DEMAND ACTIVATED TRANSIT

REPORT TO THE URBAN MASS TRANSPORTATION ADMINISTRATION

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By

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ABSTRACT

DEMAND ACTIVATED TRANSIT

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This study focus on the problem of estimating the ridership increase experienced when regular fixed-routed and fixed-scheduled bus systems adopt a Dial-A-Bus Policy. The mathematical model used to accomplish such estimation is a modal split model.

Dial-A-Bus is a new bus operation which has many characteristics of a shared taxi. The patron telephones for a bus, which then comes to his door at a mutually accepted time and delivers the patron through to a destination while doing the same for others. At the time the study was initiated (January 1971) there were three distinct Dial-A Bus operations.

Columbia, Maryland had a system which picked-up patrons at any door-step and delivered them to the door of any destination. This is a many-to-many operation. Bay Ridges, a suburb of Toronto Ontario, Canada, used a Dial-A-Bus as a feeder system to a commuter train. Leaving the train station at fixed times, the 'out-bound' bus would drop-off patrons at their door and on the return trip to the station would pick-up patrons. This is termed, a many-to-one operation. The third bus system was in Mansfield, Ohio. The bus operated on fixed-routes at fixed-schedules and for an additional fee, the bus deviated from the route to pick-up or drop-off patrons. This is a route deviation operation. All three communities had conventional fixed-routed and fixed-scheduled bus systems before the introduction of Dial-A-Bus.

A combination of published data, data specific to Dial-A-Bus operations, and data collected from three surveys were used to develop a modal choice model which explained the transit ridership increases. The model development depended on an understanding of transit operations and the interaction of patrons with the system. The technique used to develop the model was a process of fitting empirical data, from diverse sources, into a relationship which was reasonable from transit operation experience and easy to use by a transit planner. The model was then tested using a stochastic demand process and the Bay Ridges study area. This test showed the applicability of the model for small area transit analysis.

The study also established relationships between the attitudes held by people towards the potential service of Dial-A-Bus. Many of the Dial-A-Bus attributes were ranked relative to each other and thus provides insight for the transit operation into Dial-A-Bus. The ranking of attributes used standard techniques applied to paired questionnaires and semantic scaling.

ACKNOWLEDGEMENTS

This study was formulated during January 1971 at the same time that Columbia, Maryland initiated the Call-A-Ride (C.A.R.). Mr. Robert Bartolo of the Rouse Company kindly made the records of C.A.R. available and assisted the author with a preliminary analysis. Simultaneously cooperation was obtained from representatives of General Motors Corporation and the Ford Motor Company. Mr. Richard Gustafson of G.M. sent complete copies of the attitude survey questionnaires and explained their use. He also suggested improvements to the revised questionnaire designed for Columbia. Mr. Karl Gunther of The Ford Motor Company provided copies of the reports dealing with the Mansfield Dial-A-Ride experiment, as well as sharing his knowledge of this new bus operation.

Bill Howard and Joe Desjardin of the Transit Operations Branch of the Government of Ontario's Department of Communications gave generously of their time and knowledge. They spent many hours explaining the details of the Bay Ridges, Dial-A-Ride operation.

The later surveys of the Columbia's C.A.R. were simplified by the assistance given by Bill Burton, the Director of Transit for the Columbia Community Association. The very special cooperation of the C.A.R. drivers and office personnel is particularly appreciated.

The direct financial support for this study came from the following agencies and individuals: Civil Engineering Department of the University of Minnesota, a fellowship funded from a Research and Training Grant to the University of Minnesota by the Urban Mass Transportation Administration, Dr. S. J. Navin, and the Author. Additional support has been provided by many individuals, the foremost of whom were: Robert Bartolo, Marge Bartolo, Richard Wolsfeld, Jr., Richard Pratt, Gordon Schultz, Joe Desjardin, and Richard Gustafson. To all those who have helped in this study I extend my grateful appreciation.

Professor M. Huber, my advisor, and Professor D. Gerlough must be thanked for: one, providing guidance in the formulation of the research, and; second, insisting that it be completed.

Finally, Mr. L. Norris of the Vancouver Sun newspaper is to be congratulated and thanked for adding humor to the Dial-A-Bus debate.

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Chapter I

INTRODUCTION

The focus of transportation planning is shifting from the need for highways to the entire transportation spectrum. This changing emphasis exposes a lack of knowledge about transit demands for small areas. The transit problems of large cities such as New York, Chicago and Los Angeles are well known within the transit industry. Vast amounts of Federal, State, and local funds are being invested in attempting solutions. Less known are the mobility problems facing isolated towns or suburban communities that are served only by express commuter service to the central city. The subject of this investigation is a potential transit solution for small centers.

Definition of the Problem

Demand Responsive Transit is a bus service which has most of the characteristics of a shared taxi service. The aim of the study is the development of a theoretical framework and methodology by which suitable demand responsive transit operating policies can be evaluated. This aim is very broad out of necessity, since little published work exists on this subject.

The study objectives needed to attain the aim are answers to the following questions.

1. What are the important social and economic elements in determining the travel mode?

2. What are the important transit system characteristics as viewed by the user?
3. Do transit users and non-users consider the same system characteristics equally important?
4. What has been the experience of the transit industry in small urban areas when demand bus has been attempted?

Need for the Study

The need for this study lies in the fact that 25 percent(1)* of the United States population lives in towns of 10,000 to 100,000 population. There were 1700 such urban centers in 1964.

The auto-oriented urban transportation system that has emerged since the 1920's constrains the mobility of many people. Age is a constraint in the mobility of the young who cannot obtain driver's licences and for the elderly who no longer qualify or desire to drive an automobile. There are approximately 75.7 million individuals under 20 years of age and 88 percent of them do not possess driver's licences.(1) Considering the total population over 20 years of age, the number without driver's licences is 24 percent. The distribution of driver's licences throughout the population is shown in Figure I-1. This graph indicates that automobility is not as universal an attribute as some would like us to believe. Auto ownership by age also influences mobility. Heads of households over 65 years of age number 5.5 million and of these 46 percent have no car.

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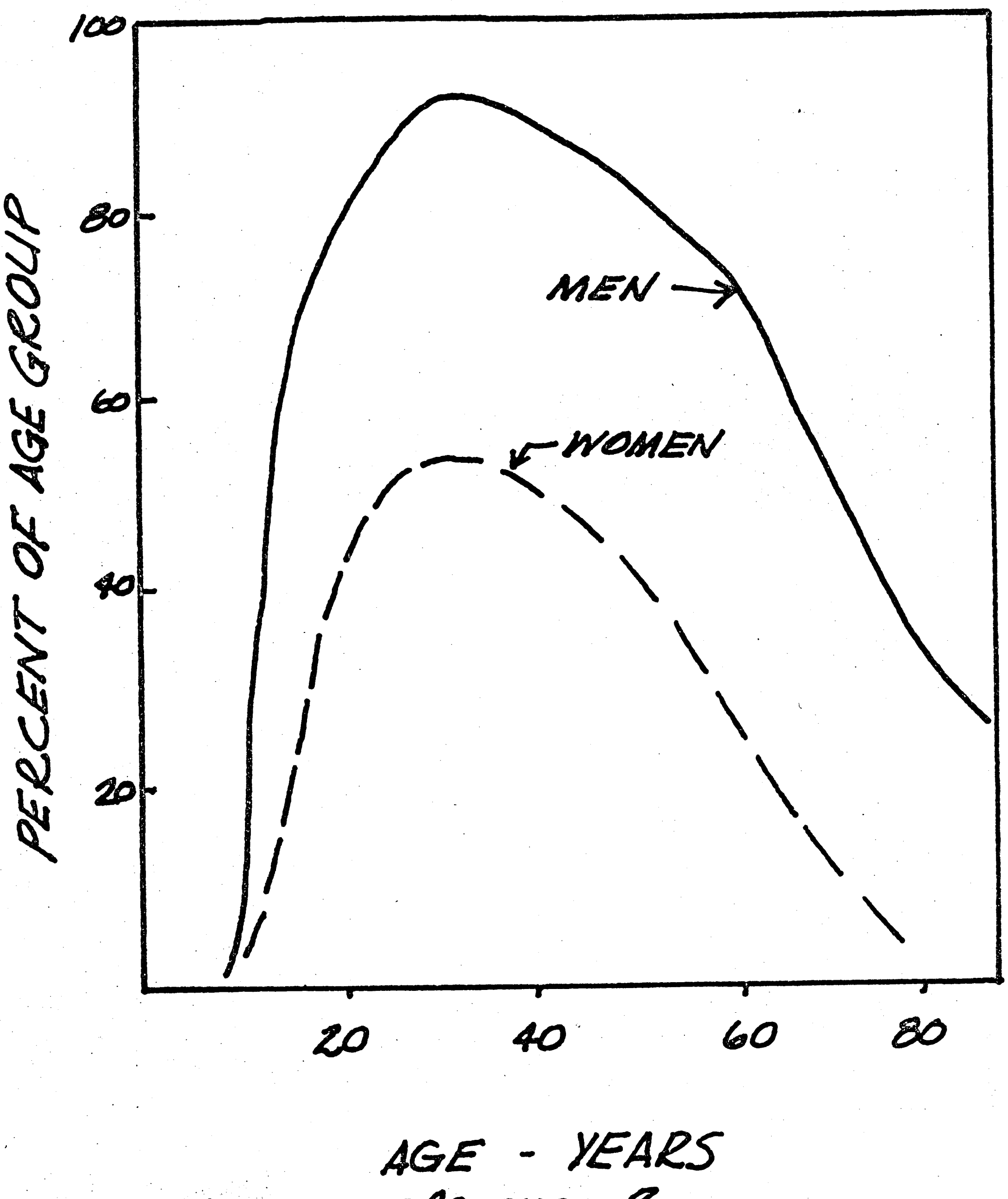
*Numbers in parentheses refer to references listed at the end of each chapter.

FIGURE I-1

PERCENT OF POPULATION LICENSED TO DRIVE BY AGE



SOURCE: reference 2

Income is a factor in auto-ownership and the very poor can not afford a personal car. There were 9.9 million households with incomes under $3,000 in 1964 and of these 46 percent did not own a car.(1)

Considering auto ownership still further, the two-car family is not the majority of the U.S. families. Households which have two or more automobiles accounted for 22 percent of the households. Approximately the same number did not have an automobile. The remaining 55 percent must satisfy work and non-work trip demands with one car.

To fill existing urban mobility needs, a variety of programs are being undertaken by public transportation agencies, private industry and interested citizens. These are:

- Interested citizens have organized special transportation facilities such as those reported by John Crain (3).
  As examples of this type of service there exists the Little House Dial-A-Bus System which services the Senior Citizen's multipurpose center in Menlo Park, California. Also there is the Chicago Mutual Enterprise for the Handicapped which services the needs of the handicapped within selected neighbourhoods.

- Private industry has responded with a successful taxi industry which, in 1970, carried some 24% of all urban public transportation trips and collected 54% of the revenue (4). Private enterprise operates conventional bus systems but more usually special charter and express bus service. Private industry has also initiated limited demand bus service in Columbia, Maryland; Mansfield, Ohio; and Batavia, New York.

- Public transportation agencies have offered transit in the form of buses, rapid transit subways, commuter trains, and an ever increasing number of demand bus transit systems such as: Haddenfield, New Jersey; Bay Ridges, Ontario;

and Regina, Saskatchewan; to mention the more ambitious or earliest applications.

The preceding list indicates the trend towards newer and more personalized transit service. The demand bus concept is an attempt, on the part of transportation companies, to service the low density suburban areas or to satisfy the special needs of selected groups in the community. The popularity of such service in the form of Dial-A-Bus has even been the subject of the political cartoonists' pen, Figure I-2.

This study attempts to quantify many of the variables known to influence demand bus ridership. Quantifying the important variables should give a planner a better understanding of the capabilities and costs of this new service concept.

FIGURE I-2

MR. NORRIS' VIEW OF DIAL-A-BUS

"... the reason they don't have Dial-a-Bus now is there's a law against obscene phone calls."

With permission of Mr. L. Norris, Vancouver Sun, Vancouver, British Columbia.

REFERENCES

1. Altshuler, A. Transit Subsidies: By Whom, For Whom?, American Institute of Planners Journal, March, 1969.

2. Sobey, A., J. Cone. The Case for Personal Rapid Transit, Record No.367, Highway Research Board, Washington, D.C., 1971.

3. Crain, J. Transportation and Older Persons, Stanford Research Institute, 1970.

4. Economic Characteristics of the Urban Public Transportation Industry, Institute of Defense Analysis for the U.S., Department of Transportation, February, 1972.

