.0T \right\} HF.AF$$

$$\bar{Y} = 29.68(38.5),\ R^2 = .81,\ S.E. = 17.59$$

and

$$SMA = \sum_{\substack{\text{Up Route}\\ \text{Sections}}} 1.0\ EMP + 0.5\ COM + .015\ SCH$$

C3. Off's Inbound, Time Period 2 (arrive at shops, etc.)

$$\text{Off's in Section} = \left\{ \underset{(.093)}{.714}(EMP)(SMH) + \underset{(.445)}{.504}(COM)(SMH) + \underset{(.015)}{.017}(SCH)(SMH) \right\} AF$$

$$\bar{Y} = 44.73(77.6),\ R^2 = .79,\ S.E. = 38.9$$

and

$$SMA = \sum_{\substack{\text{Up Route} \\ \text{Sections}}} \left[.0049\ TGTHH + .00098(OTRHH)(CAR\$) + 5.0T \right] HF$$

C4. On's Outbound, Time Period 2 (leave shops)

$$\text{On's in Section} = \left\{ \underset{(.053)}{.621(EMP)(SMH)} + \underset{(.236)}{.299(COM)(SMH)} + \underset{(.0085)}{.0086(SCH)(SMH)} \right\} AF$$

$$\bar{Y} = 36.48(64.89),\ R^2 = .89,\ S.E. = 22.92$$

and

$$SMA = \sum_{\substack{\text{Down Route} \\ \text{Sections}}} \left[.0049\ TGTHH + .0018(OTRHH)(CAR\$) + 5.0T \right] HF$$

General Comments about the Model

The difference in $\bar{Y}$'s for similar trips is due to the different number of sections inbound and outbound, because of the loops and model assumptions (see Figure 2.2). For instance, in C1, off-peak trips from home, $\bar{Y} = 32.09$, while in C3, the same off-peak trips arriving at shops, etc., $\bar{Y} = 44.73$. Some of this difference is also due to sampling error.

It is observed that the weights in SMA for Attractors in, say, Equation C1 should correspond to the coefficients for Equation C3. Conversely, the weights in SMH for Households in Equation C3 correspond to the coefficients in C1. The model was calibrated by an iterative procedure until an acceptable correspondence between weights and coefficients was reached. In some cases the coefficients for Attractors were not used as weights in SMA for the corresponding Household equation. This was because of very low significance of the partial regression coefficients for the Attractors. In these cases, there was an a priori estimate available which was used. The whole calibration procedure is discussed fully in Chapter 3.

Table 2.1 presents the results of a special set of regression runs for equation sets A and C where no up route or down route weights were used.

TABLE 2.1. COMPARISONS OF MODEL COEFFICIENTS AND DIRECT TRIP GENERATION RATES

	Land Use					
Equation	TGTHH (No. of Households)	OTRHH (No. of Households)	EMP (1000's EMP)	COM (1000's ft. frontage)	SCH (Enrollment)	UT (0,1 variable)
A1. Leave home	.0049	.0014				
Direct estimate	[.407]	[.220]				
A3. Arrive home			.26	.199	.005	2.11
Direct estimate			[1.87]	-	[.014]	[18.5]
A2. Arrive home	.0059	.0018				
	[.547]	[.262]				
A4. Leave work			.556	.164	.0042	2.66
			[4.45]	[.012]	-	[19.5]
C1. Leave home	.0049	.00098				
	[.482]	[.270]				
C3. Arrive shops, etc.			.714	.504	.017	
			[5.20]	-	[.02]	
C2. Arrive home	.0049	.0018				
	[.452]	[.288]				
C4. Leave shops, etc.			.621	.299	.0086	-
			[4.49]	[.117]	[.01]	[4.69]

While these equations fit the data almost as well as the model selected they are not recommended because they would not perform as well in a new situation, since there is no control on the absolute number of trips generated. The results are presented here to give an understanding of the trip generation rates and trip attraction rates implied by the model coefficients. The direct trip generation rates for the home end of the trips appear to be quite reasonable and in general agreement with those presented in Appendix A for the city of Calgary. There is a difference in the two estimates in the relative ratios between the coefficients for the target and other households. The model equations appear more reasonable in that they imply (given the respective number of households) about 20 to 25 percent of all riders would come from other households. The 1972 Austin Transit Survey found that 22 percent of the bus riders were riders who chose transit over other modes.

In general, the model coefficients seem reasonable, and during the calibration process all the household coefficients and total employment coefficients exhibited good stability in terms of their values and also consistently high significance levels.

The estimated values for the major Adjustment Factors (Fares, Headways and Car cost) are shown in Figure 2.4. Detailed discussion of these factors and their derivation is given in Chapter 4. Only the headway factor was used in the model estimation procedure. Examination of the residuals indicated that the estimated headway factor is reasonable. The car cost factor was tested and appeared to be plausible; it really requires further data for its more accurate determination.

The fare factor was not applied to the model estimate and thus the model equations are "normal" for an average fare per boarding passenger of 18 cents in the peak periods (1,3) and 10 cents in the off peak period (2).

The capacity and condition factors are discussed in Chapter 4 but it would be pure speculation to suggest any relationships at this time.

Model Data Requirements

While the model equations appear rather formidable, they are in fact quite easy to calculate and would normally be solved by a small computer

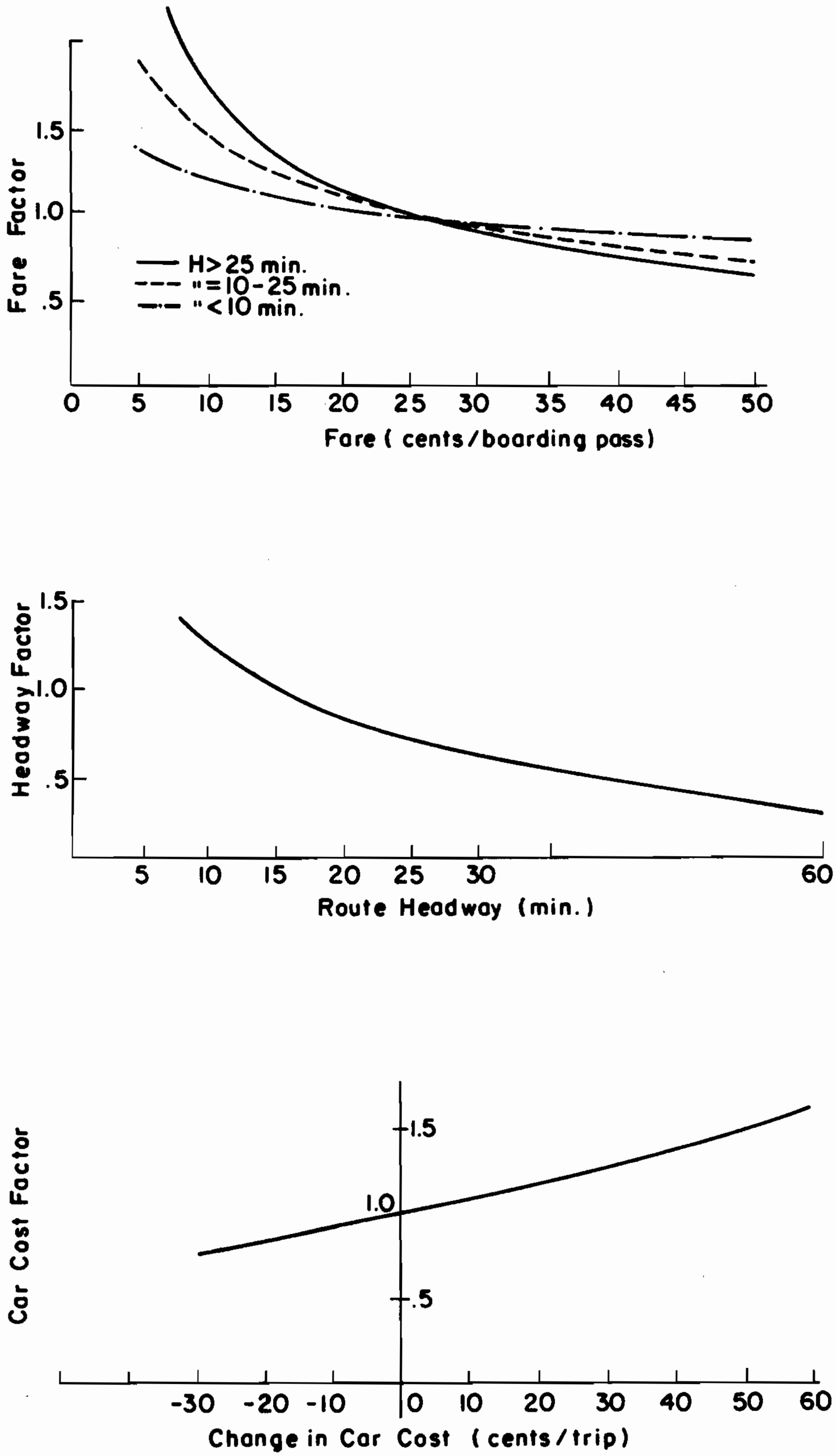

Figure 2.4. PROPOSALS FOR FARE, HEADWAY AND CAR COST FACTORS

program. The data requirements and procedure to apply the model are itemized below.

(1) Identify Route Location and the Route Sections, noting any adjacent or overlapping routes.

(2) Mark out the primary and secondary trade areas.

(3) Find the number of target and other households for each section and both trade areas. In the study this was done quite readily using block census data.[8] Another approach would be to use aerial photographs and census tract household data.

(4) Determine the 1000's of feet of commercial frontage in each section. This will probably be revised to commercial square footage in the ultimate model or retail employment.

(5) Estimate total employment and school enrollments within 750 feet of the route location for all sections. In Austin the determination of employment was a problem, due to lack of detailed locational data.

(6) Itemize other special generators (hospitals, C.B.D., universities, welfare offices, etc.) for each section.

(7) Identify the route characteristics (headways, fares, reliability, equipment, etc.) by time period.

Conclusions

(1) There is a need for a model of transit demand to provide a framework for determining the effect of changing transit route variables and location for use in design.

(2) The model structure proposed is comprehensive with all important variables included.

(3) The feasibility study results show that the model can be successfully calibrated utilizing boarding and exiting data from existing transit routes. For each route observation, all the model variables must be recorded.

(4) The model data requirements and analysis requirements are both modest and should encourage its wide usage.

(5) The model structure is logical and related to the expected land use variables and the predominant types of transit trip making.

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[8] U.S. Bureau of the Census, Block Statistics, Austin, Texas, Urbanized Area, Dept. of Commerce, Washington, 1971.

(6) The model should be reviewed by the appropriate institutional transit body to insure compatibility of all definitions of transit usage and land use. Then a program of data gathering should be instituted nationwide to provide data to fully calibrate the model.

(7) Some special studies will be necessary, utilizing origin/destination data to estimate parameters which cannot be estimated by regression analysis. For example, the coefficient for the secondary trade area households and the transfer coefficients.

CHAPTER 3

MODEL DEVELOPMENT, CALIBRATION AND THE AUSTIN FEASIBILITY STUDY

To test the feasibility of the modelling approach being proposed, as well as to refine the model structure, four transit routes in the city of Austin were studied. They were North Lamar, Holly, Burnet/Mesa, and Johnston. The first two and the last two operate as connected routes through the C.B.D. Figure 3.1 illustrates the general situation. The Holly and Johnston routes both have 30-minute headways and serve a lower income area. They are overlapping routes in section 4. In each case, the section 4 boundary is extended the width of the primary trade area away from the overlap sections.

The Burnet/Mesa and the North Lamar Route are both one-hour routes but have corresponding half hour overlapping routes up to the end of sections 5 and 4 respectively. The North Lamar route has extensive commercial development in sections 2, 3, and 4 and serves a medium income residential area. The Burnet/Mesa route has very extensive strip commercial development in section 5 and serves a high income residential area in sections 7 and 8. The four routes selected provided a good cross section of the variables and route conditions.

An on-board survey was conducted during February and March of 1975, during a period when Austin Transit was conducting a special passenger count program. Three or more round-trip runs were sampled in each time period for each route, using part-time, student help. The sampling consistency was not as good as it could be and the sample has probably a larger than normal variance. Table B-1 of Appendix B gives the control totals for this survey.