Chapter II

HYPOTHESIS

The hypothesis established for this study is: there exists a simple, yet adequate, modal demand model which will represent the potential for demand transit in small cities and local areas of larger cities.

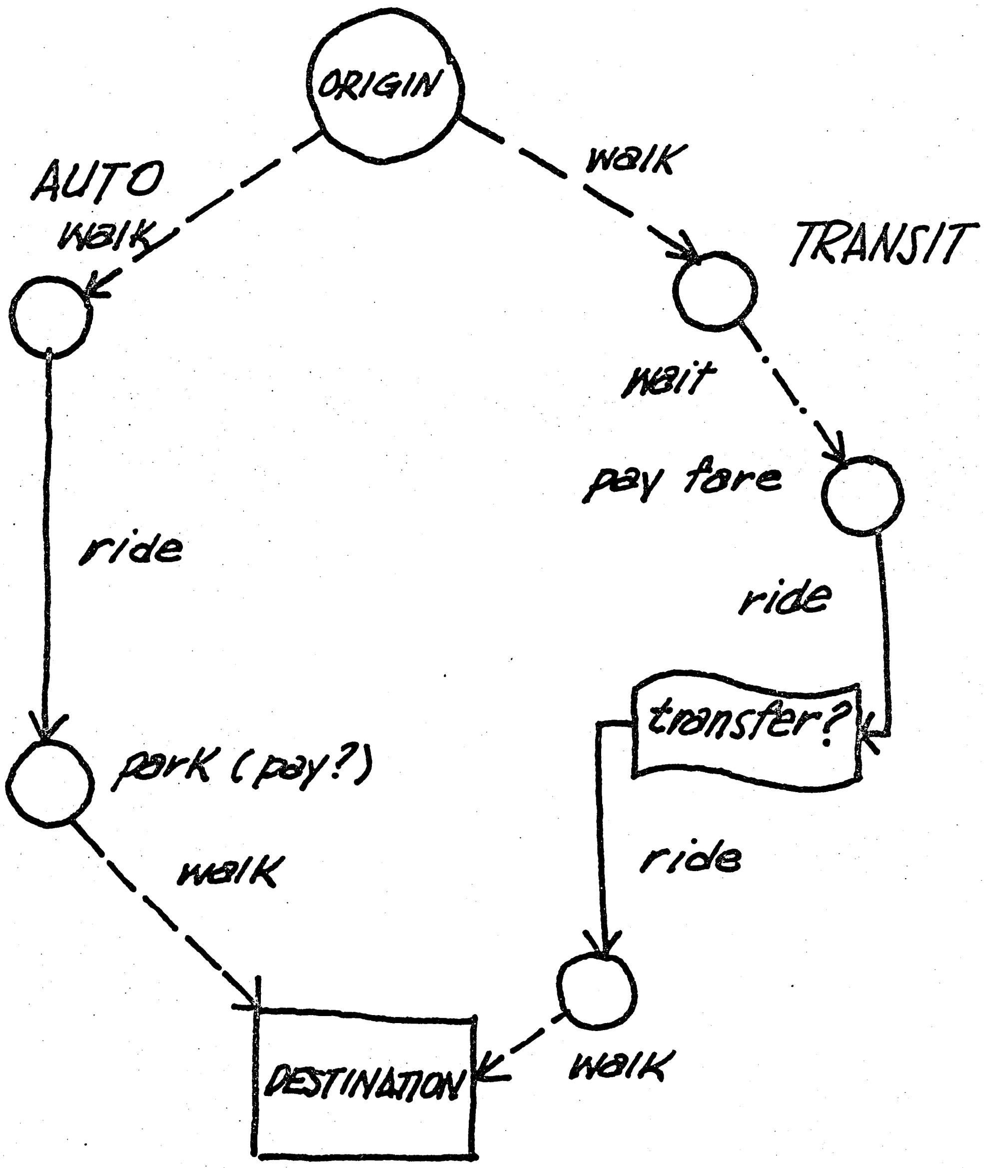
Simple, for the purposes of this study, implies that the variables used in any equation are easily obtained. Adequate implies that any model should be able to reproduce the ridership increases experienced on the existing demand transit systems.

The model to be developed assumes that the number of trips by all modes, between any origin, is known or can be estimated. The problem is then one of estimating the trips by each mode. The process of trip making is assumed to be similar to that shown in Figure II-1. One usually walks to a vehicle, waits for it, rides it, possibly transfers, and finally walks to a destination. The trip may be made by a number of modes each of which must be related to the other.

To develop the model suggested by the hypothesis, the following relationships must be understood. First, the relative importance of walking, waiting, transferring and riding must be defined for each mode. To make the comparison between modes valid, the relationship which equates bus riding to automobile riding must be outlined. If these two sets of relationships can be established, then it should be possible to estimate the transit/ ridership expected with demand transit.

FIGURE II-1

STEPS IN TRIP MAKING



Chapter III

STUDY DESIGN

Introduction

This study is divided into five major phases:

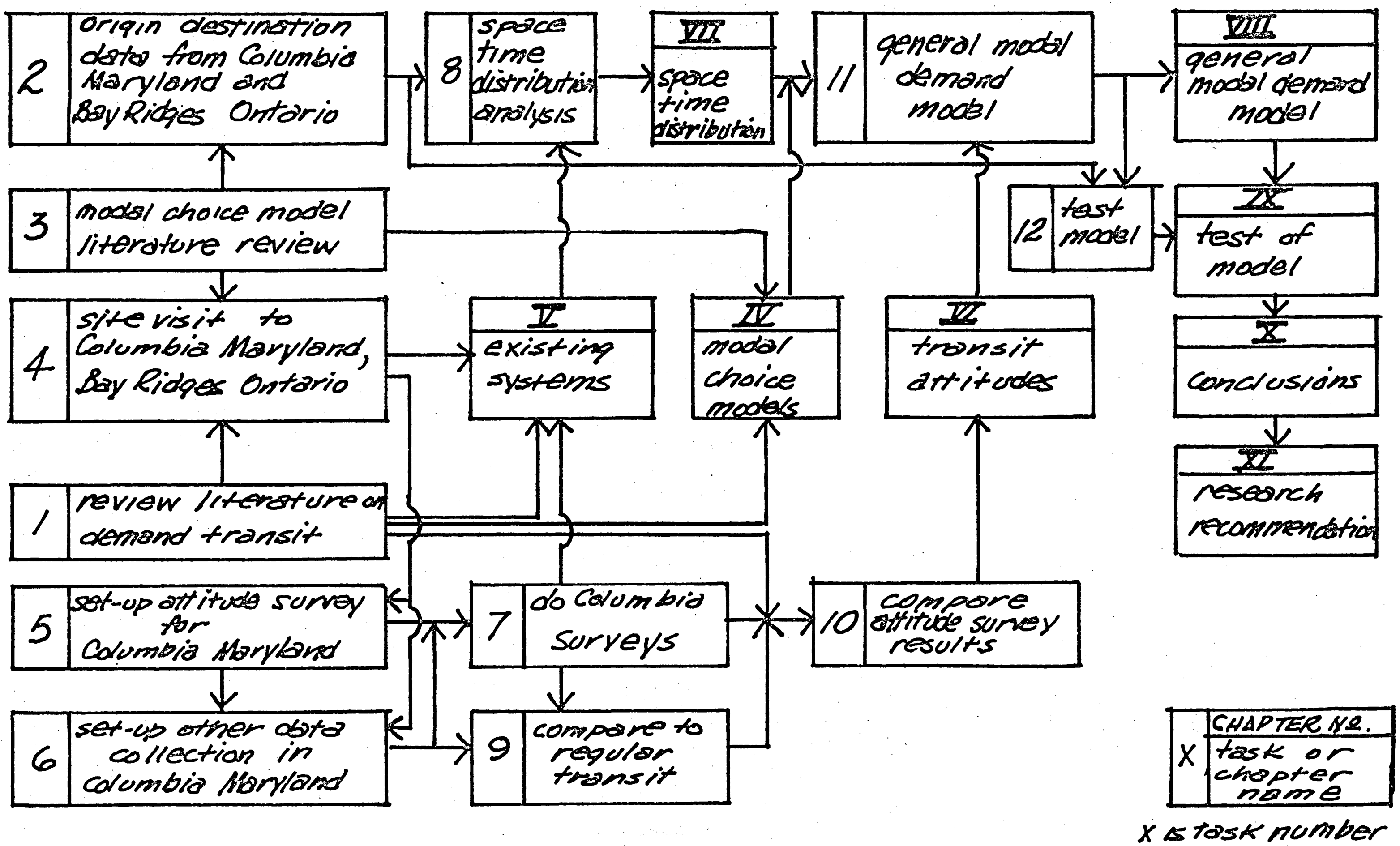
1. Data collection of the socio-economic factors thought to influence modal choice,
2. Collection of economic and ridership data for a representative sample of existing demand transit operations,
3. Analysis of the data,
4. Development and testing of a general demand transit modal choice model,
5. Recommendations for further research.

The work in the first three phases has considerable overlap and conclusions from one often lead to further analysis in another. A generalized study design is presented in Figure III-1. The diagram includes the major tasks leading to chapters in this report.

Phase One

The first study area includes tasks 1 and 3. Task 1, review of the literature, indicates a need for an analysis of demand transit by a person familiar with transit planning, operations and implementation. To establish socio-economic factors considered important in mode choice, a review of other models was undertaken. The purpose of this review and subsequent analysis was to formulate a preliminary modal choice model. The model would have most of the characteristics considered important by transit planners such as measurable variables and system sensitivity. The summary of this

FIGURE III-1
DEMAND TRANSIT STUDY DESIGN



effort is included in Chapter IV.

Phase Two

The effort for this area of the study was to collect data associated specifically with demand transit and includes tasks 1, 2,4,5,6 and 7. Data were collected on ideal systems that were studied in mathematical or computer model form. This gave the operational characteristics which were to be studied. An attitude study of demand transit by General Motors provided another set of theoretical characteristics to demand transit operations. Chapter IV, Classical Mode Choice Models, summarizes this area of Phase Two.

In preparation for the existing system data collection, a visit (Task 4) to Columbia, Maryland and Bay Ridges, Ontario, Canada was made. The purpose of this was to assure the author that the problem could be brought to a level which was within the financial capabilities and time constraints of the dissertation. Also, the potential cooperation of individuals and organizations was evaluated. The outcome of tasks 1 and 4 are reported in Chapter V, Existing Systems.

The next step was to set up the attitude surveys and on-board bus survey for Columbia, Maryland. (A similar survey was not made in Bay Ridges because the authorities responsible for the transit system did not want a survey to be undertaken at that time.) The Columbia attitude survey was made compatible with the attitude survey undertaken by the Research Laboratories of General Motor Corporation. A number of other surveys of the Columbia bus systems and its users were needed to allow an evaluation of who used the bus and for what purpose. Similar data were available for Bay Ridges and a few other demand bus systems.

Phase Three

This is the analysis phase and includes tasks 8,9,10, the results of which are the basis for Chapters V and VII. The effort of Task 9 is to enumerate the purpose of trips attracted to demand transit and establish if they are different from those attracted to conventional systems.

Using the log books and other records from Columbia and Bay Ridges (Task 8), space and time profiles of transit use can be drawn. These profiles lend themselves to an analysis of the regularity of demand in time and space. Such regularity, if it exists, should allow for an optimal operating policy to service the regular patrons and then an alternate policy may be developed to satisfy other customers. (Chapter VII summarizes this analysis).

The analysis of the attitude survey results, Task 9, estimated the degree of similarity between the perceived attitude of persons who did or did not have demand transit service. The people of Warren, Michigan only visualized a system as explained by interviewers. Columbia, Maryland had a demand transit system operating at the time of the survey and therefore had knowledge of such system. The results of this analysis are included in Chapter VI.

Phase Four

The aim of this study is the development of a simple yet adequate modal demand model. If it is shown that attitudes of all persons are essentially similar (Task 10) and that the spatial and temporal behavior are also predictable (Task 7) then it should be possible to develop a set of demand equations. This effort is presented in Chapter VIII. The testing of the model confirms its applicability for small area planning, and its use for operating procedures considerably different from existing systems. Model testing is reported in Chapter IX.

Phase Five

The conclusion and recommendations for further research are included in this final division. The work of Phase Five is included in Chapters X and XI.

Chapter IV

SEARCH OF THE LITERATURE

Introduction

The search of the literature has two purposes; first, to verify the need for the study and, second, to reveal any potentially useful sources of information in the pursuit of the study objective. The search is undertaken in two phases; first, a review of existing modal choice models based on modifications of economic demand theories and, second, a review of the theoretical studies of demand bus systems.

Classical Models

The classical approach to the modal choice in urban transportation planning may be summed up as being a collection of descriptive models. The models were based on the use of regression analysis with many variables that were not amenable to policy decisions by the planner or local community.

An example of the variables used is shown in Table IV-1. The models all have a few elements in common, these are:

- o characteristics of the trip,
- o characteristics of the tripmaker, and
- o network characteristics.

Stated another way, the models all incorporate some element of the zone of origin (trip characteristics or parking cost), and

Table IV-1

VARIABLES USED IN MODAL SPLIT MODELS BY FOUR TRANSPORTATION STUDIES

Variable Name	Study Location			
Trip Characteristic	Chicago[1]	Milwaukee[1]	Buffalo[1]	Iowa City[2]
Number of trip purposes	2	7	2	1
Trip length	•	•	x	•
Time of day	•	•	x	•
Orientation to CBD	x	•	•	•
Employment density	•	•	•	x
Trip Maker Characteristics				
Auto ownership	x	x	x	•
Workers per household	•	•	x	•
Dwellings per acre	•	•	•	x
Network Characteristics				
Travel time	•	•	x	x
Parking cost	•	•	x	x
Accessibility	•	x	•	•

(1) Creighton, R., Hamburg, J., Data Requirements for Metropolitan Transportation Planning, NCHRP Report 120, Highway Research Board, Washington, D.C., 1971.

(2) Dueker, K.J., Stover, J., Mass Transit Technical Study: Iowa City; Iowa City, Iowa, May 1971.

a characteristic of the system linking the two locations. The structure of the models is such that the element that is of critical importance, the transit system, often plays only a minor role in the outcome.

Kraft (3,4) and his colleagues at Charles River Associates attempted to correct some of the difficulties in the previous modal choice models. They hypothesized that a person's modal choice decision is not independent of elements such as the cost associated with various modes. This modal choice decision in turn influences the trip destination. For example, an improvement in the freeway travel time to downtown may not only divert shoppers from the regional shopping to downtown, but may also shift travellers from transit to auto. It may also stimulate an increase in the total number of shopping trips. These increased trips represent the "induced" demand for transit which has recently received attention from Hoel(5) and his colleagues at Carnegie-Mellon University. The equation used by Kraft accomplished the task of trip generation and trip distribution at the same time. The equation has the form:

$$N(i,j,i|P_o,M_o) = \phi\left[\underline{S}(i|P_o), \underline{A}(i|P_o), \underline{T}(i,j,i|P_o,M_o), \underline{C}(i,j,i|P_o,M_o), \underline{T}(i,j,i|P_o,M_\alpha), \underline{C}(i,j,i|P_o,M_\alpha)\right] \quad (1)$$

where

$N(i,j,i|P_o,M_o)$ = the number of trips between origin (i) and destination (j) for purpose (Po) by mode (Mo).

$\underline{S}(i,P_o)$ = socio-economic characteristics for purpose (Po) to describe travellers residing in zone (i)

$\underline{A}(i, P_o)$ = socio-economic and land-use characteristic to describe the activity for purpose (Po) destination zone (j)

$\underline{T}(i,j,i|P_o,M_o)$ = travel time components for the round trip from origin (i) to destination (j) for purpose (Po) by mode (Mo)

$\underline{C}(i,j,i|P_o,M_o)$ = travel cost components for the round trip from origin (i) to destination (j) for purpose (Po) by mode (Mo)

$\underline{T}(i,j,i|P_o,M_\alpha)$ = travel time components for the round trip between origin (i) and destination (j) for purpose (Po) by each alternate mode (M_α) and α= 1,2....

$\underline{C}(i,j,i|P_o,M_\alpha)$ = travel cost components for the round trip between origin (i) and destination (j) for purpose (Po) by each alternate mode (M_α) where α= 1,2......

Equation 1 states that the number of direct round trips between any zonal pair for a given purpose and mode is a function simultaneously of the number of individuals at the origin zone and their socio-economic characteristics. It also states the appropriate level of activity plus other relevant socio-economic and land-use characteristics, in the destination zone, together with the round-trip travel times and costs of the subject mode along with those of competing modes, determine modal usage.

The Kraft model represents an attempt to circumvent the "latent demand" or "induced trip" dilemma inherent in previous techniques that did not have a variable in the trip generation equations to represent the influence of the transportation system.

How does all this tie into the problem at hand, namely, estimating transit ridership on demand transit systems in local centers? The foregoing discussion underlines the need to introduce as many transportation system variables as possible.

Economic Mode Choice

The transportation of persons about an urban area is not a single good to be purchased for its own value but rather a conveyor for some predetermined purpose such as shopping or work.

Consumer decisions may be explained through a generalized cost relationship. The generalized transportation cost often referred to as a "disutility"*is a combination of user perceived cost. For example, a person may choose between a 20 minute bus ride at a fare of 50 cents or a 5 minute taxi ride at the cost of $1.50. If the person values his time at $2.00 per hour the disutility of the bus in dollar units may be $1.16 (.66+.50) and the taxi utility cost of $1.66 (.16+1.50). On a pleasant spring day the bus with a lower utility (1.16 vs. 1.66) may obtain the rider. If, on the other hand, the day is wet and cold, the 50 units of disutility may be more than outweighed by the comfort of the taxi. In this situation a general disutility relationship would have to distinguish a comfort variable. A trip-maker chooses the mode for which he anticipates the least disutilities. To simplify the development of the subsequent mathematics (6), the following assumption must be made: total disutility of a mode is a linear

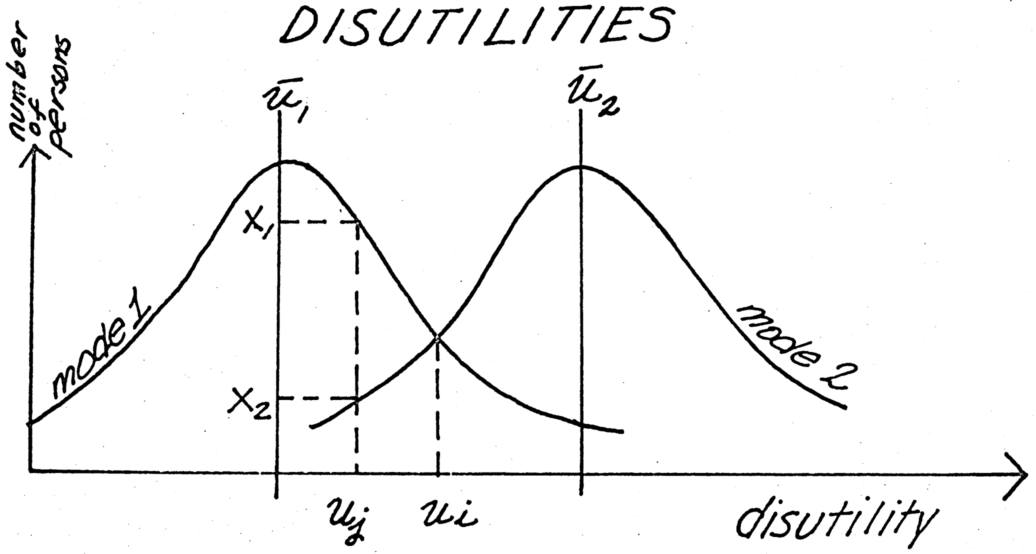
*Disutility is the economic term for minimizing the costs person "K" associates with a particular travel mode.

function of the disutility a user perceives as being associated with each of the attributes describing the mode. For example, in the above bus-taxi situation the value a person places on time is $2.00 per hour no matter if the time involved is 5 minutes or sixty minutes. The total disutility of time is thus $2.00 multiplied by the mode travel time plus the fare. The following inequality represents the generalized costs and disutility "U" perceived by individual "K" for modes 1 and 2.

$$u_K^1 < u_K^2 \qquad (2)$$

From equation 2 mode 1 with a disutility of u_K^1 is accepted by individual "K" since he perceives it as having less disutility than mode 2. The user is a single individual and his evaluation of the disutilities may differ from those of another individual. The law of large numbers is presumed to apply in this case, thus, on the average, people will select the economically correct mode. Also the choice of mode will be normally distributed about the disutility means, $\bar{u}_1$ and $\bar{u}_2$, as shown in Figure IV-1. This distribution subject will be pursued later in the analysis but let it suffice to say at this time some persons evaluating two competing modes will "mistakenly" perceive a mode to have more or less disutility. The number who mistakenly identify a mode will probably be proportional to the difference in the utilities separating the modes.

FIGURE IV-1
HYPOTHETICAL DISTRIBUTION OF DISUTILITIES



Thus in Figure IV-1 at a disutility value of U_j out of a total of ($X_1 + X_2$) persons, X_1 will select mode 1 and X_2 will select mode 2. The elements that make up the disutility in equation 2, if assumed to be additive, may thus form the generalized inequality:

$$\sum_{i=1}^{N} u^{1}_{i,k} < \sum_{i=1}^{N} u^{2}_{i,k}$$

where

$u^{j}_{i,k}$ = disutility of attribute (i) for mode (j), as perceived by user (k)

N = total number of attributes describing the modes (subscript i)

M = total number of users (individuals, subscript k)

The elements of the disutility function $\mathcal{U}^j_{i,K}$ may be hypothesized to be made up of two independent sets of components. The first component depends only on attirbutes of the mode. They include travel time and cost, ease of access to mention only a few. These attributes are weighted by an additional component depending only on the attitude of the user to each of the modal attributes. In a mathematical form the disutility becomes:

$$\mathcal{U}^j_{i,K} = A^j_{i,K} \left(I_i \right) \qquad (4)$$

where

I_i = importance users place on attribute (i)

$A^j_{i,k}$ = measure of disutility for attribute (i) of mode (j), as perceived by user (k).

Using relationship 4, the inequality 3 may be rewritten as:

$$\sum_{i=1}^{N} I_i \cdot A^{j=1}_{i,K} < \sum_{i=1}^{N} I_i \cdot A^{j=2}_{i,K} \qquad (5)$$

this may be simplified into:

$$\sum_{i=1}^{N} I_i \left(A^1_{i,K} - A^2_{i,K} \right) < 0 \qquad (6)$$

If all the elements in the preceding equation were measurable, then equation 6 provides an "ideal" modal choice in the economic view. The choice is ideal because consistent measurable decisions are possible. Selected modal attributes may be measured and a probability distribution function devised. The total importance vector "I" is a total for all individuals and as such is subject to the accepted errors of measurement, omission, and specification. Not only are those errors to be expected but when dealing with people the "unexpected", must also be considered. The economic models used to date have some of the characteristics of equation 4 as represented in the following. The disutility function* between unique origin destination pairs for each mode is:

$$U^j = R^j + f_e \times E^j + f_t \times C^j \tag{7}$$

where

U^j = disutility to all users for mode (j) expressed in in-vehicle travel time units

R^j = running time inside vehicle of mode (j) in minutes

E^j = travel time outside the vehicle of mode (j) such as walking and waiting (excess time)

C^j = total out-of-pocket costs associated with the trip by mode (j)

f_e = average importance factor used to convert excess time to equivalent in-vehicle time

f_t = average importance factor used to convert out-of-pocket costs into equivalent in-vehicle time.