On each run the direction of travel as well as the on's and off's were recorded to the nearest street intersection. This was done to leave flexibility in defining the section boundaries. This proved to be unnecessary as the definition of section boundaries did not create any difficulties, using the definition given in Chapter 2.

The On's and Off's were factored up to the control totals from the Austin Transit passenger counts. In addition to the counts it was necessary

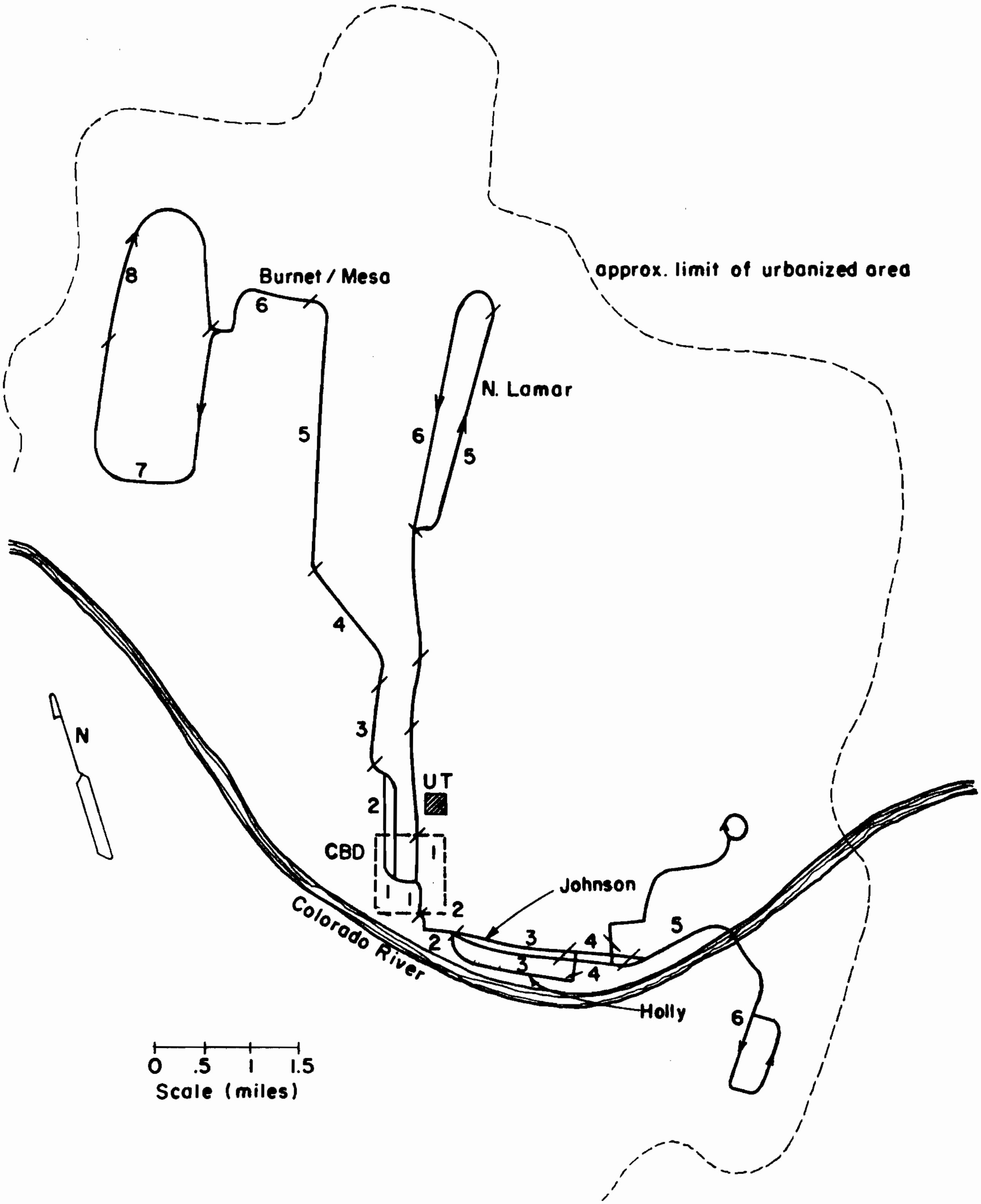

Figure 3.1. THE FOUR AUSTIN ROUTES STUDIED

to utilize daily revenue data recorded at the C.B.D. on each trip. The transit count program did not separate out routes as defined by this study, (C.B.D., out, in, C.B.D.). The resulting ridership data are given for each section in Appendix B. The On's and Off's follow the conventions introduced in Figure 2.2.

It should be emphasized that because of the random nature of the sample there are some inconsistencies in the ridership data. These would be avoided if the samples were taken in a continuous manner over a few days. This would then in turn improve the R^2 and standard errors for the estimated models.

The household land use data for each section were obtained very easily from the U.S. census block statistics. In the outlying areas household counts were brought up to date by reference to plats of recent subdivisions and aerial photographs obtained from the Austin Planning Department. These data are also shown in Appendix B for each section.

Considerable difficulty was experienced in obtaining data for attraction land uses within 750 feet of the routes. The available sources of data were

(1) 1974 employment by postal zip code drawn from Texas Employment Commission data. These data identify employees by mailing address, and, for instance, the central postal station post office box numbers were postal addresses for some 12,658 employees. Thus, these data have some drawbacks. On the positive side the data can be disaggregated by Standard Industrial Classification (S.I.C.) code.

(2) The 1972 Census of Business, has a section on Major Retail Centers which will have the number of retail establishments and retail sales for all major retail centers in Austin, for example section 5 on Burnet/Mesa. At the time of the study these data were not yet available.

(3) The City of Austin has developed a 1974 land use map with categories of commercial, industrial and several classes of residential land uses. The commercial land use includes many uses, such as offices and wholesaling, in addition to retail uses.

(4) The City of Austin completed a report on the core area of Austin in 1972[1] and this study developed locational employment data for the C.B.D., the Capitol area and The University of Texas, all in the core area. These employment data were divided by broad S.I.C. codes.

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[1] City of Austin Planning Department, Austin Tommorow: Core Area Technical Report, Austin, Texas, 1974.

(5) The Austin Independent School District maintained up-to-date information on school enrollments.

The study utilized the following classes of attraction land use variables:

(1) Total employment within 750 feet of a route estimated from data source (1). Many approximations were necessary.

(2) School enrollment from item (5) for all high schools and junior high schools within 750 feet of a route.

(3) The number of 1000's of feet of frontage of strip commercial along the route and within 750 feet. This was taken from item (3) above as a surrogate for retail employment and was judged to be more accurate than using the data available from (1). The Census of Business, (2), when available will provide a good basis for estimating the retail employment of major retail shopping centers. Fortunately, only the Burnet/Mesa route had any shopping centers on it and the effects were estimated in terms of equivalent 1000's of feet of commercial frontage.

The attraction land uses are shown in Appendix B. As indicated above, there is room for improvement in the measurement accuracy of the attraction variables used in the study.

The other variable of interest in Appendix B is the headway factor, which had to be estimated before any of the other parameters, and includes the route share factor. For example, consider section 5 of the Mesa route. It has an hourly headway but has an overlapping route on the half hour. The combined headway is one half hour and the headway factor is .6. This is multiplied by one half to reflect the route share, for a final factor of .3.

Model Structure

After considerable thought, a literature review,[2] and discussion, a model structure evolved which was based on

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[2] It is not the purpose of this report to present a literature review or discussion of model building, therefore the remarks are restricted to those which will aid in the understanding of the proposed model. The bibliography at the end gives a list of most of the papers and reports consulted during the course of the study.

(1) The nature of transit ridership. This led to the disaggregation into low income and non-low income groups, the definition of trade areas, the distinction between inbound and outbound movements, and the major model assumptions about On's and Off's.

(2) The design requirements of the transit industry: the use of three time periods and the inclusion of the other major design variables, route location, headway, fares, and bus condition.

(3) The elasticity approach. This approach is relatively well developed in transport demand models and was used as the basis for the adjustment factors, which are discussed in Chapter 4.

(4) The data limitations. The author would have liked to include some cross elasticities and interaction effects between certain variables. However, it was felt that the available data would not be sufficient for estimation of the required parameters. These sorts of refinements can be added at a future date once the model structure and its data requirements do not preclude these possibilities.

(5) The standard Urban Transportation Planning Process. The model equations are basically trip generation and attraction equations with the SMA and SMH terms (sum over possible attractions or households) representing a modified version of the gravity model. Also, the car cost term incorporates a modified choice modal split model into the equations for the higher income households.

6 The utility approach. The model has several adjustment factors for fares, headways, etc. which really are separate measures of the disutility of travel by either transit or car. Chapter 5 discusses the possibilities of developing a single utility based measure, but this is not proposed at the moment and may not be desirable if the model would become too complicated and difficult to understand.

The Effect of Distance

The gravity model has a term closely resembling one over the distance to a power, usually distance squared. The first model tried included such a distance factor within the SMA and SMH terms. Surprisingly it was not necessary. In fact in many cases the opposite seemed to be the case; distance to the C.B.D., the major trip attractor, was positively correlated (not significantly) to the model residuals when no distance term was used. This may have to do with the car cost factor as discussed later. The explanation for not needing a distance term was speculative. It may be that people who intend to use transit locate near a transit line and that this coupled with the fact that the C.B.D. is the major trip destination removes distance as a factor. This finding was well received as it considerably simplified the model calibration procedure.

The Use of a Zero Intercept

When the first regression analyses were done, equations with and without intercepts were run for all 12 equations. Comparison indicated that about 2/3 of the equations had a very low intercept while the others were quite significant. The standard errors were lower for the 0 intercept models in all but one equation. Moreover, logically it is desirable to have zero intercepts, so that if there is no land use there are no trips. Thus, the zero intercept form of the model equations was adopted.

Adjustment Factors

Only the Headway Factor was necessary to actually run the model for the Austin Study. During the first model runs, residuals for all equations were plotted against the Headway Factor and the partial correlation coefficients between this factor and the residuals were closely examined. There was no evidence of any relationship and it was therefore assumed that the proposed Headway Factor was plausible. In fact, the Headway Factor, the overlapping definition, and the assumptions about trade areas for adjacent routes were all involved in this test of plausibility.

The Car Cost Factor as proposed in Figure 2.4 can be applied to each route section in the sense that all costs for bus and car can be assumed to be fixed with distance except the cost of operating the car. A perceived operating cost of five cents per mile was assumed and a Car Cost Factor included in the model equations. The goodness of fit results were about the same with or without the Car Cost Factor and the values of the model coefficients for the target and other households were not significantly different. It was observed that the number of other households per section was correlated .75 with distance, which may explain the results. It was therefore decided not to use the Car Cost Factor on a distance basis, but rather to use it only to reflect overall changes in car costs relative to bus costs. When further data become available, especially for longer routes, the distance effect could be examined again.

Secondary Trade Area

At first coefficients for households in the Prime and Secondary Trade Areas were estimated separately in the regression equations. However, as might be expected there were very high correlations between the two trade areas for a given household class (.95 and .96) and as a result most equations ended up with one positive and one negative coefficient in the two trade areas. It was necessary to estimate one of the coefficients independently. The 1972 Austin Transit Survey found that 78 per cent of all bus riders walked less than 500 feet to the bus. Since, for the routes studied, households in the Secondary Trade Area outnumbered those in the Prime Trade Area by 1.77 to 1 a factor of .22/(1.77)(.78), or 0.16, was used to weight households in the Secondary Trade Area to get the equivalent number of prime trade area households. In this way each type of household was reduced to one variable in the regression equations. Clearly the validity of the 0.16 coefficient should be checked by further studies.

Transfers

The regression coefficients for transfers were never estimated with any degree of consistency or significance. An attempt was made to estimate this coefficient directly from the original street-by-street study data, but there was no way to distinguish which boarding or exiting passengers were in fact transfers. It appeared that two to four transfers per time period per transfer point was a reasonable estimate. Given that the average Headway Factor was .4 a coefficient of 5.0 was selected. More study is required.

Coefficient Values

Table 3.1 is taken from O'Brien[3] and shows the proportion of weekday average transit trips by time period and trip purpose for home origins and home destinations for Kitchener, Ontario. For instance, in Table 3.1 if we sum the first four time periods for school trips with home origins (column one) we get 1.0 or all of the average weekday school home origin trips. Similarly column 4 gives the distribution of all school trips with home destinations. Non-home-based trip ends have no separate origin-destination definition. In Kitchener non-home-based trips were only three percent of all transit trips.