The disutility difference between two competing modes corresponding to equation 6 then becomes for each origin to destination pair:

$$U = U^1 - U^2$$

---

*The $\sum$ sign is omitted since in transit planning model building U^j is the average disutility for all individuals in the traffic analysis zone having the origin to destination pair being evaluated.

and to date an empirical graphical relationship has been used to relate the number of persons that use mode 1, relative to mode 2 depending on the difference between the two disutilities. Such curves are shown in Figure IV-2. The equations used to calculate the disutilities represented in the studies mentioned in Figure IV-2 are:

$$u^j = R^j + 2.5(E^j) + \frac{48}{I}(C^j)10^4 \quad (8)$$

where

R^j and E^j are in minutes
I and C^j are in dollars
I is annual income in minutes*

This formulation was used by Shunk(7) in the Twin Cities and by Alan M. Voorhees and Associates (8) in Philadelphia. Another formulation used by Pratt (9) and Schultz in Skokie, Illinois, and Navin (10) in the Twin Cities is as follows:

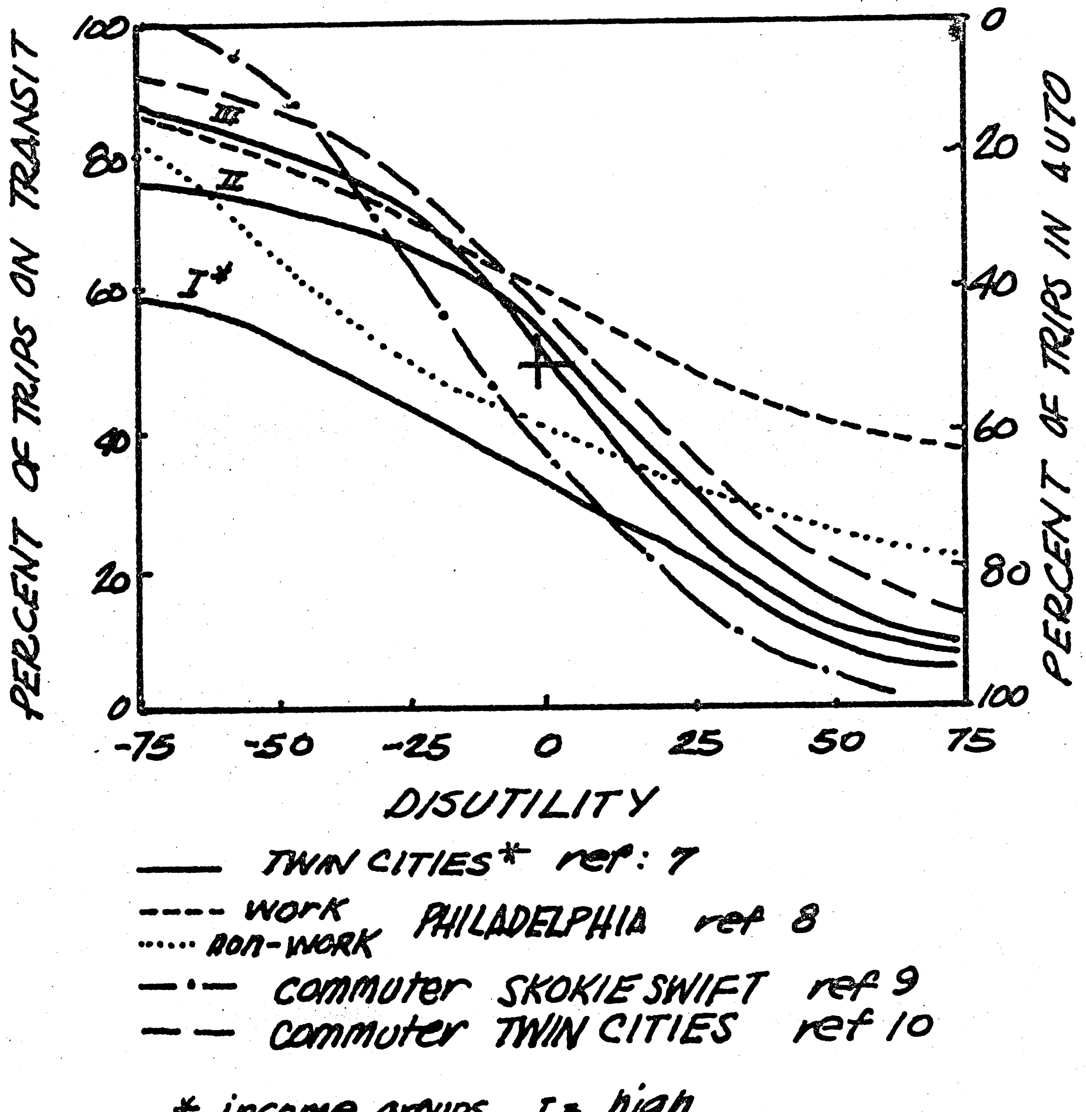
$$u^j = R^j + 2.3(E^j) + \frac{36}{I}(C^j)10^4 \quad (9)$$

At this point the reader may legitimately inquire, where do all these users attributed weights come from and what is their justification for use? Before going forward with the individual components of the attributes and weights used in the modal choice, a few words on the type of relationships used in Figure IV-2 are necessary. These curves represent a primitive attempt to incorporate economics and rational decisions into the modal choice

*The selection of annual income in these equations is due to data availability in most urban areas. See Table IV-2 for a detailed description on the value of time and its transformation into disutility units.

FIGURE IV-2

MODAL CHOICE CURVES



TWIN CITIES* ref: 7
---- work / ····· non-work PHILADELPHIA ref 8
—·— commuter SKOKIE SWIFT ref 9
— — commuter TWIN CITIES ref 10

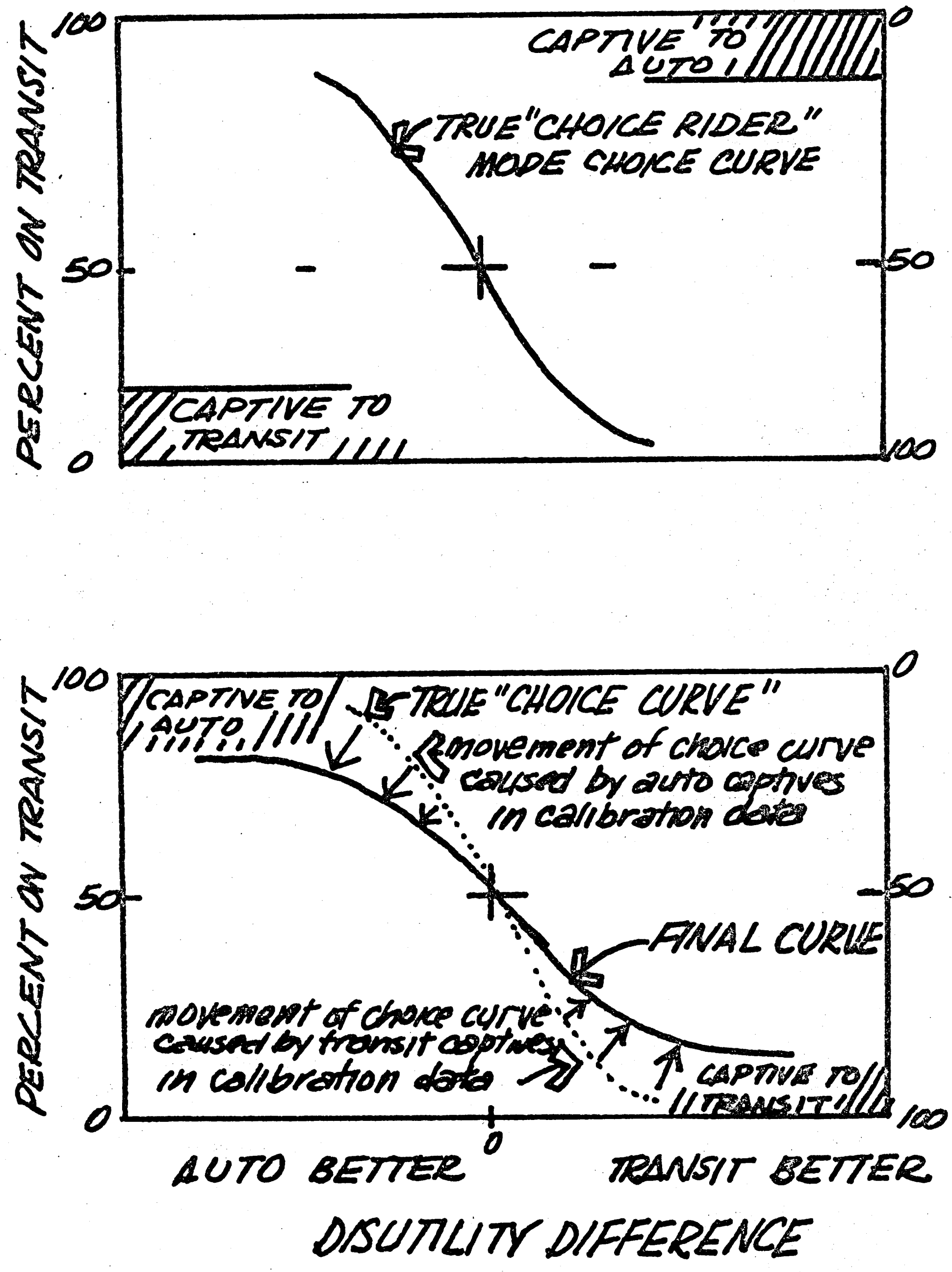
* income groups I = high
II = medium
III = low

relationship. The income represents the status of the user and is used to weight the out-of-pocket costs which are one component on the interchange (origin to destination) link. The destination zone is represented by the parking cost which is included in the out-of-pocket costs and stratification by trip purpose. The time between the two zones helps to describe the transportation link between the origin and destination. The equation says nothing directly about people "captive" to transit or automobile. Figure IV-3 indicates the influence of auto and transit captives (11). Auto captives, those requiring their automobiles, tend to supress the curves; transit captives tend to raise the curves. A "true" modal choice curve may only be devised when the captives are removed from the calibration data. The curves developed for the Skokie Swift commuter by Schultz and Pratt and the Twin Cities commuter by Navin, are essentially "choice" rider curves.

The Skokie curves were for people with high incomes and high auto availability. The data used for the Twin Cities included only those respondents who indicated that an automobile was available for the trip. The slopes of the two curves between -25 to +25 disutility difference are quite similar. The Philadelphia work and non-work curves indicate the influence of high transit captivity. This then implies that care must be taken in interpreting the results of any attitudes survey since captives are going to be different from the remainder of the population. It also implies that there is a maximum percentage that will use transit, also the group that has a choice are going to be more

FIGURE IV-3

INFLUENCE OF CAPTIVES ON MODE CHOICE CURVE



sensitive to the relationship. The group that has a choice influences the successful outcome of any transit system and can represent upwards of sixty percent of the urban person trips. (See Chapter I, Introduction).

Elementary Units in Trip Making

There are three elements to consider in trip-making. They are: the vehicle, the service characteristics and the convenience characteristics. The vehicle includes design features such as seats, air conditioning and style. Convenience involves things that make a trip more pleasant and would include having a seat and shelter while waiting. The factors involved in service are: no transferring, short waiting time and dependability. The influence of the vehicle and convenience characteristics are left until Chapter VI since their influence on transit usage is not easily measured. A trip within an urban area has a number of service factors which may be measured. They are:**

- o a walk to the vehicle,
- o an initial wait if the vehicle is public transit,
- o a ride in the vehicle,
- o a possible transfer, if public transit,
- o a walk to the final destination,
- o a fare or out-of-pocket operating cost.*

**See Chapter II, Hypothesis, for a diagram and description of the interaction of the service factors included in this list.

*This limited list of elements does not include additional legitimate elements such as: cost, trip purpose and the more classical elements to represent the trip, the tripmaker and the network. These elements will be introduced as necessary throughout the study.

Table IV-2

OBSERVED VALUE OF TRAVEL TIME

AUTHOR	VALUE
Beesley(12)*	Value = (0.42 to 0.52) x wage rate
Stopher(13)	Value = (0.32 @ income = 1000) x wage rate (0.26 @ income = 1000-1499) (0.23 @ income = 1500-1999) (0.21 @ income = 2000+)
Thomas et al(14)	Value = 1.83 + 0.32 I I = Income = 1 @ \$4000- 2 @ \$4000-5999 3 @ \$6000-7999 4 @ \$8000-9999 5 @ \$10000-11999 6 @ \$12000-14999 7 @ \$15000-20000 8 @ \$20000+
Thomas et al(14)	Value = (0.31 @ 10 minutes time saved) x wage rate (0.42 @ 15 minutes time saved) (0.37 @ 20 minutes time saved)
Lisco(15)	Excess Time** = 3 x in-vehicle run time
Quarmby(16)	Excess Time = 2.5 x in-vehicle run time