Using:

(1) the coefficients in Table 3.1 adjusted to total 1.0 for three time periods,

(2) the proportion of trip purposes in Austin in the 1972 survey--home-based work, 54 percent; home-based school, 17.5 percent; and home-based other, 27.5 percent, and

(3) the average number of attractions for the routes studied--35.0 1000's of jobs; 33.0 1000's of feet of commercial frontage; and 1,823 school enrollments,

it is possible to estimate *a priori* the relative weights for the land use attraction equations. The convention of always setting the weight for total employment at 1.0 and adjusting the other weights relatively was adopted. Table 3.2 shows these estimated land use attraction weights for the Peak Period Major Direction and the Off-Peak Period equations. Also shown in Table 3.2 are the coefficients used as weights in the home-end model equations and the coefficients estimated in the corresponding attraction-end equations. Generally there is good correspondence. Some judgment was used in selecting the model values, especially when there were low t values for the corresponding regression coefficients. Some trial-and-error analysis was also done using the standard error for equations A1, A2, C1, and C2 as a criterion for selecting the model weights. As can be seen, the employment attraction consistently had a high t value. Also the coefficients had consistent values in the trial-and-error procedure.

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[3] O'Brien, W., *The Design of Transit Routes*, M.A.Sc. Thesis, Department of Civil Engineering, University of Waterloo, Ontario, Canada, 1974.

Table 3.1 DISTRIBUTION OF TRANSIT HOME ORIGIN TRIPS AND HOME DESTINATION TRIPS OVER THE TIME PERIODS FOR KITCHENER[4], ONTARIO (1972)

Time Period	Proportion of Trip Purpose Average Weekday Demand in Period						
	With a Home Origin			With a Home Destination			Non Home Based Trip Ends
	School Trips	Work Trips	Other Trips	School Trips	Work Trips	Other Trips	
1. Weekday 6 a.m. to 9 a.m.	.863	.764	.123	0.000	.106	0.0	Ø
2. Weekday 9 a.m. to 3 p.m.	.080	.155	.562	.255	.159	.400	.647
3. Weekday 3 p.m. to 6 p.m.	.039	.060	.160	.645	.608	.295	.289
4. Weekday 6 p.m. to 11 p.m.	.018	.020	.155	.100	.127	.305	.065
5. Saturday all day	.080	.401	1.6	.080	.401	1.6	Ø
6. Sunday all day	.000	.000	.43	.000	.000	.43	Ø

[4]Source, W. O'Brien, *ibid.*
Kitchener's population in 1972 was about 180,000

Table 3.2 COMPARISON OF ATTRACTION WEIGHTS: A PRIORI ESTIMATE, MODEL VALUES, AND REGRESSION COEFFICIENTS

Situation	Employment	Commercial	School	U.T.
A Peak Period Major Direction **a.m. Peak inbound**				
a priori estimates for A1	1.0	.08	.007	-
model values for A1	1.0	.08	.007	9.3
Regression coefficients	(.260)[1] 1.0[2] (t=6.0)[3]	(.199) .77 (t=.7)	(.0051) .019 (t=7.3)	(2.11) 8.1 (t=.7)
p.m. Peak out bound				
a priori estimates for A2	1.0	.37	.005	-
model values for A2	1.0	.44	.012	4.85
regression coefficients A4	(.556) 1.0 (t=13.0)	(.164) .30 (t=.96)	(.042) .075 (t=1.0)	(2.66) 4.80 (t=1.5)
C Off Peak Period **Inbound**				
a priori estimates for C1	1.0	1.94	.003	-
model values for C1	1.0	1.0	.01	
regression coefficients C3	(.714) 1.0 (t=7.7)	(.504) .71 (t=1.1)	(.017) .024 (t=1.1)	-
Outbound				
a priori estimates for C2	1.0	.54	.025	-
model values for C2	1.0	.50	.015	-
regression coeffieients C4	(.621) 1.0 (t=11.7)	(.30) .49 (t=1.25)	(.0086) .014 (t=1.0)	-

1 Actual regression 2 adjusted so Employment = 1.0
3 Critical t at 5% is 1.73

The model was calibrated by trial-and-error methods as each equation has weights which are related to the regression coefficients of another equation. The relationship for the household attractors is exact. That is, in equation A1 the regression coefficient for the target households is .0049 and in equation A3 the weight attached to target households is .0049. Only in the attractor weights was judgment introduced and relative adjustments made as described previously and as illustrated in Table 3.2.

The calibration process was stopped because of time resources as soon as it became clear that a reasonable model fit had been obtained. It is observed in Table 3.2 that some further refinement of the calibration was possible. However, since this was only a preliminary study this was not considered necessary.

Throughout the calibration the main coefficients maintained quite good stability. For example, the various regression coefficients obtained in the calibration procedure for the target households in equation A1 were .00511, .00489, .00497, and .00445. Results were similar for other households and the total employment variables.

The B equations, for Peak Period Minor Direction, were assigned weights from the results of equation set A, with the exception of the C.B.D. variable, which was calibrated. Except for the C.B.D. variable, the t values for these equations were not as good as for the other equations. However, because of the low number of trips and the importance of the C.B.D. variable, the standard errors of estimates were very good in comparison to the other equation sets.

Mixed Activity Model

For several time periods a so-called Mixed Activity Model was considered. These models attempted to include the minor activity direction (inbound from employment to households and vice versa) as well as the major activity direction (inbound from households to attractions and vice versa). For example, for time period 2 equation C1 in the mixed activity mode was

$$\text{On's in Section} = \left\{ \underset{(.0005)}{.0042}(\text{TGTHH})(\text{SMA})(\text{HF}) + \underset{(.0005)}{.00011}(\text{OTRHH})(\text{SMA})(\text{CAR\$})(\text{HF}) \right.$$

$$\left. + \underset{(5.4)}{.76}(\text{EMP})(\text{SMH}) + \underset{(.43)}{.066}(\text{COM})(\text{SMH}) + \underset{(.002)}{.003}(\text{SCH})(\text{SMH}) \right\} \text{AF}$$

where

$$\text{SMA} = \sum_{\substack{\text{Down Route}\\ \text{Sections}}} 1.0\ \text{EMP} + 1.0\ \text{COM} + .01\ \text{SCH}$$

$$\text{SMH} = \sum_{\substack{\text{Down Route}\\ \text{Sections}}} \left[.0049\ \text{TGTHH} + .0018(\text{OTRHH})(\text{CAR\$}) \right] \text{HF}$$

and all other variables as defined in Chapter 2.

While the coefficients are plausible the t values for the minor activity variable are quite low. The total R^2 was .846 and the household variables alone had an R^2 of .841, so little explanatory gain was made although theoretically the mixed model is more accurate. For other mixed activity equations there were considerable problems with colinear variables and the resulting unwanted negative coefficients. The mixed activity model could be calibrated using origin destination data rather than boarding and exiting data, but this would add considerably to the data collection costs. For all these reasons the use of a mixed activity model is not recommended.

Summary

A model was developed and calibrated for estimating boarding and exiting passengers on a transit route. The model was kept as simple as possible and more complicated forms such as the mixed activity model were rejected. The model restricts itself to modelling the major transit trip making activities. The model coefficients were stable and appear to have reasonable values.

The Austin feasibility study indicated that the data for a route could be obtained readily, except for some difficulty with total employment. The amount of work involved in collecting data to use the model was not excessive and indicated promise for the usefulness of the model in day-to-day transit design.

The data collection for calibration should not present any difficulties. A total of about 150 man-hours was expended to collect a ready-for-model input of all the land use and ridership data for the four Austin routes studied. With standardized procedures this could be reduced. It should be noted that the area of ridership data sampling for each section requires some attention.

Finally, the residuals were carefully checked against routes, distance from the C.B.D., households in sections, etc. and no omitted model variables were indicated. One exception was section 2 on the Holly and Johnston routes, where the model tended to underestimate trips from employment. This section has a lot of low income employment and this indicates that later revisions of the model should consider the inclusion of this variable. The difficulties with trying to include low income employment[5] in other modal split models would suggest that this would not be productive.

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[5] Vandertol, A. Transit Usage Estimates from an Urban Travel Demand Model, M.A.Sc. thesis, Dept. of Civil Engineering, University of Waterloo, Ontario, Canada, 1971

CHAPTER 4

ADJUSTMENT FACTORS

Headway Factor

The effect of Bus Headway on demand is an important factor and one which is not well documented. Most studies utilize the elasticity of demand with respect to headway (or alternative bus miles of service) for whole systems. Only a few studies have studied variation in time headway on a single route. The best source of data for individual routes is the Detroit Grand River Avenue Study.[1] For eight weeks in April and June of 1962, headways were cut from 20 to 70 per cent. The total number of weekly bus runs was increased from 80 to 147. The existing weekday headways were cut from 3½ to 2 minutes in the peaks, 6 to 3½ minutes in the daytime off-peak, and 15 to 10 or 12 to 10 minutes in the evening off-peak. Headways on express and weekend service were also cut.

The study results indicated that there was an advertising promotional effect during the study. That is, demand increased for several weeks at the beginning of the study and then was decreasing at the end of the study. The elasticities used were taken over the whole of the study period. The Grand River Corridor is a well established, heavile travelled, well serviced transit corridor and may not be typical of most urban bus routes. Also,the study did not control for the effects of increased capacity. During the peak periods, the increase in bus service would have drastically reduced or eliminated the number of standees. The effect of this on ridership is not separable from the headway effects.

The Grand River headway elasticity data are given in Table 4.1 and illustrated in Figure 4.1. The elasticities are probably overstated. The negative effects during the early morning periods are thought to represent riders switching from one time period to another, perhaps in response to increased frequencies or the resulting seat availability in the other time period.

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[1]City of Detroit, "Grand River Avenue Transit Survey," 1964, available from NTIS, PB 174-416.

TABLE 4.1. ELASTICITY OF DEMAND WITH HEADWAY CHANGES FROM THE GRAND RIVER AVENUE STUDY

Day of Week and Time	Headway Change (min.)	Percent Change in Riders	Percent Change in Service	Headway Elasticity
Friday				
12 pm - 6 am	20 - 15	- 6.4	28.6	- .23[4]
6 am - 9 am	3½ - 2	15.4	55	.27
9 am - 3 pm	6 - 3½	21.7	52.5	.41
3 pm - 6 pm	3½ - 2	26.9	55	.49
6 pm - 12 pm	15 - 10	24.9	40	.62
Monday				
12 pm - 6 am	20 - 15	-17.6	28.6	- .61[4]
6 am - 9 am	4 - 2	0.9	66.6	.01
9 am - 3 pm	5 - 3½	5.4	35.2	.15
3 pm - 6 pm	4 - 2	7.5	66.6	.11
6 pm - 12 pm	12 - 10	9.7	18	.54
Saturday				
12 pm - 6 am	24 - 20	- 1.6	18	- .09
6 am - 12 am	8 - 5	- 1.6	30	- .05
12 am - 6 pm	6 - 3½	8.1	53	.15
6 pm - 12 am	14 - 9	18.1	43	.42
Sunday				
12 pm - 6 am	24 - 19	-19.7	23	.85[4]
6 am - 12 am	18 - 9½	34.3	45	.76
12 am - 6 pm	16 - 9½	35.2	51	.69
6 pm - 12 am	20 - 15	63.0	28.6	2.20[4]

Source: City of Detroit, op. cit.

[2]The data were derived from two one-day passenger counts, on April 13, 1962, and June 1, 1962.

[3]A reduced Headway is shown as a positive increase in service.

[4]Calculated at the midpoints.

[5]These data points are not plotted in Figure 4.1.