*References at the end of Chapter IV

**Excess time is all that travel time spent outside the vehicle.

Value of Total Travel Time

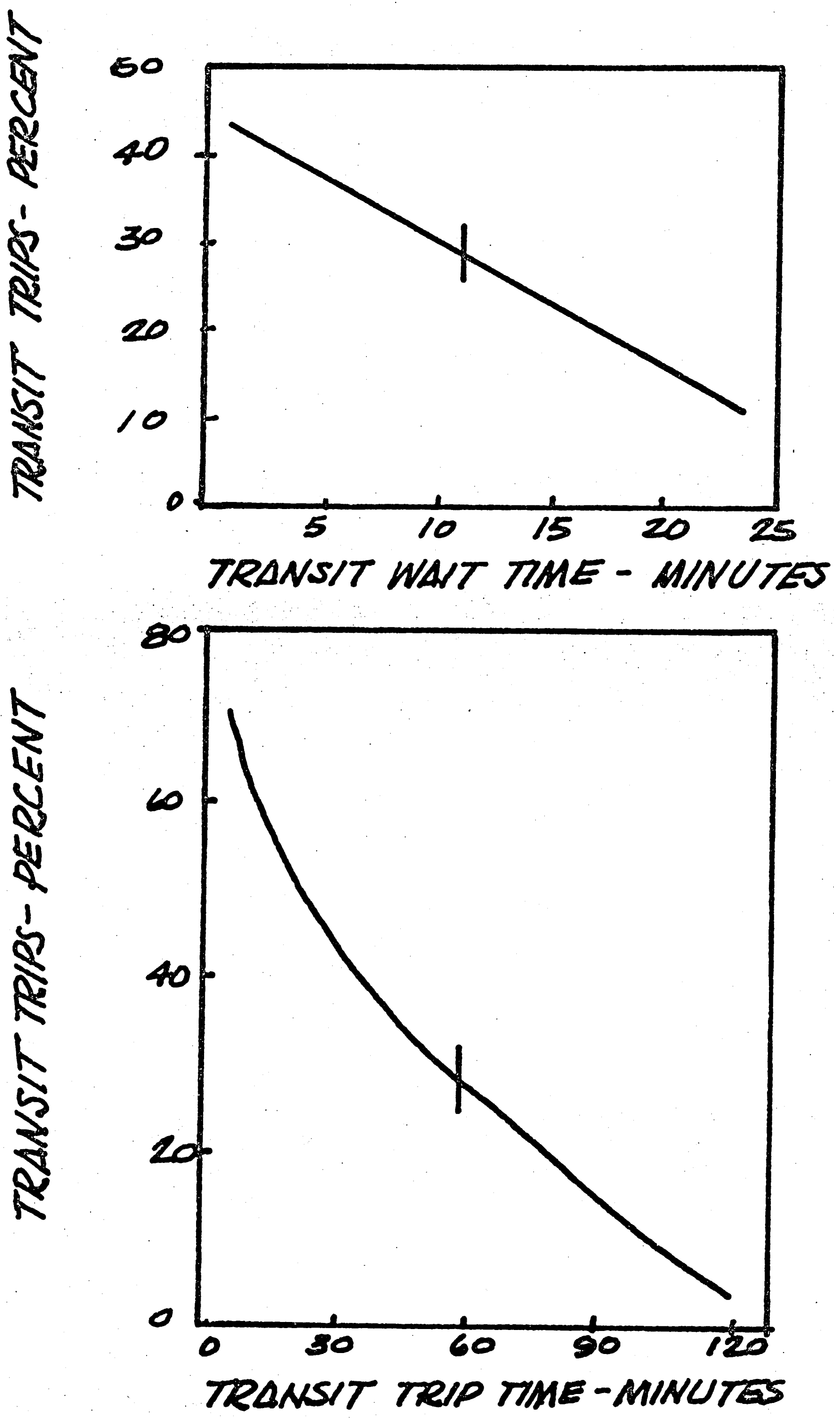
The most studied and best understood service factor is the value of time. Table IV-2 summarizes the major studies published to date. The work by Beesley (12) in the early sixties indicated that workers in London's downtown placed the value of time at one-half to 4/10 of their hourly wage rate. Additional studies for commuters to a British university by Stopher (13) related the values of time to income. Stopher showed that the relative importance of time decreases with increasing income. These values uncovered by Stopher are considerably less than those proposed by Beesley. Thomas et al (14) undertook studies of automobile commuters in California and found a relationship between annual income and time saved. The value of time was again found to be a decreasing factor of time while the absolute dollar value of time increased. The value of time postulated by Thomas increases in a non-linear manner compared with income. Thomas also postulated that a saving in time is somehow proportional to the amount of time saved. The maximum benefit is derived when approximately 15 minutes is saved.

Value of Excess Time

The value of excess time (time outside the mode vehicle) has also been estimated by a number of authors as shown by the last two references on Table IV-2. Lisco (15) estimated the excess time to be approximately three times more important than an equivalent amount of in-vehicle travel time. Quarmby (16) used an estimate of 2.5 for studies in Leeds, England. Pratt and Dean,(17)

FIGURE IV-4

INFLUENCE OF TRANSIT WAIT AND TRAVEL TIME



SOURCE: reference 18

in studies involving submodal* splits estimates for Washington, D.C., used a value of 2.5 as a weight for excess time. This value was based on observed data from Skokie, Illinois and Philadelphia. Using values from transit studies in Chicago (18) as graphed in Figure IV-4 indicates a value of 3.4. This value was devised from the following equations. The first wait time (t_W) influences the percent transit (P_T) as:

$$P_T = 45.0 - 1.45\, t_W \tag{10}$$

where P_T = percent transit

t_W = first wait for a transit vehicle

and the influence of total travel time**(t_T) is:

$$P_T = 52.0 - 0.42\, t_T \tag{11}$$

where t_T = total transit travel time

The slope of the two lines gives an approximate relationship between the influence of the two times, thus:

$$\frac{\text{slope waiting time}}{\text{slope total travel time}} = \frac{1.45}{0.42} = 3.4 \tag{12}$$

This implies that the waiting time is approximately 3.4 times more influential on transit ridership than the time spent inside the vehicle. This value is somewhat more than that proposed by Lisco or Pratt.

*They were attempting to allocate transit trips to a subway and surface bus system.

**This is a "handfitted estimate" of the best line between the total travel time on Figure IV-4.

Table IV-3

AVERAGE VALUE CHARACTERIZING TEN MODES OF TRAVELLING BETWEEN HOME AND WORK (CHICAGO IITRI WORK SURVEY)

COLUMN NUMBER	1	2	3	4	5	6	7	8	9
Trip Type	Percent Occurrence	One-way Distance (miles)	Travel Time (minutes)	Speed (mph)	Cost ($)	Cost per mile ($)	Distance Walked (Blocks)	Numbers of Transfers	Waiting Time (minutes)
o Walk	5.5	0.5	13	2.5	0.00	0.000	5.7	-	-
o Drive Car	50.1	15.2	38	24.3	0.84	0.056	0.5	-	-
o Ride in Car	13.3	15.8	27	25.5	0.17	0.011	0.6	-	-
o Bus	2.4	6.7	50	8.0	0.30	0.045	2.8	1.1	14
o El-Subway	10.1	12.4	45	16.6	0.30	0.024	4.6	0.4	6
o Bus + El.	9.6	12.3	59	12.4	0.38	0.031	3.0	1.5	12
o Car + Bus and/or El.	2.3	17.3	61	17.1	0.50	0.029	1.2	1.0	7
o RR + Bus and/or El.	1.9	23.9	79	18.1	1.21	0.050	6.3	1.6	12
o RR + Car + Bus and/or El.	4.2	26.9	76	21.2	1.18	0.044	3.2	1.5	11
o Other: taxi bicycle etc.	0.6	-	-	-	-	-	-	-	-
o All	100.0						3.7*	1.3*	9.5*

*Transit users only
Source - Table 18 Reference 18.

Value of a Transfer

A transfer on transit is often unavoidable and it is one of the more unpleasant elements of public transit use. The average number of transfers, by mode, experienced in the Chicago Transit System is given in Table IV-3. While many persons must transfer, the influence of transferring on ridership has not been adequately investigated. The rule of thumb often employed in the transit industry is that a transfer will result in a fifty percent loss in ridership for the trips that must transfer. The following is a brief discussion on the influence of transfers employing data from Toronto, (19) New York City, (20) and attitude surveys by the author and General Motors.

The rate of transfer exhibited in the eighth column of Table IV-3 indicates that users of public transit in Chicago transfer (on the average) once. The most direct routes are provided by the line haul elevated and subway system where 2 in 5 patrons transfer. Theoretically, the bus which services the other major portion of public transit trips has 100 percent of the persons making a transfer. This poor service offered by the bus-only mode is probably the result of using the bus for feeder service to the subway and elevated systems. The bus-only mode is used by only 2.4 percent of all urban trips while the bus is used by 20.4 percent of all trips for at least one portion of the journey to work. The difficulty of the transit mode relative to the auto is also shown in Table IV-3. For an additional 0.011 dollars per mile the auto driver can avoid a walk of 2.8 blocks, a 14 minute wait and a possible transfer.

Table IV-4

HUDSON RIVER CROSSINGS MODE EQUATIONS AND VARIABLE EQUIVALENCES

MODE	TIME	ORIENTATION	EQUATION COEFFICIENTS ΔTIME (minute)	ΔCOST (cents)	ΔTRANSFERS	CONSTANT	VARIABLE EQUIVALENCES VALUE OF TIME (¢ min.)	VALUE OF TRANSFER (cents)	TIME VALUE OF TRANSFER (minutes)
AUTO	Peak	CBD + non CBD	-0.536	-0.073	-	-1.915	7.3	-	-
	Off-Peak	CBD	-0.695	-0.038	-	-2.052	18.3	-	-
	Off-Peak	non-CBD	-0.624	-0.050	-	-1.277	12.5	-	-
BUS	Peak	CBD	-0.249	-0.063	-	+0.085	4.0	-	-
	Peak	non-CBD	-0.386	-0.227	-	-0.781	1.5	-	-
	Off-Peak	CBD	-0.324	-0.091	-	-0.275	3.6	-	-
	Off-Peak	non-CBD	-0.427	-0.160	-	-0.534	2.7	-	-
RAIL	Peak	CBD	-0.360	-0.081	-1.399	-0.030	4.4	19.7	3.9
	Peak	non-CBD	-0.557	-	-	-2.821	-	-	-
	Off-Peak	CBD	-0.306	-0.077	-0.470	-0.642	4.0	6.1	1.5
	Off-Peak	non-CBD	-0.438	-0.162	-	-1.297	2.7	-	-

Note the equations have form $e^{+a\Delta t+b\Delta c+c\Delta F}$

Source: Reference 20.

The influence of transfers on the rail patronage was observed in a mode choice study (20) of travellers crossing the Hudson River in New York. The equations derived in the study are shown in Table IV-4. The influence of a transfer was similar to a 20 cent fare increase, or in other words; to make the influence of the transfer approximately zero the cost of the trip would have to be lowered by 20 cents during the peak hour, and 6 cents in the off-peak. The influence of a transfer is further dramatized in Figure IV-5. Trips made without a transfer are very sensitive to time differences and cost differences. Trips made with a transfer are insensitive to time and cost differences and are probably made by persons captive to the system. This implies that the addition of one transfer in a system will dramatically alter the outlook that a potential transit user (rail user) has of the system and reduce the probability that transit will be used.

All the foregoing indicates that transfers have a fairly substantial influence on transit, even in such a transit oriented location as New York.

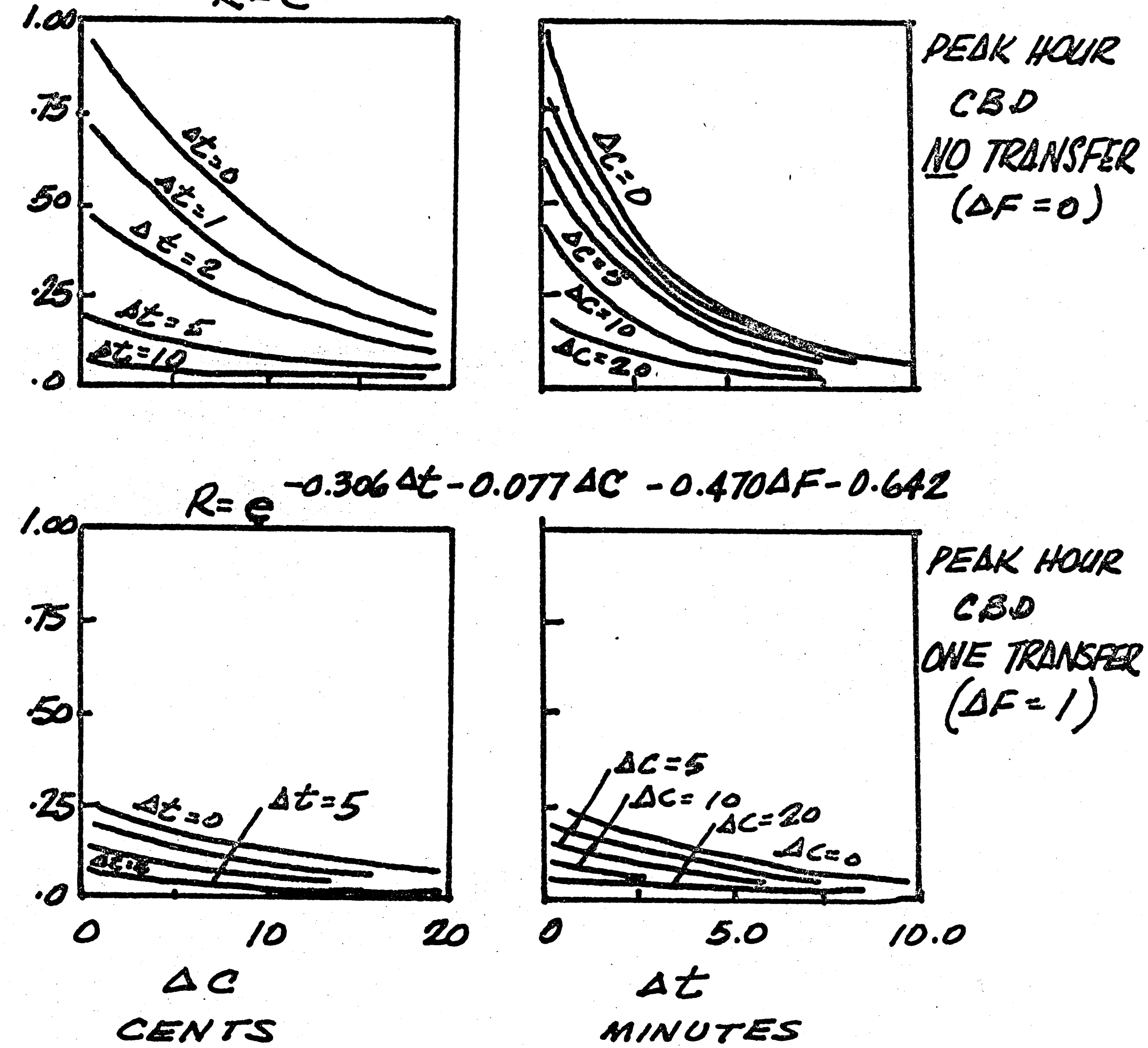
Walking, Waiting and Transferring Time

An approximate relationship may be established between the first wait and transfer time using Toronto (19) data. The influence of excess time on Toronto transit ridership is shown in Figure IV-6. The ratio of the slope of each of these curves gives an indication of the relative weight of the first wait to transfer time. The implicit assumption is that the walk time is similar for both ends of the trip and that the principle difference

FIGURE IV-5
RAIL ALLOCATION MODELS
FOR
HUDSON RIVER CROSSINGS

$$R = e^{-.360\Delta t - 0.081\Delta C - 1.399\Delta F - 0.030}$$

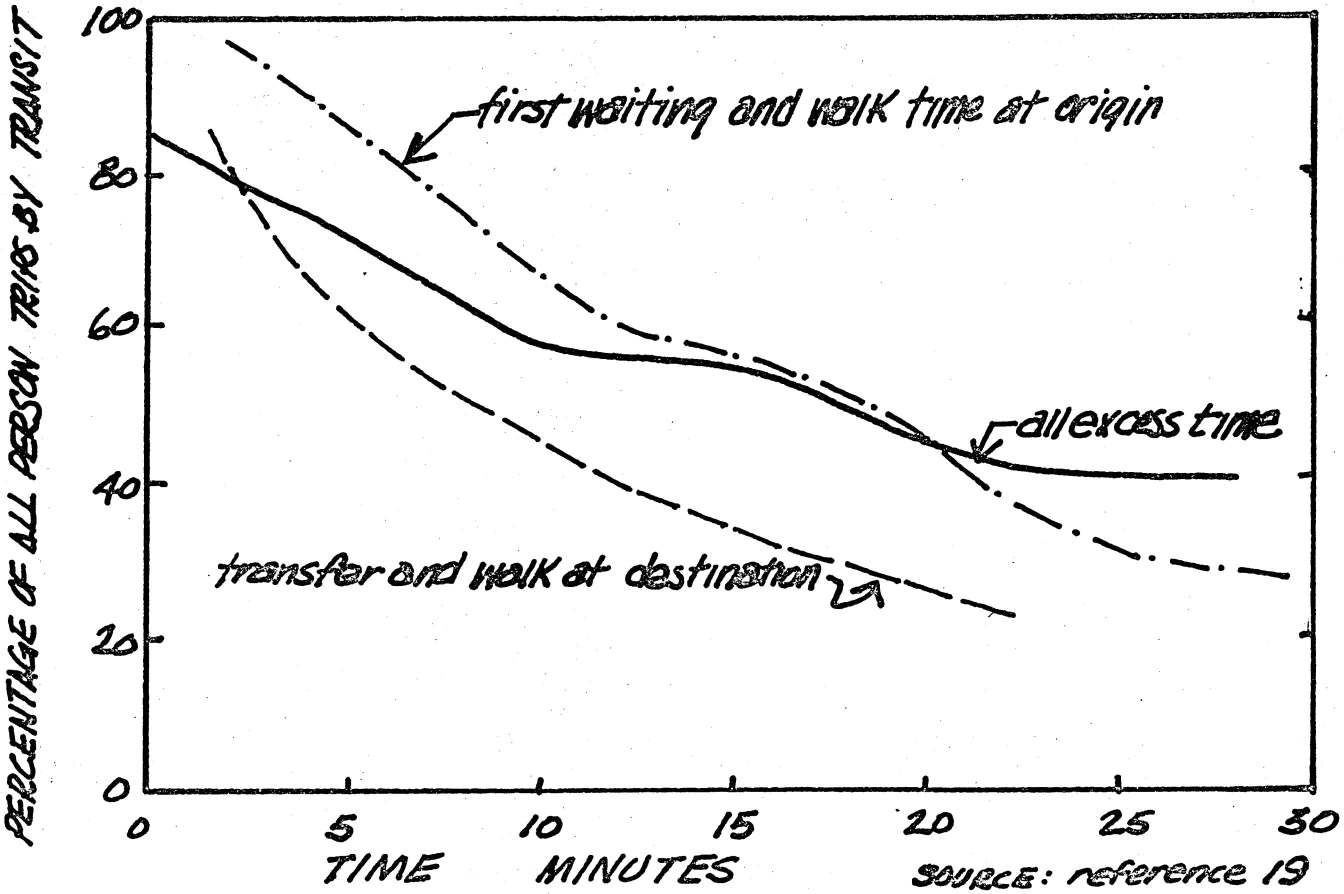
$$R = e^{-0.306\Delta t - 0.077\Delta C - 0.470\Delta F - 0.642}$$



SOURCE: reference 20

FIGURE IV-6

EFFECT OF EXCESS TIME ON TRANSIT RIDERSHIP



SOURCE: reference 19

between the two curves is accounted for by the wait and transfer time. Using the curves of Figure IV-6, approximate equations* may be written for the influence of the various excess time combinations on the percentage transit. The equation for "waiting and walking at the origin" less than 10 minutes may be written as:

$$P_T = 85.0 - 2.4(t_{W1} + t_W) \tag{13}$$

where P_T = percent transit

t_{W1} = first walk time

t_W = wait time

Similarly for the time greater than 10 minutes:

$$P_T = 65.0 - 1.1(t_{W1} + t_W) \tag{14}$$

The percentage transit equation for "transferring and walk to the destination less than 10 minutes" i.e. given by:

$$P_T = 90.0 - 4.8(t_t + t_{W2}) \tag{15}$$

where t_t = transferring time

t_{W2} = walking to destination

and for the time greater than 10 minutes:

$$P_T = 58.0 - 1.7(t_t + t_{W2}) \tag{16}$$

The average slope for the waiting curve of equation 13 between 0 to 10 minutes is 2.4 and for a similar time range, the average

---

*The equations in this section are the best straight line "hand-fitted estimates" of the curves in Figure IV-6. The "bump" in the curves is ignored. The equations are of the form: y=a+bx where "a" is constant and "b" is the slope of the line.

transfer curve (equation 15) slope is 4.8. Similarly, from equation 14 the slope for waiting at a time greater than 10 minutes is 1.1 and from equation 16 for transferring the value is 1.7. Assume that all the influence is due only to waiting or transferring (origin and destination walks assumed similar). The ratio of the two slopes, waiting to transfer, becomes 2.0* and 1.5** for 0 to 10 minutes and greater than 10 minutes respectively. These results support the findings suggested by the Hudson Crossing data. These observations may be summarized as follows. The influence of a transfer becomes less as total travel time of the transferring mode increases. The same happens when the travel time difference between two modes becomes large. The importance of a transfer diminished because other factors start to exert greater influence on the mode choice.

Walking Time

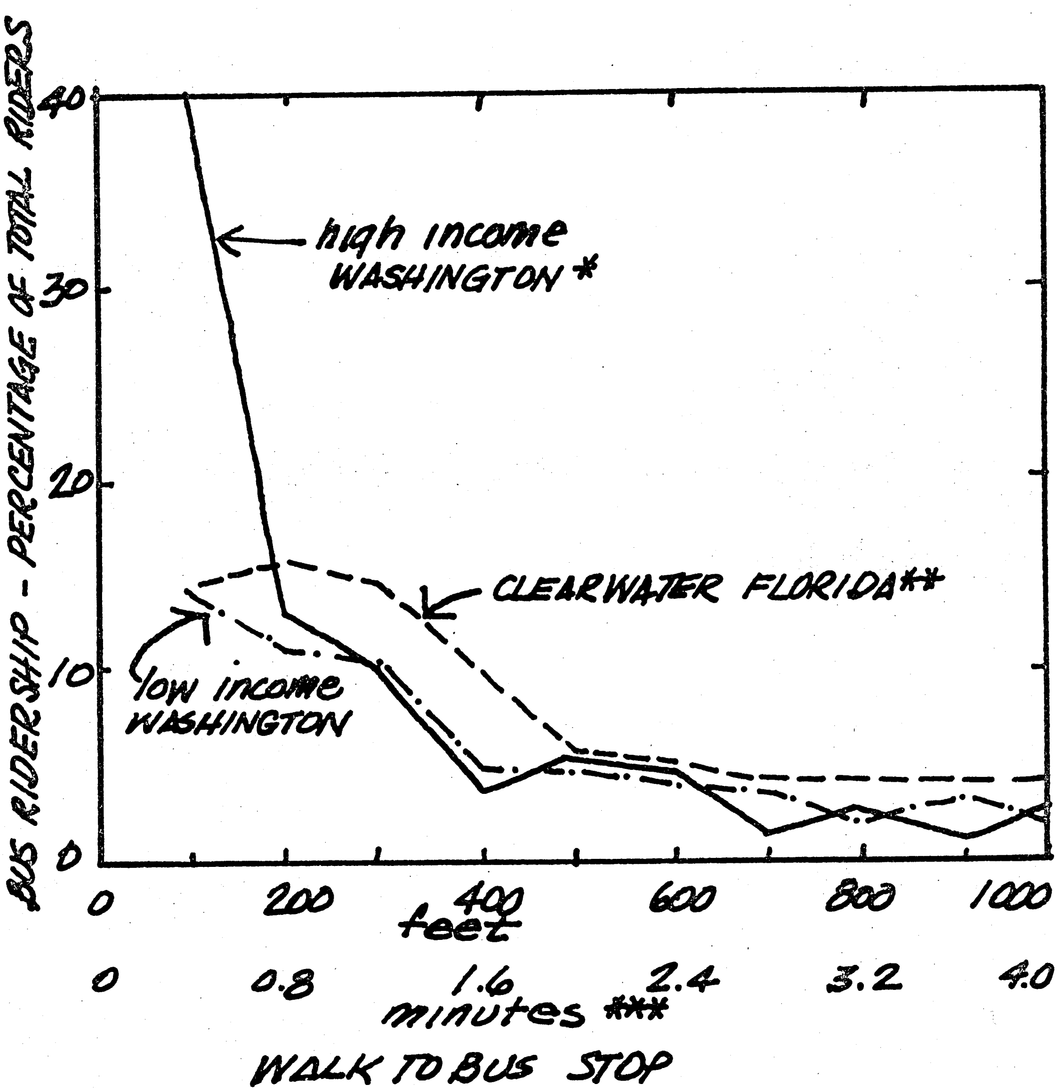
Another measurable element of transit trip making is the influence of walking on the number of people using transit. The influence of distance from a transit stop on the bus usage in Washington, D.C. (21) and Clearwater, Florida, (22), (23) is shown in Figure IV-7. The usage of transit drops off rapidly to approximately 600 feet from the bus stop (approximately a block and a half) and then is rather insensitive to distances beyond 600 feet. The distances beyond 600 feet account for 25% of all transit users in Washington, D.C. and Clearwater, Florida. The influence of

---

* $\frac{4.8}{2.4} = 2$ ** $\frac{1.7}{1.1} = 1.5$

FIGURE IV-7

INFLUENCE OF WALKING TO A BUS STOP ON TRANSIT PATRONAGE



* SOURCE reference 21

** SOURCE reference 22, 23

*** assumed 3 mph walk speed

distance on transit ridership is a ten percent loss of potential riders for each one hundred feet distance (within the first 600 feet) from a bus stop. This relationship assumes that the trip making density is uniform and that the maximum potential transit ridership in an area is that observed in the first one hundred feet.