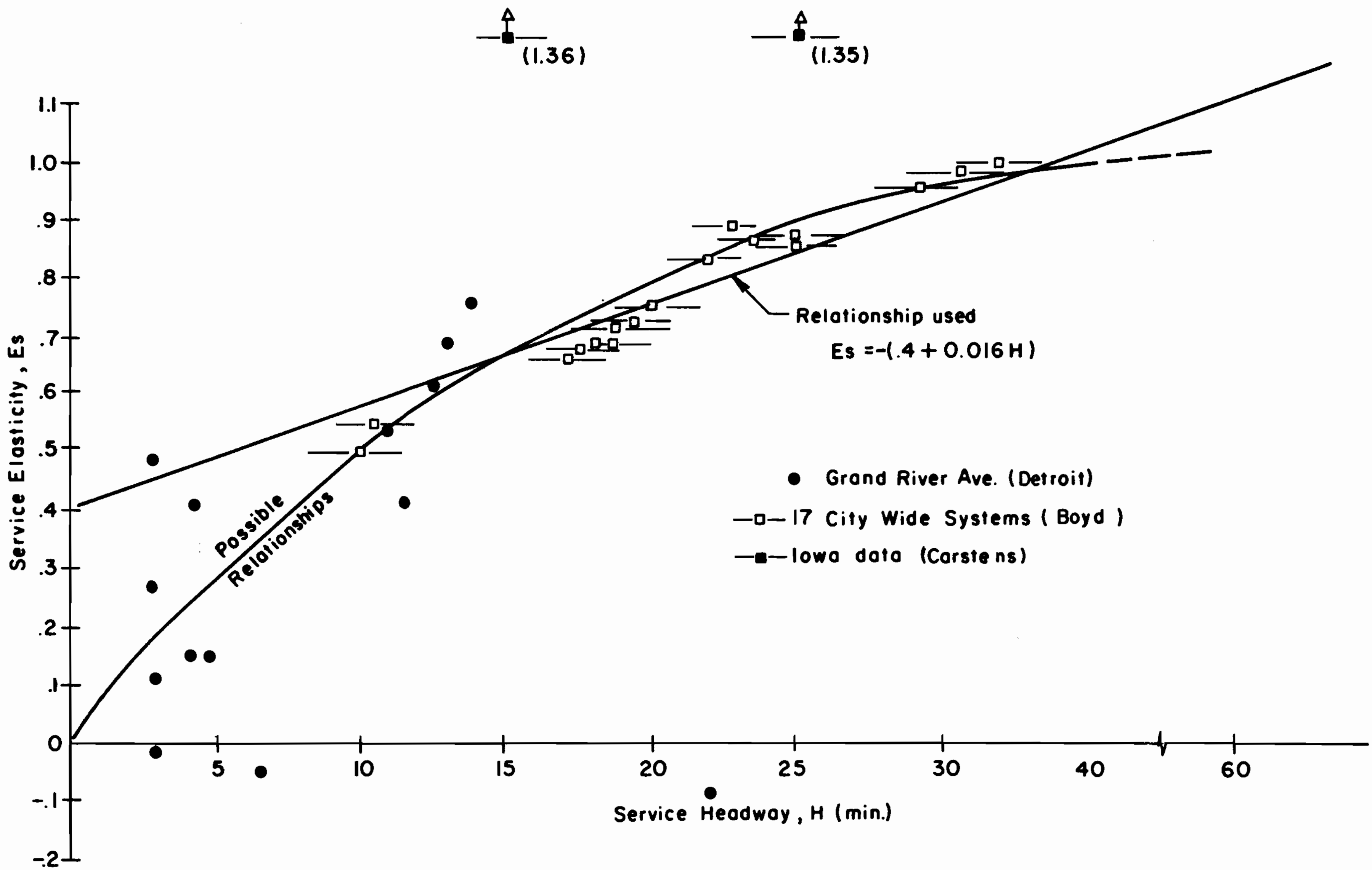

Figure 4.1. SERVICE ELASTICITY VS HEADWAY

Other studies have estimated the effects of headway (or service) changes on ridership. In Sacramento[6] eight routes were studied over the period of 1956-1968: however, no explicit estimates of service elasticity were made. A similar approach using industry-wide data was done by the Institute of Defense Analysis.[7] Year-to-year data for 17 transit properties (city populations 75,000 to 950,000) were studied using elasticity models estimated by regression analysis. The study notes that "estimates (of service elasticities) for each firm yielded approximately the same values as the regression results." The study estimated long-term constant service elasticities of .765 (standard error .096) and .838 (standard error .075) with different model forms. Using variable elasticity, model formulation service elasticities were 1,027 - 0.034 (bus miles/capita) and 1,073 - 0.049 (bus miles/capita). Bus miles per capita varied from 4.3 to 15.5 for the cities studied. The table showing the individual service elasticities is reproduced here as Table 4.2. These data are plotted on Figure 4.1 with the following assumption.

Bus Miles/Capita	Range-of-Time Headways
0 - 5	60 - 30
5 - 10	30 - 20
10 - 15	20 - 10
15	10

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[6] Barnes, C.W., Service Charges and Their Effects on Revenue Ridership and Riders per Mile, Sacramento Transit Authority, California, 1970. Available from NTIS, PB 197-821.

[7] Boyd, J.H., et al. Demand for Urban Bus Transit - Two Studies of Fare and Service Elasticities, Institute for Defense Analysis, Arlington, Virginia, 1973 (NTIS, PB 224-943).

TABLE 4.2. ESTIMATES OF THE ELASTICITY OF DEMAND WITH RESPECT TO THE QUALITY OF URBAN BUS SERVICE[8]

City	1970 Population[a] (x 1,000)	Bus-Miles Per Capita	Range of Service Elasticities[b]	Mean Value
1. Jacksonville, Fla.	530	10.0	.66- .84	.75
2. Savannah, Ga.	164	15.5	.33- .67	.50
3. Indianapolis, Ind.	820	7.5	.75- .97	.86
4. Louisville, Ky.	739	7.6	.77- .97	.87
5. New Orleans, La.	962	14.4	.40- .70	.55
6. Fitchburg and Leominster, Mass.	78	11.4	.58- .78	.68
7. Flint, Mich.	330	4.3	.82-1.18	1.0
8. Grand Rapids, Mich.	353	4.7	.82-1.16	.99
9. Springfield, Mo.	121	10.6	.63- .81	.72
10. Syracuse, N.Y.	376	11.7	.57- .77	.67
11. Charlotte, N.C.	280	11.3	.59- .79	.69
12. Raleigh, N.C.	152	7.2	.75- .99	.87
13. Harrisburg, Pa.	241	7.9	.73- .95	.84
14. Greenville, S.C.	157	8.1	.72- .94	.83
15. San Antonio, Tex.	773	10.6	.63- .81	.72
16. Charleston, W. Va.	158	11.3	.59- .79	.69
17. Green Bay, Wisc.	129	5.3	.81-1.11	.96

[a]Urbanized area populations, 1970 Census.

[b]Point estimate plus and minus one estimated standard deviation

[8] Reproduced from Boyd, J.H., *et al.*, *ibid*.

Carstens[9] studied 13 transit systems in Iowa using year-to-year data from 1955 to 1965. Ten of the cities had a population of less than 63,000 and the largest city was 207,000. He estimated a relationship between annual rides per capita and bus miles per capita of

$$\text{rides/capita} = -1.3 + 1.89\ (\text{bus miles/capita}) + 0.081\ (\text{bus miles/capita})^2$$

The calculated arc elasticities are all greater than 1.35 and increase with increasing service levels. Three points are plotted in Figure 4.1 using the approximation given above. Given that there was no control for fare in the relationship, these data are only used to indicate the possibilities of service elasticities greater than 1.0 for headways in excess of 20 to 30 minutes.

The Institute of Defense Analysis[10] utilized annual data for 51 bus transit firms in 1968 and 44 firms in 1960 in two cross-sectional analyses of transit demand. They formulated a form of a demand function:

$$\text{In Demand} = a\ (\text{bus miles/capita})^{-0.3} + c\ (\text{Fare})$$

The resulting estimates of service elasticity were

$$(1968)\quad \text{service elasticity} = 8.81 \left(\frac{\text{bus miles}}{\text{capita}}\right)^{-0.3} \quad \text{or} \quad 1.35$$

$$(1960)\quad \text{service elasticity} = 6.49 \left(\frac{\text{bus miles}}{\text{capita}}\right)^{-0.3} \quad \text{or} \quad .92$$

These values were "somewhat larger than expected" and are probably due to other variables not controlled for in the model. Later demand models

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[9] Carstens, R.L., "A Model for Estimating Transit Usage in Cities in Iowa," HRB Record 213, pp. 42-49, 1968.

[10] Wells, J.D., et al., Economic Characteristics of the Urban Public Transportation Industry, U.S. Government Printing Office, Washington, 1972 (No. 5000-0052).

by the same organization, previously discussed, show lower values. However, the change from 1968 to 1960 is in the expected direction, with lower service elasticities with higher levels of service (and corresponding lower headways).

Several studies with other objectives have also developed measures of service elasticities. Kemp,[11] using data for Atlanta, estimated service elasticities of 0.3, 0.33 and 1.13 using monthly data for different time periods and with different model forms. It is noted that the models and variables used are not "capable of giving anything approaching a definitive answer (on service elasticity)." Elsewhere Kemp[12] gives a survey of elasticity estimates and quotes elasticities of -0.71 for transit excess time for work trips and -0.59 for shopping trips. Reversing the sign for service elasticities these could be taken as possible estimates.

In summary, there has been little attempt to systematically study the demand effects of service or headway changes in bus routes while controlling for other factors. Figure 4.1 summarizes the best available information and a possible relationship between service elasticity and the existing service headway on a route is indicated. This relationship logically passes through zero. As the headway gets close to zero, or continuous service, the effect of service increments drop to zero. One area of concern is the values of service elasticity in the area of time headways from 60 to 30 minutes. No evidence could be found in this area.

For use in the model, it is more convenient to use a linear relationship for the elasticity:

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[11] Kemp, M.A., Transit Improvements in Atlanta - The Effects of Fare and Service Changes, The Urban Institute, Washington D.C., 1974.

[12] Kemp, M.A., "Some Evidence of Transit Demand Elasticities," Transportation 2, pp. 25-52, 1973.

if

$$\text{Elasticity} = a + bH$$

then[13]

$$\text{Demand} = (K\,H^{a}\,e^{bH})\,D_o \quad .$$

From Figure 4.1 the relationship used for the service elasticity is $-(.4 + 0.016\,H)$ and the resulting Headway factor in the demand equation is

$$\text{Headway factor} = 3.76\,H^{-.4}\,e^{-.016\,H}$$

The b coefficient is negative since headways get smaller as service gets better. It is noted that the assumed linear elasticity relationship is close to the possible relationship in the area of headways from 10 minutes to 60 minutes, which are most commonly found in practice. A more complicated form of the Headway factor can be estimated if the possible curve in Figure 4.1 is used, but this can be considered when better data are available. In practice the Headway factor itself would probably be estimated directly.

The Headway factor proposed has the following values and is plotted in Figure 2.4:

Headway (minutes)	Service Elasticity	Headway Factor ($3.76\,H^{-0.4}e^{-0.016H}$)
10	.56	1.27
15	.64	1.0
20	.72	0.82
30	.88	0.60
60	1.36	0.28

---

[13] $$\frac{dD/D}{dH/H} = a + bH$$

$$\frac{dD}{D} = a\,\frac{dH}{H} + b\,\frac{dH.H}{H}$$

$$\ln D + K' = a\,\ln H + b\,H + K''$$

$$\text{or } D = K\,H^{a}\,e^{bH}$$

Fare Factor

The literature on ridership response to changes in fares is very extensive. The question really is one of how can they all be utilized to estimate a fare elasticity and the corresponding Fare Factor?

The popular 30% shrinkage factor rule was developed by Curtin.[14] He utilized 77 fare changes which occurred between 1952 and 1963 in major bus properties and developed the equation

$$\text{Per cent loss in traffic} = 0.80 + 0.30 \text{ (per cent Fare Increase)}$$

In the original formulation there is a constant fare elasticity plus a constant term which could perhaps be thought of as a shock factor or a threshold effect. That is, during those years when there was a rapid growth in car ownership any fare increase would help to force or accelerate the car purchase decision.

Lassow[15] in studying the detailed aspects of a fare increase (in New York) found that with a fare increase from 15 cents to 20 cents there was a 10 per cent fall in ridership on the buses (elasticity, e, of -.3) but only a loss of 2.4 per cent (e = -0.07) on the subways. Furthermore, when considering time periods the results were

Time	Per cent Loss	e
7-10 a.m.	2.4	-.07
10 a.m.-4 p.m.	8.0	-.24
4-7 p.m.	5.0	-.15
7-11 p.m.	14.6	-.44

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[14] Curtin, J.F., "Effect of Fares on Transit Riding," Highway Research Record 213, Highway Research Board, Washington, D.C., 1968, pp. 8-20.

[15] Lassow, W., "Effect of the Fare Increase of July 1966 on the Number of Passengers Carried on the New York Transit System," Highway Research Record 213, Highway Research Board, Washington, D.C., 1968, pp. 1-7.

He also found that passenger losses were higher for low income areas than for commuter areas. He concluded that fare elasticities were higher for non-work trips and low income areas.

Similar differential results were found in Boston[16] in that "passenger traffic on the heavily travelled Reading line was the least responsive to fare reductions and increased service." Carstens[17] studied 30 "substantial" fare elasticities in Iowa for cities of less than 200,000 population. He found that "at high levels of (transit) service, elasticity is about -0.3 to -0.4, depending on city size. However, patronage is considerably more price elastic at low levels of service."

Rosner[18] in studying fare elasticity for the elderly using a telephone interview survey estimated off-peak fare elasticities due to a reduced fare program for the elderly in the off-peak period. There elasticities also include ridership shifts from the peak period. The resulting elasticities were

for the city of Pittsburgh e = -.58
for the rest of the Urban Area e = -1.275
for both combined e = -.763

Morlok[19] reports similar elderly fare elasticities of -.71 for Los Angeles and -.534 for New York. In both cases, we see the same situation of higher fare elasticities in lower service areas.

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[16] Maloney, J.F., Mass Transportation in Massachusetts, Mass Transportation Commission, Massachusetts, 1964 (NTIS, PB 174-422).

[17] Carstens, R.L., op cit.

[18] Rosner, E.S., Impact on Transit Ridership and Revenue of Reduced Fares for the Elderly, Carnegie-Mellon University, Pittsburgh, 1971 (NTIS, PB 204-432).

[19] Morlok, E.K., et al., The Effect of Reduced Fare Plans for the Elderly on Transit System Routes, Northwestern University, Evanston, Ill., 1971 (NTIS, PB 204-058).

Boyd[20] and Nelson[21] of the Institute of Defense analysis have utilized annual data for whole city transit systems to estimate transit demand models. Nelson estimated a model of the form

$$\text{Demand} = e^{-\alpha F} \cdot g(\ )$$

where

e = base of natural logarithms

α = fare elasticity parameters

F = Fare

$g(\ )$ = other variables

Two sets of cross-sectional data were used for 1960 and 1968 and the respective fare elasticities were -.81 (mean fare 18 cents) and -.67 (mean fare 22 cents). A number of other model forms were tried and the elasticities showed some stability; however, the standard error of the α was about 50 per cent of α. In this model form the fare elasticity is equal to $-\alpha F$ and is variable with fare and is 0 at zero fare. It is not clear that either of these conditions is true.

In the later study Boyd used longitudinal data for 17 transit properties for 10 years. He first used a constant elasticity model and controlled for time effects, including inflation. The report states that individual estimates for all firms were close to estimates for all firms combined. Moreover, the model estimated the elasticity for both the first and the second year after a fare change. The elasticity estimate was -.4747 for the first year and -.0585 for the second or a total of -.533 (standard error .088). In another model a fare elasticity of -.64 was estimated.

An attempt was made to estimate a variable elasticity model and found:

> There is no *a priori* reason for expecting fare elasticities to remain constant as the fare varies. Nevertheless, our attempts to estimate variations in the price elasticity gave no evidence that elasticity varies with fare.

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[20] Boyd, J.H., *op cit*.

[21] Chapter IV in Wells, J.D., *op cit*.

In one formulation, Boyd found a significant relationship showing fare elasticity varying with time (from 1960 to 1970) as

$$\text{fare elasticity} = -.896 + .032\,t$$

This could be due to the effect of lower levels of service and time headways over the decade. Unfortunately, the study did not test the relationship between fare and service levels directly.

Iowa City,[22] population 50,000, in 1971 reduced transit fares from 25 cents to 15 cents along with adding new buses and increasing levels of service. The result was an increase of 165 percent in ridership. As usual, the separate effect of each design variable is not determinable. However, prior to 1971 a private company operating 14-year-old buses had introduced fare changes in 1966, from 25 cents to 10 cents; then, starting in 1967, the fare was increased five cents at a time until 1970, when it was again 25 cents. Service levels were realtively constant during this period. The fare elasticity for this period was more or less constant and had a value of -1.05. There is a high level of university student ridership in Iowa City.

The town of Wilkes-Barre,[23] Pennsylvania, population 222,000, had free transit for 101 days in 1972 due to a flood disaster relief program. After this period a 15-cent fare was introduced and ridership fell 17 percent over the next six-week period. A very low fare elasticity is implied, quite contrary to the Iowa City results. It suggests that a constant elasticity model may be incorrect near the zero fare level. Scheiner in fact proposes a variable elasticity model, $e = -.06\,(\text{Fare})$.

Kemp[24] has done an excellent review of the literature on fare elasticities. As well as reviewing operational experience, he has reviewed the fare

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[22] Dueker, K.J., and J. Stoner, "Examination of Improved Transit Service," Highway Research Record 419, Highway Research Board, Washington, D.C., 1972.

[23] Scheiner, J.J., "The Patronage Effects of Free Fare Transit," Traffic Quarterly, Vol. 29, No. 1, 1975.

[24] Kemp, M.A., "Some Evidence of Transit Demand Elasticities," Transportation, Vol. 2, Elsevier, Amsterdam, 1973.

elasticities which result from models of modal split and also economic demand models. The latter two are important in that attempts are made to control for other variables besides fare. These latter studies support the concept of varying fare elasticities with varying conditions. For example, from a Boston[25] study, fare elasticities were -.1 for work trips, but -.32 for shopping trips.

Kemp argues that fare elasticities are dependent on the weaker of two trip-making determinants; (1) the desire to make the trip, and (2) the desire to make the trip by transit. The first relates to trip purpose; the desire for a work trip is higher than for shopping. The second relates to the available alternatives; for a C.B.D. journey on a rail system there would be few or no alternatives, and desire would be strong. Thus for a C.B.D. rail work trip, the fare elasticities would be low (-.1 to -.3), but for a suburban shopping trip on an infrequent bus, the fare elasticities would be high (-.4 to -.7).

Kemp concludes that

> short-run direct fare elasticities are characteristically observed to lie within the range of -0.1 to -0.7. A more precise value in a particular instance will depend on a variety of factors... in very large cities, central city areas, at peak hours, and in other circumstances where the prices of alternative modes are high, transit fare elasticities are usually numerically at the lower end of the range.

In subsequent articles[26] Kemp reported on fare changes in Rome and Stockholm which supported the previous conclusion. He also developed a model of transit demand, utilizing month-by-month statistics, which included variables for fare, time trends, service levels, and seasonal variations in demand. With this model he estimated the following fare elasticities:

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[25] Domencich, T.A., G. Kraft, and J. Valette, "Estimation of Urban Passenger Travel Behavior: An Economic Demand," Highway Research Record 238, Highway Research Board, Washington, D.C., 1968.

[26] Kemp, M.A., Reduced Fare and Fare-Free Urban Transit Services - Some Case Studies, The Urban Institute, Washington, D.C., 1974.

__________, Transit Improvements in Atlanta - The Effects of Fare and Service Changes, The Urban Institute, Washington, D.C., 1974.

San Diego (1972, decrease, 40¢ to 25¢), e = -0.4 to -0.45

Cincinnati (1973, decrease, 55¢ to 25¢), e = -0.38

Atlanta (1971, increase, 35¢ to 40¢), e = -0.4

Atlanta (1972, decrease, 40¢ to 15¢), e = -0.18

Kemp also quotes a fare elasticity of -0.7, estimated for Auburn, N.Y., population 30,000, which had a one month free fare experiment, reduced from a 25-cent fare, in 1973.

Another interesting finding was the variation in elasticity with length of time period. For Atlanta's 1972 fare decrease the results were

e = -0.16 for a 3-month period after the increase,

e = -0.17 for a 6-month period after the increase, and

e = -0.18 for a 12-month period after the increase.

This supports Boyd's findings of a large immediate effect of a fare change followed by a much smaller effect over the next year or more.

Finally, Kemp reports several instances of fare elasticities for demand responsive bus systems and taxicabs. It appears that their fare elasticities are about minus unity.

From the evidence reviewed to date, it appears that

(1) Fare elasticities range from -0.05 to -1.0.

(2) For a given situation fare elasticities can be assumed constant with changes in fare.

(3) Lower fare elasticities (-.05 to -.3) correspond to situations which also have correspondingly high levels of transit service (low headways, high capacity, C.B.D. work trips, preferential treatment, etc.).

(4) Higher fare elasticities (-.4 to -1.0) correspond to situations with low levels of transit service (20 minute or more headways, lower capacity, etc.).

(5) Fare elasticities increase up to one year after the fare change. Increases after the first six months are probably about 10 per cent of the first six months' effects.

(6) Fare elasticities are probably higher for fare increases than fare decreases.

Thus for purposes of the model it was decided to propose a Fare Factor based on constant elasticity which varies by time headways. This is based on the assumption that time headways on a route will adequately reflect the general route situation with respect to conditions governing fare elasticities.

The proposed fare elasticities are

Headway	Constant Fare Elasticity
10 minutes	-.2
10-20 minutes	-.4
25 minutes	-.6

The resulting fare factors are given in Table 4.3 and illustrated in Figure 2.4. This factor will be applied to each route as a whole. There is some evidence that different parts of the route should be treated separately, and in further work the use of a Fare Factor which would be applied at a section level could be considered.

Car Cost Factor

The selection of a factor for the modal split decision for the higher income group presented some difficulties. The study data were not adequate to calibrate such a factor and the literature gives a surfeit of models, most of which are too complex for the proposed model.

As discussed in Appendix A the breakdown between household types by income level is considered to divide the population into the transit "captive" and the transit "choice" categories. Clearly, not all the captive, or lower income, category are captive and this is reflected in the fare elasticity, the service elasticity, the fitted trip generation parameters, and so forth. However, for the choice group it was felt that an additional factor was required, both to express explicitly the modal split choice between transit and car and to allow the model to reflect policy decisions such as increases in downtown parking charges.

TABLE 4.3. PROPOSED FARE FACTOR

Fare Factor = CF^a (25¢ = 1.0)

Average* Fare (cents)	High Service (H<10min) C=1.90 a= -.2	Medium Service (H=10-25min) C=3.62 a= -.4	Low Service (H> 25min) 6.90 a= -/6
5	1.38	1.90	2.63
10	1.20	1.44	1.73
15	1.11	1.23	1.36
20	1.04	1.09	1.14
25	1.0	1.0	1.0
30	.96	.93	.90
35	.93	.87	.82
40	.91	.83	.75
45	.89	.79	.70
50	.87	.76	.66

*Revenue per boarding passenger.

The form of the model selected is that put forward by Pratt.[27] The model is illustrated in Figure 4.2 and gives the percent of trips by transit by the difference in generalized cost between transit and car.

The generalized cost includes fares, operating costs, travel time, waiting and walking time, comfort, etc.[28] One usual form of the curve in Figure 4.2 is the logit model:

$$\text{probability of taking transit for a trip} = \frac{e^{-\alpha(T - C)}}{1 + e^{-\alpha(T - C)}}$$

where

e = base of natural logarithms,

α = constant of calibration, and

T,C = generalized cost of the trip by transit and car.

The general form of the generalized cost difference relevant to a typical Austin trip could be

T - C = 3.0¢/min (travel time difference) + 6.0¢/min (out of vehicle time difference) + fare - parking charges/2 - 5¢/mile (trip length) + other cost difference.

or

T - C = Constant - 5 (trip length miles)

For a typical trip in Austin, the cost difference can be thought of as a constant difference less a distance term. For typical Austin trips the constant term is probably in the range from 50¢ to more than $1.00. Further research is necessary to fully define this factor but in the meanwhile a car cost factor can be selected to be applied only to routes serving the C.B.D. It is noted that any changes in parking charges, bus fares, etc. would be reflected in the constant in the above equation.

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[27] Pratt, R.H., "A Utilitarian Theory of Travel Mode Choice for the Journey to Work," Highway Research Record 283, Highway Research Board, Washington, D.C., 1969.

[28] Hutchinson, B.G., Principles of Urban Transport Systems Planning, Chapter 3 - Modal Split. Toronto, Canada: McGraw Hill, 1974.