Fare

The next area of interest in transit usage is the influence of user costs (fare) on ridership. The transit fare elasticity has been observed to be between 0.25 to 0.33 (24) percent ridership loss for each one percent increase in fare. The mode choice relationship developed by Lisco (25) gave a ridership loss of 0.30 percent for each one percent increase in the fare. The ridership fare elasticity by age group in Clearwater, Florida may be calculated from the data of Table IV-5. The young react with a ridership loss of 0.44 percent, the elderly at 0.43 percent and the group between these at 0.20 percent. These losses are consistent with the levels of affluence of the three groups. The actual loss suffered due to a fare rise appears to be twelve percent more than that expected from a prior survey.

Relative Values of Excess Time

This rather lengthy discussion into the measurable factors considered in some recent transit studies, lends credence to the phenomenon that the travelling public reacts unfavourably to excessive time demands to get to and from a transit system.

Table IV-5

RIDERSHIP REDUCTIONS BY AGE GROUP
CLEARWATER, FLORIDA

FARE	10 CENTS*		20 CENTS		DECREASE	
AGE	Riders	Percent	Riders	Percent	Actual Percent	Predicted from survey
20 or less	1913	47	1065	43	44	33
20 - 60	739	19	589	24	20	17
60+	1389	34	799	33	43	25
TOTAL	4041	100	2453	100	39	27

*At a 10¢ fare approximately 35 percent claimed they did not make the trip before.

They, the patrons, also feel that the first waiting time is more obnoxious than walking but, is less so than subsequent transfer and wait times. It is difficult at this time to derive an exact relationship of the transformation weights that should be used to transform these various times into common units. A comparison may be made as shown in Table IV-6. The proposed transformation weights of Table IV-6 show the range of values that are consistent with those uncovered so far in this chapter. Notice that the time spent transferring is by far the most important time element of trip making, followed by waiting, walking and then riding. The importance of the fare may be estimated by the approximation that travel time is valued at approximately 1/4 to 1/3 the annual income for any unit of time.

Table IV-6

WEIGHTS TO BE USED FOR VARIOUS TRAVEL TIMES

Attributes	Existing	Proposed
First walk	2.3 - 2.5	2.0 - 3.0
First wait	2.3 - 2.5	3.6 - 4.7
Ride	1.0	1.0 - 1.0
Transfer	2.3 - 2.5	6.8 - 8.5
Second walk	2.3 - 2.5	2.0 - 3.0
Fare	$\frac{\text{fare}}{\text{(Income)}}$	$\frac{\text{fare}}{\text{(Income)}}$

Analytical Studies of Demand Bus

Demand-Activated Road Transit (D.A.R.T.)

J. D. Garcia (26) and his associates at the Institute of Public Administration during 1969, undertook the task of developing analytical tools to aid planners in selecting potential

D.A.R.T. demonstration sites. The particular request from the U.S. Department of Transportation included the following:

1. Develop the best analytic methods for priori estimates of D.A.R.T. patronage as function of cost, service and location characteristics.

2. Obtain high and low estimates of D.A.R.T. patronage, performance and costs in specific areas as a function of:

   o size and shape of the area,

   o boarding and deboarding time of passenger,

   o vehicle crossing speed, and

   o demand distribution throughout the area.

3. Regulate demand varying price and service during various times of the day.

The critical assumptions made in the analysis involved the distribution of demand. Garcia assumed transit demand to have a uniform distribution in time and space. The uniform demand over space was recognized as the most difficult condition for transit and thought to be the trend in auto-oriented cities such as Los Angeles, Detroit and Houston. The assumption of uniform demand over time was based on a comparison of the demand for bus and taxi needs in New York and Los Angeles. Taxi usage has a maximum at noon while bus usage peaks at eight a.m. and five p.m. Assuming that D.A.R.T. will operate to get a maximum of off-peak trips and operate as an efficient bus in the a.m. - p.m. peaks, an approximate uniform distribution of demand results.

The analytical results of D.A.R.T., compared to other modes, is summarized in Figure IV-8. The alternate modes are conventional bus, taxi and the automobile. The demand densities range from 10 to 110 trips per square mile per hour with the shape of the service area* being represented by the value S. As might be expected the cost for taxi and automobile operation per mile is essentially independent of the demand density and shape of the area. Taxis have a unit cost of 70 cents per passenger mile, the automobile is approximately one tenth the taxi cost.

Generally the relationship between the "best" choice, conventional bus and D.A.R.T. is a function of the length of the service area, and demand density. The line dividing the regions of "best" choice between the two modes of transit, demand and conventional, is also shown by the dash-dot line in Figure IV-8. The dividing line assumes an exponential form. Using a linear approximation with log paper, the equation of this dividing line becomes:

$$S = 0.26 \log_{10} D \qquad (17)$$

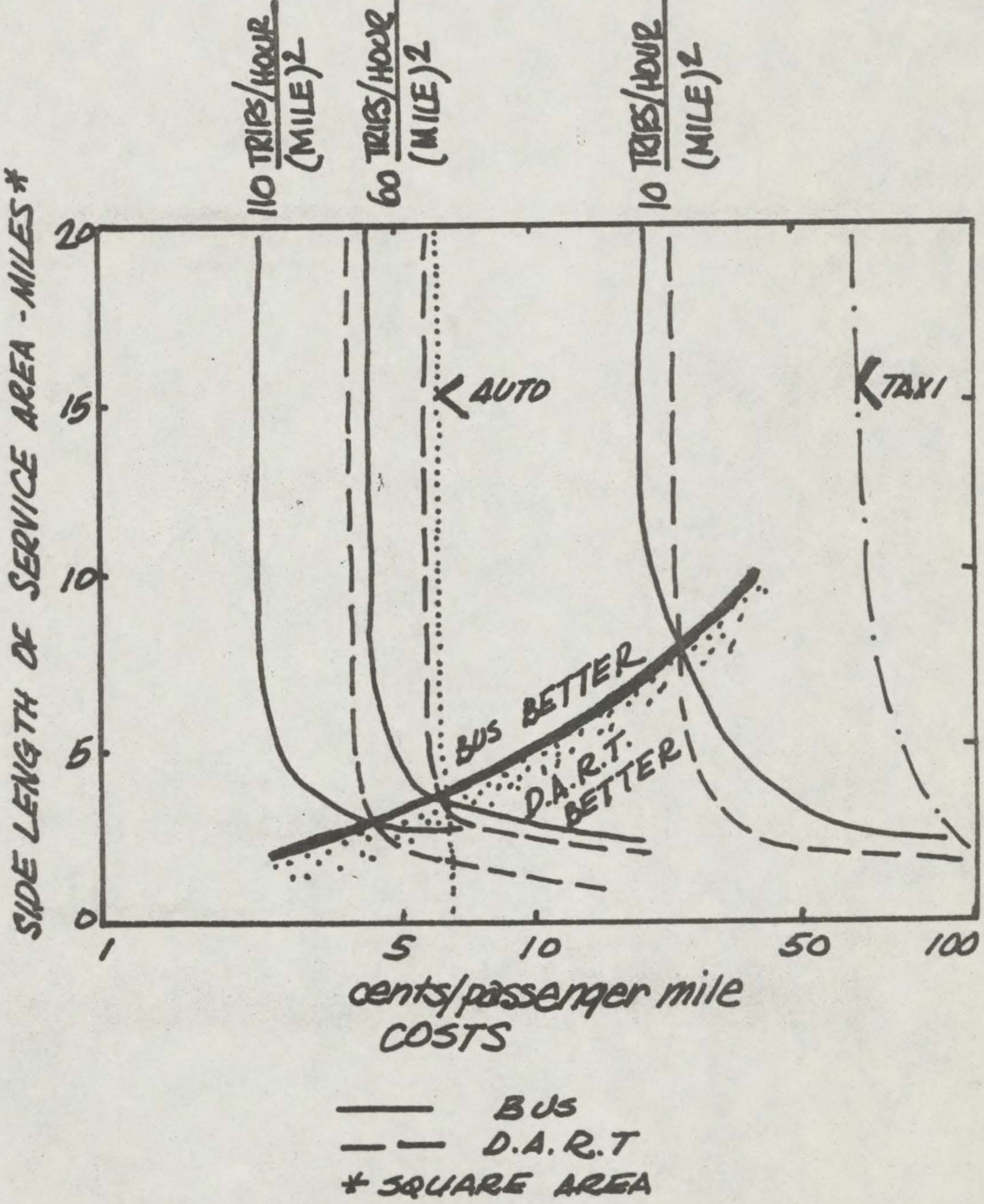
where S = the shape of the area in miles (length of one side of a square)

D = transit demand density (rides/mile^2)

Equation 17 indicates that the shape of the service (length of a side of a square) changes logarithmically with the density (assuming a uniform density over the area). This is similar to

*Garcia assumed a rectangular service area, S represents the length of one side of this rectangular area. However, for this presentation all areas are square.

FIGURE IV-8
RELATIVE PASSENGER COSTS AS A FUNCTION OF: MODE, AREA SHAPE, AND DEMAND DENSITY



SOURCE: reference 26

results reported by the author (27) in an analysis of demand bus serving as an access mode for new fixed guideway transit modes. A measure of the relative efficiency of bus and D.A.R.T. performance is presented in Figure IV-9. D.A.R.T. is more efficient than the bus for smaller service areas although the auto is cheaper than either D.A.R.T. or bus for areas larger than 4 square miles.

The major conclusions reached by Garcia were:

1. There are no really good analytic methods of obtaining priori demand estimates for D.A.R.T. as a function of price and service.

2. Good estimates of D.A.R.T. demand must be based on extensive experiment because such a service has not been offered to the public (this was before the current experience in Columbia and Bay Ridges).

Other results of this exploratory work undertaken by Garcia are:

1. D.A.R.T. is an inefficient alternative to a bus-taxi arrangement if confined to an area of less than 15 square miles.

2. Optimum operating conditions for a D.A.R.T. taxi-like service, is not accomplished at costs less than 15 cents per passenger per mile in small areas of low demand density.

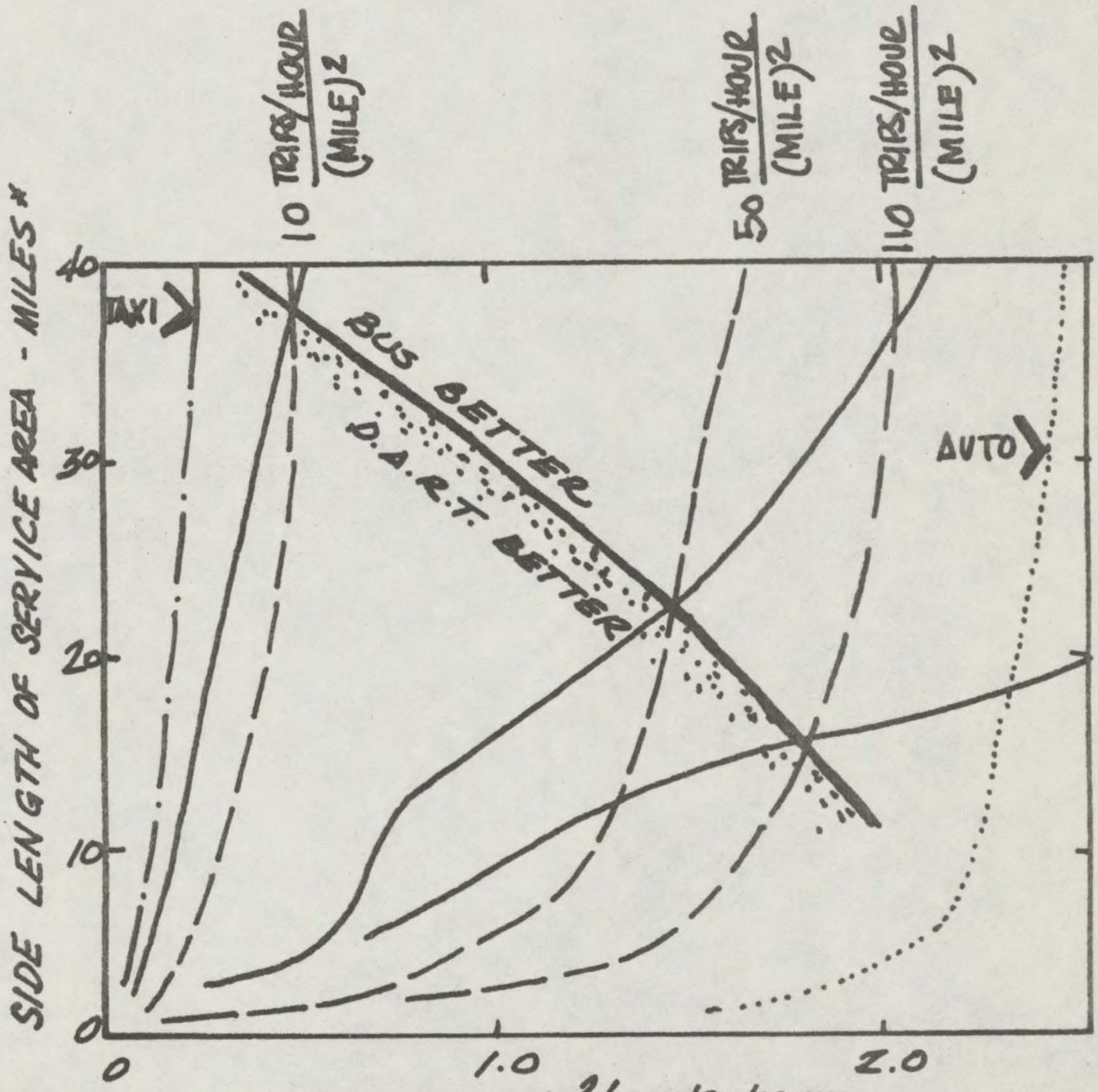
3. As the area increases, assuming demand, speed and other parameters are constant the efficiency of D.A.R.T. increases linearly to approximately 100 square miles. Efficiency in this case is defined as the ratio of D.A.R.T. speed and income per revenue mile.