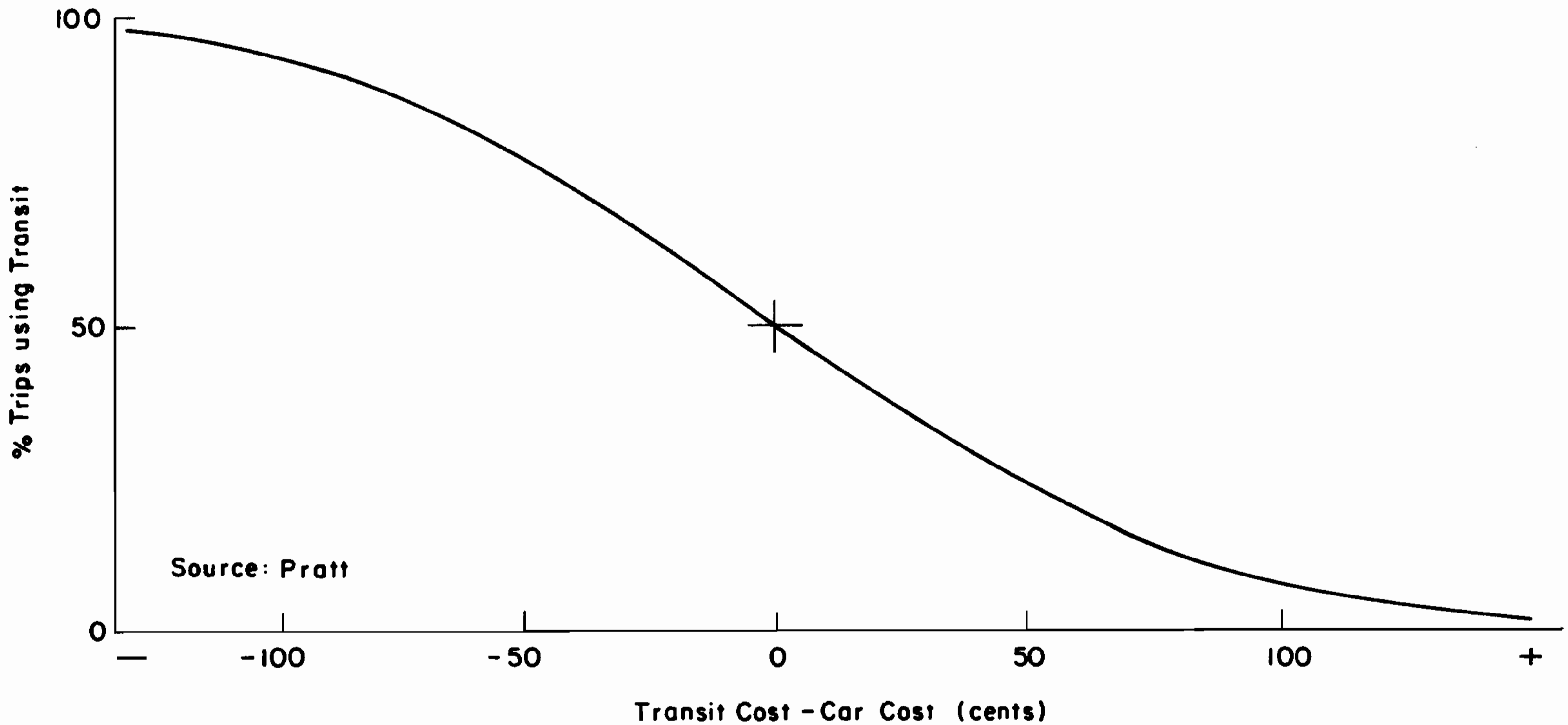

Figure 4.2. TYPICAL "CHOICE" MODAL SPLIT VS COST DIFFERENCES

In the 1972 Austin Transit[29] Study, the riders were asked: for this trip, "Could you have used a car?" and 22.2 percent of the riders responded "yes" to this question. This, of course, does not mean a 22.2 percent modal split among the higher income households, but it does indicate a considerable number of choice riders. Currently the choice modal split is probably in the range of 5 percent for C.B.D.-oriented trips.

In the logit model, besides the generalized cost difference, the parameter α must be estimated. Previous studies[30] have found values ranging from 0.3 to 0.6 for α. The parameter α plays the role of showing how sensitive the response is to a change in cost difference; the higher the α the more sensitive the response is. In the same way, the expressions for service headway and fare elasticity have comparable sensitivity parameters. To the extent that all these factors are measuring the same things, namely, the cost and/or disutility of a transit trip, it is expected that they would demonstrate the same sensitivity. Sensitivities for fares and headways are in the range of 0.012 to 0.6.

The only way to test the possible values of α in this study was to generate a Car Cost Factor by assuming a value of α and the constant in Equation 3 normalizing the factor so that at a distance of four miles the factor had a value of 1.0. This factor was entered in the model since it varied with distance, and by inspection of the residuals, coefficients, R^2, and the standard error it was determined that the assumed values were reasonable.

As discussed in Chapter 3 a car factor was tried with α = .02 and the constant = 100 normalized so at four miles the factor was 1.0 (see Figure 2.4). Results were inconclusive both ways. The decision was made not to use the factor in the proposed model on a route distance basis. However, it is put forward as a factor for the overall route to reflect changes in

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[29] Austin Transit Study, Vol. 1, 1972.

[30] Wilson, A.G., et al., "Calibrating and Testing of the SELNEC Transport Model," Regional Studies, Vol. 3, No. 3, 1969.

Archer, E., and J.H. Shortreed, "Potential Demands for Demand Scheduled Buses," Highway Research Record 367, Highway Research Board, Washington, D.C., 1971.

O'Brien, W., "The Demand for Transit" Chapter 2 in Urban Bus Transit: A Planning Guide, Transport Group, University of Waterloo, Waterloo, Ontario, Canada, 1974.

parking costs, gasoline costs, and so forth. When more cross-sectional data are available it will be possible to do more work on this factor.

Reliability Factor

No factor is proposed at this time. It seems clear that the following considerations are involved.

(1) An early bus has a larger negative impact on ridership than an equally late bus.

(2) While reliability is a probabilistic variable, it is the extreme value, low probability situations which have the most effect on ridership. Measures for this factor should reflect this. Also, this makes the actual determination of reliability of a route difficult.

One solution would be to ignore this factor and assume that any reliability effects are in fact system-wide characteristics and as such would be included within the local City Factor.

Bus Capacity Factor

This is potentially an important factor as it affects both the passengers' comfort and the transit system's image. Again, this study has not done any in-depth analysis and without cross-section data such analysis is not possible. In order to gather data, variable definitions are required. For bus condition, a simple four-point scale is suggested:

Bus Condition	Description
1 (EXCELLENT)	Clean new buses with A/C where required
2 (GOOD)	Buses in good condition
3 (FAIR)	Older buses in fair condition
4 (POOR)	Old, poorly kept buses

For capacity, the measure suggested is the percent of standing passengers over the whole time period, taken at the maximum load point.[31] Once the

[31] See for example O'Brien, W., Urban Bus Transit: A Planning Guide, Chapter 5, Transport Group, University of Waterloo, Waterloo, Ontario, Canada, 1974.

data are collected, the factor can be determined. Following the discussion of fare elasticities and strength of desire it is expected that the impact of the capacity on demand will be very inelastic.

Marketing[32]

Marketing effects are listed under the Bus Capacity Factor but they could also be included under the City Factor. The proposed measure of marketing is the percent of operating costs spent on Marketing, Information and Public Relations within the transit property. Categories suggested are (a) less than 0.5 percent, (b) 0.5 to 1.0 percent, and (c) greater than 1.5 percent.

Considerable efforts are being made in the area of marketing for public transit[33] but the number of controlled study results are limited and tend to indicate that marketing may be a relatively minor factor. Blattberg[34] reports the results of a marketing demonstration program in 1968 in Pittsburgh, Pennsylvania. The demonstration indicated that advertising of transit service did not seem to increase riders or improve attitudes towards transit, and was considered a "poor investment."

In Austin,[35] a limited study of the impact of the multimedia promotion campaign aimed at increasing the use of buses to a local festival found that "only one (out of 53) respondent indicated that information brought about bus ridership." Of course even with a two percent increase in ridership a marketing program of 1 or 1½ percent of revenues could be cost effective.

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[32] Marketing includes promotional effort, marketing research, personal contacts, and changes in the system in conformance with information derived from research. However, most efforts to date have only considered promotion, which in and of itself is not likely to have much impact. Advertising is only one of the marketing variables and the effects of the others are not understood at this time.

[33] See, Alpert, M., and S. Davies, Segmenting a Transportation Market by Determining Attributes of Modal Choice, Council for Advanced Transportation Studies, Austin, Texas, 1973, for a good bibliography and review of marketing.

[34] Blattberg, R., and S.R. Stivers, "A Statistical Evaluation of Transit Proportion," Journal of Marketing Research, Vol. V, No. VII, 1970.

[35] Burd, Gene, Dissemination of Information to Increase Use of Austin Mass Transit: A Preliminary Study, Council for Advanced Transportation Studies, The University of Texas at Austin, 1973.

City Factor

This factor is a locally determined factor and is included to account for any general deviation of the model estimates and local results. Such deviations may be observed due to a variety of factors:

(1) location effect, such as the cities in Texas near the Mexican border or the east and west coast cities;

(2) time effects, including starting times for work (9:00 a.m. versus 8:00 a.m.), staggered work hours, evening shopping hours, etc.;

(3) population characteristics such as number of young people, percent of population over 65 or handicapped, and so on;

(4) work activity factors, that is, white collar versus blue collar cities, locations of major office employment (C.B.D. or a manufacturing location), and so forth; and

(5) history of transit in the city, land use, etc.

These and many more factors may require the use of a City Factor, perhaps for each time period.

CHAPTER 5

GENERAL DISCUSSIONS

The study conclusions are given at the end of Chapter 2. In general, the model proposed: (1) seems to address the need, (2) adequately models the underlying relationships, (3) is capable of calibration, and (4) is suitable for use as a design tool. The model would, of course, be used in conjunction with models of transit costs in the design process.

The purpose of this chapter is to discuss other items, which did not fit elsewhere, and to offer some suggestions for further research.

Transfers

Non-C.B.D. transfers between C.B.D. routes and crosstown routes were included as a model variable. The transfer variable is included with the household variables rather than the attraction variables. The assumption is that transfers basically represent additional households coming to the route to access attractions on the route. The use of one factor for all transfer locations in a time period was decided on to simplify the model. If transfers from a crosstown route are made solely to allow residences on the crosstown to access the C.B.D. destinations, then it may be that different values for the transfer coefficient should be used, depending on how many C.B.D. routes a crosstown route intersects with.

A second area of concern is the relative frequencies of the two transferring routes and the corresponding waiting times. If the C.B.D. route has a 10-minute headway and the crosstown 30 minutes, then the expected transfers would be much less than if the crosstown headway were 10 minutes also.

Both of these possibilities should be studied in a separate transfer study. It is hoped that a rather simple approach, similar to that proposed, can be used, so that variables for other than the route being designed are not involved. There is some encouragement in this direction by the generally low number of transfers observed in Austin and also by a study done by Barnes.[1] His study observed that when a crosstown route was introduced in Sacramento it was expected to act as a transfer line to increase flexibility of existing users but in fact its actual usage was not as a transfer line; instead it was very typical of existing C.B.D. routes. For instance, it had 13 per cent transferring riders, exactly the same as the system-wide average. This also gives some encouragement to the use of the proposed model for crosstown routes, another study which is recommended.

Coefficients for Target and Other Households

The calibrated coefficients for these two groups have relative weights of about 3.5 to 1.0. These appear to be reasonable, based on typical results, such as Table A.1. However, the estimates come from the regression analysis and should be checked utilizing existing transportation O.D. surveys where correspondence to the two household groups can be identified.

The definitions of these households, documented in Appendix A, should be reviewed for several cities to see if some adjustments should be made to account for housing costs, average city incomes, and so forth on a city-by-city basis, perhaps using local census data.

Direct Models

The proposed model includes the sum of the down route (or up route, as the case may be) attractors as a modifer of the household variables. As indicated in Chapter 3, direct models using only the household variables within the section performed quite well. They were rejected because it was felt that inclusion of variables reflecting the places a trip could go to (as well as come from) would improve the predictive capabilities of the model. Furthermore, no more data are required and only a slightly more complicated analysis is involved. Nevertheless, some forms of the direct models might be considered.

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[1]Barnes, C.W., Crosstown Line 9 - An Evaluation of a New Route, Sacramento Transit Authority, 1971 (NTIS - PB 198-138).

Use of the Model

A case study within a bus transit property should be carried out, utilizing the model as proposed in a route design situation. This would provide input as to its potential usefulness as well as suggestions for improvements. The same study might also design the final delivery form of the design tool, as a handbook, a set of design charts, a computer program, etc.

The Secondary Trade Area Coefficient

The value used to weight secondary trade area households, 0.16, can be checked from existing data generally collected on passenger characteristics. A more in-depth study will be necessary in order to determine if separate coefficients are required for the target and the other households.

A Total Utility Approach

Much of the recent concern in transportation planning and demand modelling has been to develop a utility-based approach to model structure as well as a disaggregation of the dependent variables.[2] The proposed model is disaggregated by income class and many of the factors derive from a utility approach. However, the factors generally work independently of each other. If there is a fare change, this enters into the Fare Factor but not into the Car Cost Factor. The need for an integrated approach is noted by Kemp:[3]

> I find it useful to think of the "price" of a journey by a particular mode as incorporating not only the money paid out for the journey but also each of these other aspects which contribute to the total disutility of travelling... the price can be regarded as a vector quantity incorporating a number of components (fare, travel time, comfort, safety, etc.)... a price elasticity is a convenient summary measure of the degree to which the level of demand for a particular commodity

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[2] Urban Travel Demand Forecasting, HRB Special Report 143, Highway Research Board, Washington, D.C., 1973.

Behavioral Demand Modeling, HRB Special Report 149, Highway Research Board, Washington, D.C., 1974.

[3] Kemp, M.A., Reduced Fare and Fare Free Urban Transit Services - Some Case Studies, Urban Institute, Washington, D.C., 1974.

is influenced by a change in the price of the commodity... for public transport services there are a number of price elasticities of interest, each one corresponding to a different component of the price vector."

Thus in the proposed model we have the Fare Factor, the Headway Factor, etc., all based on some elasticity values for an individual component. The difficulty is illustrated in Figure 5.1. The vertical axis shows utility or personal satisfaction. It is generally considered that behavior (here transit demand) is, broadly speaking, directly related to utility. In Figure 5.1 the shape of the curve represents the decreasing marginal utility with increases in the stimuli, here the total generalized cost of a transit trip (including travel time, fare, comfort, etc.) Figure 5.1 illustrates how the effect of an equivalent cost reduction causes two quite different responses (A and B), depending on the level of the original cost for a trip.

This is seen in the proposed model, where the response to fare depends on the level of trip cost. At higher cost levels (C.B.D. areas, work trips, etc.) the response (fare elasticity) is lower. Similarly the response to headway in the model varies with the headway.

Now, ideally, if we could combine all the trip costs into one measure, then we could use this measure to predict the transit demand. In this way people's differential response to changes in fares, headway, comfort, etc. could be accounted for in a continuous manner with the variations in the original cost. One difficulty would be to account for changes in competing modes with this approach. This is one area which could be the object of further research.

The Nature of Empirical Models

In closing it is worth remembering that what is proposed is an empirical model. It attempts to predict the demand for transit on a route for a variety of situations utilizing as small a number of input variables as possible. The model is an average, representing considerable variation in levels of demand, households, etc. Such a model can provide a good basis for design but clearly would not be the only input.

As a general philosophy of model development, the approach taken was to aim for comprehensiveness, simplicity, and accuracy rather than for mathematical

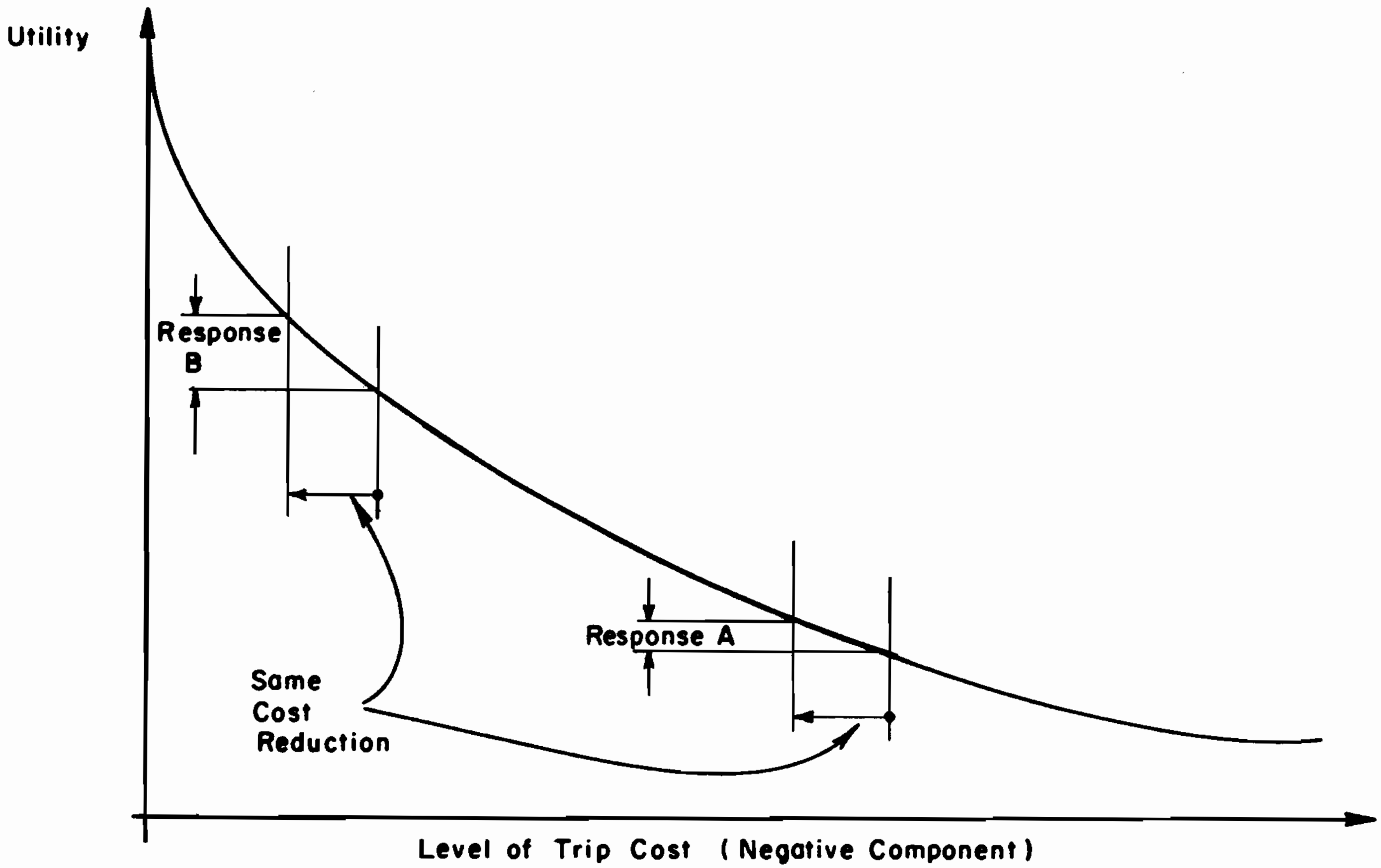

Figure 5.1. A CONCEPTUAL VIEW OF UTILITY RESPONSE TO COST REDUCTION

structure. It is noted that many relationships inherent in any such model can never be tested because of data requirements and will, therefore, always remain as assumptions. It is intended that the model's most important function is to provide a framework of variable definitions and a basic structure that will allow for the collection of data. This will ensure that the results of on-going demonstrations, route changes, and so forth will be effectively recorded and input into future design procedures to assure more effective transit sytems.

APPENDIX A

THE SELECTION OF HOUSEHOLD CATEGORIES

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THE SELECTION OF HOUSEHOLD CATEGORIES

The importance of household categories in the demand for transit is clearly illustrated in Table A-1, taken from a study on the city of Calgary. The effect of car ownership (and thus indirectly income) on transit ridership is clearly evident.

Figure A-1 shows the relationship between income levels[1] and transit ridership for Austin. The percent of population in a census tract below the poverty level is plotted against the transit rides to work per 1000 work trips as reported by the 1970 census. It was possible, for some areas, to compare the 1970 census tract transit ridership with the 1972 Austin Transit study data, and there was good agreement. Figure A-1 shows a clear relationship between low income levels and transit ridership.

The difficulty remained as to how to divide the population into groups in order to account for variations in transit demand with income. It is usual to divide the population into two groups, those more or less "captive" to transit and those who predominately have a "choice" between transit and car. The question was what level of income would be an appropriate dividing line and how could it be measured. The poverty level seemed to be a reasonable figure to use both because of the relationship defined by Figure A-1 and because the poverty level is defined and regularly available as a standard statistic.

The most appropriate census geographical breakdown for the model was the census block. Block statistics are available on a block-by-block basis showing the number of dwelling units by owner occupied and rental accommodation. The average value and the median contract rent are given for each block. It was assumed that the households for each block would be relatively homogeneous within each category. It was necessary to relate house value to contract rent.

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[1] U.S. Department of Commerce. 1970 Census of Population and Housing, Census Tracts, Austin, Texas, Standard Metropolitan Statistical Area, Washington, D.C., 1972.

TABLE A-1. CALGARY CATEGORY ANALYSIS[1]

24-Hour Home-Based Total Trip Production

Cars per Household	Persons per Household					
	1	2	3	4	5	6+
0	0.98	2.05	2.69	3.83	3.86	3.29
1	3.10	5.51	6.10	6.63	7.44	8.74
2+	4.00	7.18	9.12	10.46	11.65	13.10

24-Hour Home-Based Work Trip Production

Cars per Household	Persons per Household					
	1	2	3	4	5	6+
0	.33	.74	1.00	1.31	1.40	.80
1	1.26	2.22	2.40	2.47	2.51	2.39
2+	1.53	3.18	3.68	3.74	4.06	3.54

24-Hour Home-Based Transit Trip Production

Cars per Household	Persons per Household					
	1	2	3	4	5	6+
0	.46	.98	1.56	2.02	1.62	1.98
1	.15	.49	.72	.67	.91	1.40
2+	.35	.18	.36	.47	.70	1.11

24-Hour Home-Based Transit Work Trip Production

Cars per Household	Persons per Household					
	1	2	3	4	5	6+
0	.17	.36	.64	.70	.93	.66
1	.01	.31	.36	.30	.33	.34
2+	.12	.12	.18	.17	.25	.24

[1]From Mouall, J.F., and L.H. Morash, "Calgary Transit Planning Models," Papers on Trip Generation Presented at the 1973 Road and Transportation Association of Canada, published by the Transport Group, University of Waterloo, Waterloo, Ontario, Canada, 1974.

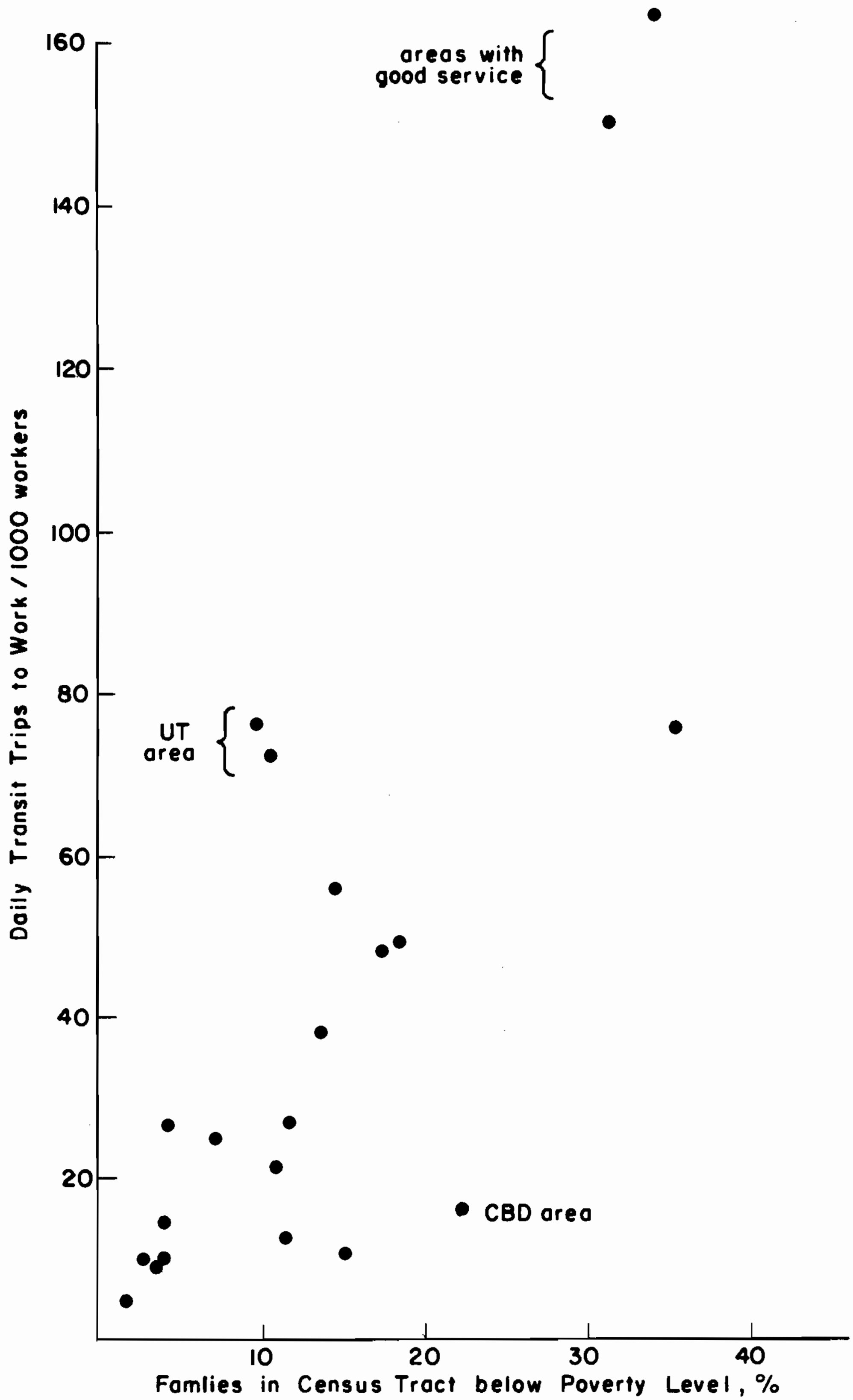

Figure A-1. TRANSIT USE VERSUS INCOME LEVELS (1970) FOR AUSTIN CENSUS TRACTS

Table A-2 gives the relationship used for relating household rents to house value. The problem remained of selecting a rent-value combination which represented a good dividing line between households. In Figure A-1 it is noted that at a percentage poverty level of 10 percent of the census tract there is a sort of dividing line. Table A-3 shows for some Austin census tracts the median income, house value, and contract rent as well as the percentage of households below the poverty level. As can be seen, there is considerable variation at the census tract level in the mix of incomes within a census tract.

Finally, using some judgment and based on the poverty level income and the Austin data, a dividing line between the two household groups was selected, $13,000 in value of an owner-occupied unit of $105 per month in contract rent.

For this dividing line it would have been useful to have a set of data for house value or contract rent and the use of transit for the work trip.

The use of some variable for persons per household would be desirable (see Table A-1), but this would have meant the use of census tracts rather than census block data.

As always, these criteria for the division of households could be reviewed before the collection of data for the calibration of the model. However, it is thought that the model's goodness-of-fit is not sensitive to this choice.

TABLE A-2. HOUSE VALUE VERSUS CONTRACT RENT

(For Total U.S.)*

Household Income (1969)	House Value (median)	Contract Rent (median)
less than $4,000	$10,200	$84
$4,000 to $7,000	$12,600	$102
$7,000 to $10,000	$14,900	$115
$10,000 to $15,000	$18,600	$133
more than $15,000	$26,000	$165

*Source. U.S. Census, 1970, Housing Characteristics by Household, Subject Report, U.S. Department of Commerce, 1973. Tables A-1 and A-2.

TABLE A-3. SELECTED HOUSEHOLD INCOME CHARACTERISTICS FOR AUSTIN**

Census Tract	Median Family Income	Median House Value	Median Contract Rent	% Households Below Poverty Income Level
1	$11,600	$23,000	$128	7.9%
2	$6,500	$13,400	$109	14.1%
13.01	$2,300	$13,400	$99	16.8%
15.02	$3,500	$13,300	$101	6.0%
15.03	$2,900	$12,600	$107	7.5%
16.01	$3,600	$24,100	$112	10.4%
18.01	$9,600	$16,600	$148	8.1%
20	$9,100	$13,400	$90	9.2%

**Source. Austin Census Data, op. cit.

APPENDIX B

BASIC DATA

APPENDIX B

BASIC DATA

This appendix contains two data tables. Table B-1 gives, for the routes studied, the total ridership levels by time period and direction. Also included are the factored-up samples for the boarding passengers. This is to indicate the sampling accuracy. As can be seen it was quite variable, for reasons discussed in Chapter 3.

Table B-2 gives the basic land use and ridership data for the route sections shown in Figure 3.1.

TABLE B-1. DATA SUMMARY

CATS TRANSIT DEMAND STUDY

	ROUTE	6 a.m.-9 a.m. ON	6 a.m.-9 a.m. OFF	9 a.m.- 3 p.m. ON	9 a.m.- 3 p.m. OFF	3 p.m.- 6 p.m. ON	3 p.m.- 6 p.m. OFF
NORTH LAMAR	Inbound	73	64	91	60	40	22
	Outbound	107	113	223	201	145	162
	Total	180 (108)*	177	314 (324)	261	185 (140)	184
HOLLY	Inbound	154	55	188	239	92	46
	Outbound	106	60	207	395	172	204
	Total	260 (360)	115	395 (344)	634	264 (386)	250
JOHNSTON	Inbound	241	97	203	117	118	94
	Outbound	143	138	236	233	186	298
	Total	384 (455)	235	439 (503)	350	304 (309)	392
BURNET/ MESA	Inbound	96	94	160	167	119	127
	Outbound	74	175	135	154	175	224
	Total	170 (158)	269	295 (318)	321	294 (148)	351

Control Totals Based on Austin Transit Passenger Counts and Revenue Data

* Estimate based on CATS sample factored up directly by the number of trips sampled in the time period. Note that the data were actually factored up to the control totals. These estimates are included only to indicate the samples accuracy and comparisons are possible for on's only.

TABLE B-2. DATA FOR AUSTIN ROUTES

			LAND USE												RIDERSHIP											
			Household				Attractions							6 a.m. to 9 a.m.				9 a.m. to 3 p.m.				3 p.m. to 6 p.m.			
														Inbound		Outbound		Inbound		Outbound		Inbound		Outbound	
Section No.	Section Length	Dist. to C.B.D.					Total Employment	Commercial Frontage	School Enrollment	Transfers	UT	Car Factor	Headway Factor	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
NORTH LAMAR																									
1	0,0	0,0	0	0	0	0	30,0	0,0	0	0	0	0	0,00	0	32	86	0	0	258	190	0	0	51	117	0
2	1,6	1,7	520	1038	464	651	4.5	15,0	0	1	1	1	,30	42	33	3	22	56	33	30	81	28	6	37	36
3	,8	2,9	122	228	101	135	1.3	3,5	0	0	0	1	,30	16	0	3	16	20	2	7	14	1	3	3	22
4	1,3	4,0	174	315	273	383	1.3	5,1	0	0	1	1	,28	14	6	6	17	10	6	2	15	5	4	8	21
5	2,9	6,1	262	373	387	578	,2	2,8	0	0	0	1	,28	26	0	0	20	26	0	0	31	21	0	0	44
6	3,1	9.1	210	372	502	808	.6	12,5	0	0	0	1	,28	58	0	0	32	39	0	0	53	12	0	0	26
HOLLY																									
1	0,0	0,0	0	0	0	0	30,0	0,0	0	0	0	0	0,00	0	17	9	0	0	138	120	0	0	34	123	0
2	,4	,9	262	319	2	8	,5	3,8	0	0	0	1	,41	2	12	5	9	9	32	0	5	5	3	0	6
3	1,4	1,8	373	561	2	6	.3	,6	872	0	1	1	,60	44	11	17	15	76	46	23	41	16	4	11	41
4	,8	2,9	473	821	0	0	.1	4,6	0	0	0	1	,41	20	0	14	8	30	37	9	14	14	15	7	11
5	1,6	4,1	73	154	8	24	.2	0,0	0	0	0	1	,60	7	0	10	5	0	5	5	14	3	3	11	13
6	3,1	5,6	407	592	10	19	.1	3,0	0	0	0	1	,60	57	0	0	11	64	0	0	83	29	0	0	80
JOHNSTON																									
1	0,0	0,0	0	0	0	0	30,0	0,0	0	0	0	0	0,00	0	98	44	0	0	93	158	0	0	54	154	0
2	,4	,9	262	319	2	8	.5	3,8	0	0	0	1	,41	6	2	0	0	10	0	13	3	0	0	3	12
3	,9	1,6	384	822	7	10	.2	7,5	0	0	1	1	,60	68	5	28	8	69	40	34	60	24	21	15	106
4	,8	2,4	395	735	0	0	.2	4,0	0	0	0	1	,41	80	11	27	18	44	7	14	38	19	22	8	59
5	1,6	3,6	304	583	0	14	.2	,8	1023	0	0	1	,60	35	25	35	26	40	11	9	77	31	13	26	109
6	2,9	5,1	92	129	60	101	.1	0,0	1485	0	0	1	,60	23	0	0	76	60	0	0	35	26	0	0	9
BURNET/MESA																									
1	0,0	0,0	0	0	0	0	30,0	0,0	0	0	0	0	0,00	0	77	63	0	0	134	72	0	0	69	140	0
2	1,4	1,6	321	808	332	449	4,0	7,0	0	1	0	1	,30	13	20	8	26	33	28	20	20	11	12	40	26
3	1,4	3,0	378	793	240	434	1,5	5,0	0	0	1	1	,30	12	3	19	19	43	9	10	17	14	10	12	24
4	1,5	4,4	159	416	309	501	1,6	18,0	0	0	0	1	,30	27	6	1	12	33	9	7	14	29	34	10	44
5	2,1	6,2	83	215	361	782	2.0	29,0	731	0	1	1	,30	27	1	0	26	29	8	8	19	30	4	2	78
6	1,1	7,8	0	0	156	328	.7	,6	0	0	0	1	.28	6	0	*	3	0	0	0	4	2	2	0	11
7	3,5	10,11	0	0	370	840	.1	0,0	895	0	0	1	,28	5	0	0	25	15	0	0	21	5	0	0	19
8	2,5	13.1	1	2	292	319	.1	5.5	2287	0	0	1	.28	13	0	0	10	10	0	0	8	0	0	0	10

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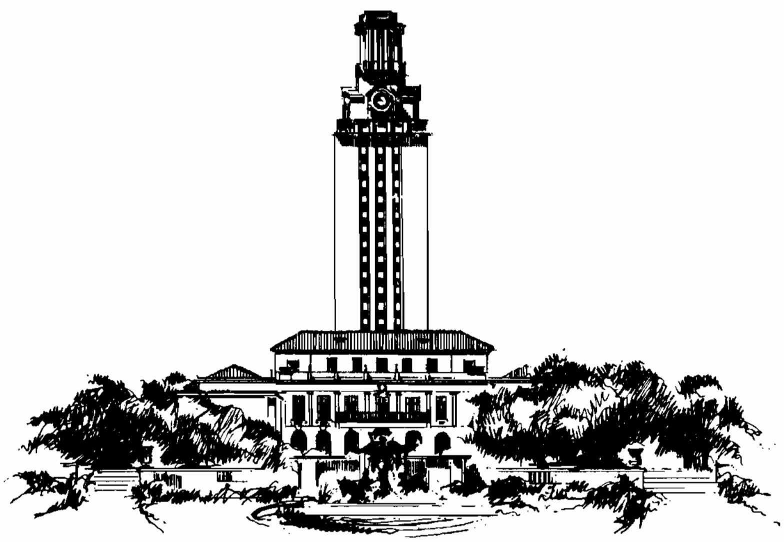

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