4. The reliability of D.A.R.T. increased with the area, all other parameters being held constant.

5. As a general rule conventional bus systems are better in corridors with a demand of 500 transit trips per square mile, per hour and D.A.R.T. is better in areas of less transit demand than 100 trips per square mile per hour.

FIGURE IV-9

RELATIVE SPEED-COST RATIO AS A FUNCTION OF: MODE, AREA SHAPE, AND DEMAND DENSITY



SPEED COST RATIO

— BUS

– – D.A.R.T.

* SQUARE AREA

SOURCE: reference 26

6. Probably the only feasible plan to operate D.A.R.T. is on a city wide basis in an attempt to reduce the peaking demands by attracting the maximum number of persons during the off-peak hours.

Garcia considers that the main unanswered question in the use of D.A.R.T. is what will be the demand for the system as a function of price and service in reality. Garcia's work gives an excellent theoretical framework within which the general analysis of D.A.R.T. may be undertaken. He has also given good order of magnitude estimates for the influence of the service area size (shape) and costs as shown in Figure IV-9.

Garcia had major oversights in two areas. The first oversight is the relative importance of various elements of the total travel time. As pointed out in the previous sections of the chapter, the urban travellers perceived the influence of waiting and walking as 2 or 3 times more important than an equivalent time spent in the vehicle. The second area of difficulty arises in the use of average statistics in the analysis of transit. Transit should probably be analysed at the margin since average values tend to reduce the importance of walking and transferring in the modal choice decision.

A Demand Bus Study

A recent study of a demand bus service for the Twin Cities of Kitchener and Waterloo, Ontario, Canada was reported by Archer and Shortreed (28). The authors concluded that Demand Bus Service would have the same level of ridership as a regular fixed route and scheduled bus system at a disproportionate difference in costs. They arrived at this conclusion using a modal choice planning model proposed by Wilson (29) which has the following form:

$$T_{ij}^{kn} = A_j^n \cdot B_j \cdot O_i^n \cdot D_j \cdot e^{-\beta^n C_{ij}^k} \qquad (18)$$

where T_{ij}^{kn} = number of trips between (i) and (j) by mode (k) by persons type (n)

$$A_j^n = 1 \Big/ \sum_j \sum_{k \in y(n)} B_j \cdot D_j \cdot e^{-\beta^n C_{ij}^k}$$

$$B_j = 1 \Big/ \sum_i \sum_n \sum_{k \in y(n)} A_j^n \cdot O_i^n \cdot e^{-\beta^n C_{ij}^k}$$

O_i^n = number of trip origins (productions) in zone (i) by persons of type (n)

D_j = number of trip destinations (attractions) in zone (j)

$y(n)$ = set of modes available to persons of type (n)

C_{ij}^k = generalized cost of travelling from zone (i) to zone (j) by mode (k)

β^n = parameter that determines the mean of the trip length distribution for persons of type (n)

The constraints that the equation give are:

$$\sum_k \sum_j T_{ij}^{kn} = O_i^n \qquad (19)$$

$$\sum_{K}\sum_{n}\sum_{i} T_{ij}^{Kn} = D_j \quad (20)$$

$$\sum_{K}\sum_{j}\sum_{i} T_{ij}^{Kn} \cdot C_{ij}^{K} = C^{n} \quad (21)$$

where C is the total expenditure on transportation by persons of type (n).

The model is calibrated over the β^n values while A_i^n and B_j are solved by iteration to the correct answer. The definition of person type (n) may be on any available socio-economic variable related to tripmaking rates. The model used by Archer and Shortreed had a modification to the Wilson model which was the replacement of β^n with a linear cost such that $e^{-\beta^n C_{ij}^K}$ becomes $e^{-(\beta^n - \alpha^n C_{ij}^K)}$. They report that the previous application of the model by Wilson required two values of β^n, one for trip distribution, another for modal choice. The Kitchener-Waterloo model becomes:

$$T_{ij}^{Kn} = A_j^n \cdot B_j \cdot O_i^n \cdot D_j \cdot e^{-(4.5 - 1.0\, C_{ij}^K)} \quad (22)$$

where

$$C_{ij}^{auto} = \frac{1}{\phi}\left[\frac{P}{2} + C_m \cdot d_1\right] + K\left[T_1 + 60\left(\frac{d_1}{V_1}\right)\right] \quad (23)$$

$$C_{ij}^{transit} = F + K\left[T_2 + 60\left(\frac{d_2}{V_2}\right)\right] \quad (24)$$

where

ϕ = average auto occupancy = 1.50

P = daily parking costs

C_m = out-of-pocket cost per vehicle mile

K = time cost per minute

T_1 = automobile trip walking and waiting time

d_1, d_2 = network trip length in miles, when 1 is auto and 2 is transit

V_1, V_2 = network speed, in mph from the respective networks

T_2 = transit trip walking, waiting and transferring time, walking at 2.5 mph and waiting time ½ the bus headways

f = transit fare

This analysis of the Demand Bus System has a major weakness. The analysis used a 15 cent value (subtracted from the transit fare of 30 to 60 cents) to represent the benefit of using a small personalized vehicle with door-to-door service. This was also introduced to compensate for the fact that the model was calibrated on the existing transit service. If the previous relationships of costs and time hold any validity, then the 15 cents savings for a person at $5000 annual income is about 10 minutes of travel (in vehicle time) or about 4 minutes walking time. These savings are probably low as is indicated by the positive reaction of persons in Bay Ridge to a high level transit service.

Other sections in this chapter concerned with attitudes indicates that work trips are very sensitive to time. The most efficient time system will be used and out-of-pocket costs play a more minor role. The non-work trip is more sensitive to walking and waiting time as well as out-of-pocket costs, rather than a simple direct comparison of travel time between modes. Because of these shortcomings Archer's conclusion, that a demand bus system is not a viable alternative in small urban areas, is open to question.

Demand Bus Operating Algorithms

There have been a number of studies into the computer algorithms needed to operate a demand bus system. The early work was undertaken by Hansen at MIT* in 1965-1966 and at Northwestern University (30) and by the Westinghouse Air Brake Company (W.A.C. Co.)(31) during 1967-1968. The operating process has been refined by the MIT Methodology (32), and even more recently (1970) by General Motors Research Laboratory (33). The operating models all have one failure, none have been used in an actual operational situation where it is possible for:

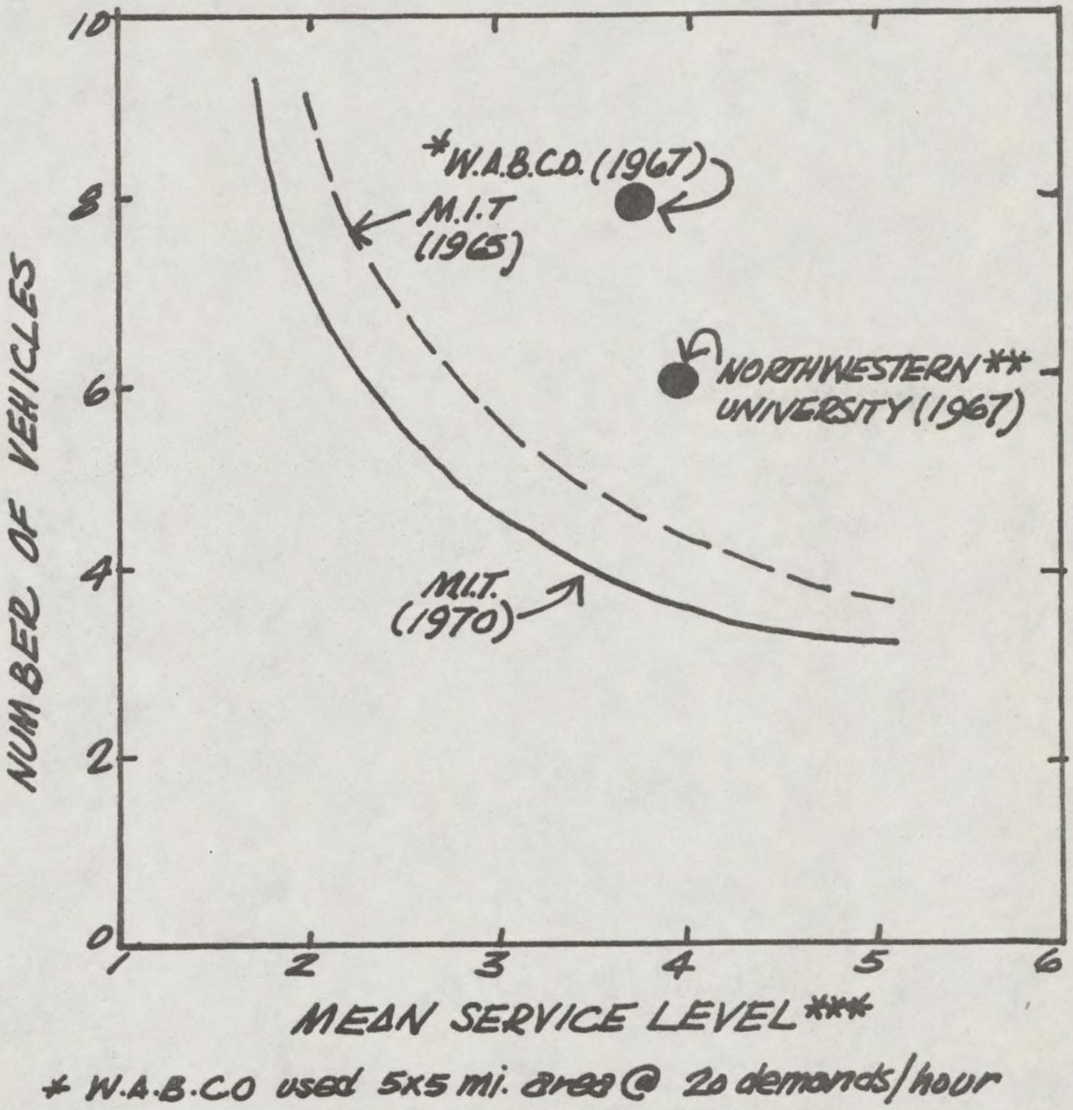
1. vehicles to breakdown
2. drivers to get lost,
3. passengers not to show for a bus, and
4. any number of other pessimistic events that may happen in a real world transit operation.

N. Wilson (32) has compared the M.I.T. bus routing with various other authors as well as the work by Garcia. The comparisons are graphically summarized in Figure IV-10 and Figure IV-11. The M.I.T. routing algorithms are approximately forty percent more efficient in the employment of buses at a fixed level of service

*Massachusetts Institute of Technology

FIGURE IV-10

COMPARISON OF THE EFFICIENCY OF SELECTED DEMAND BUS ROUTING ALGORITHMS



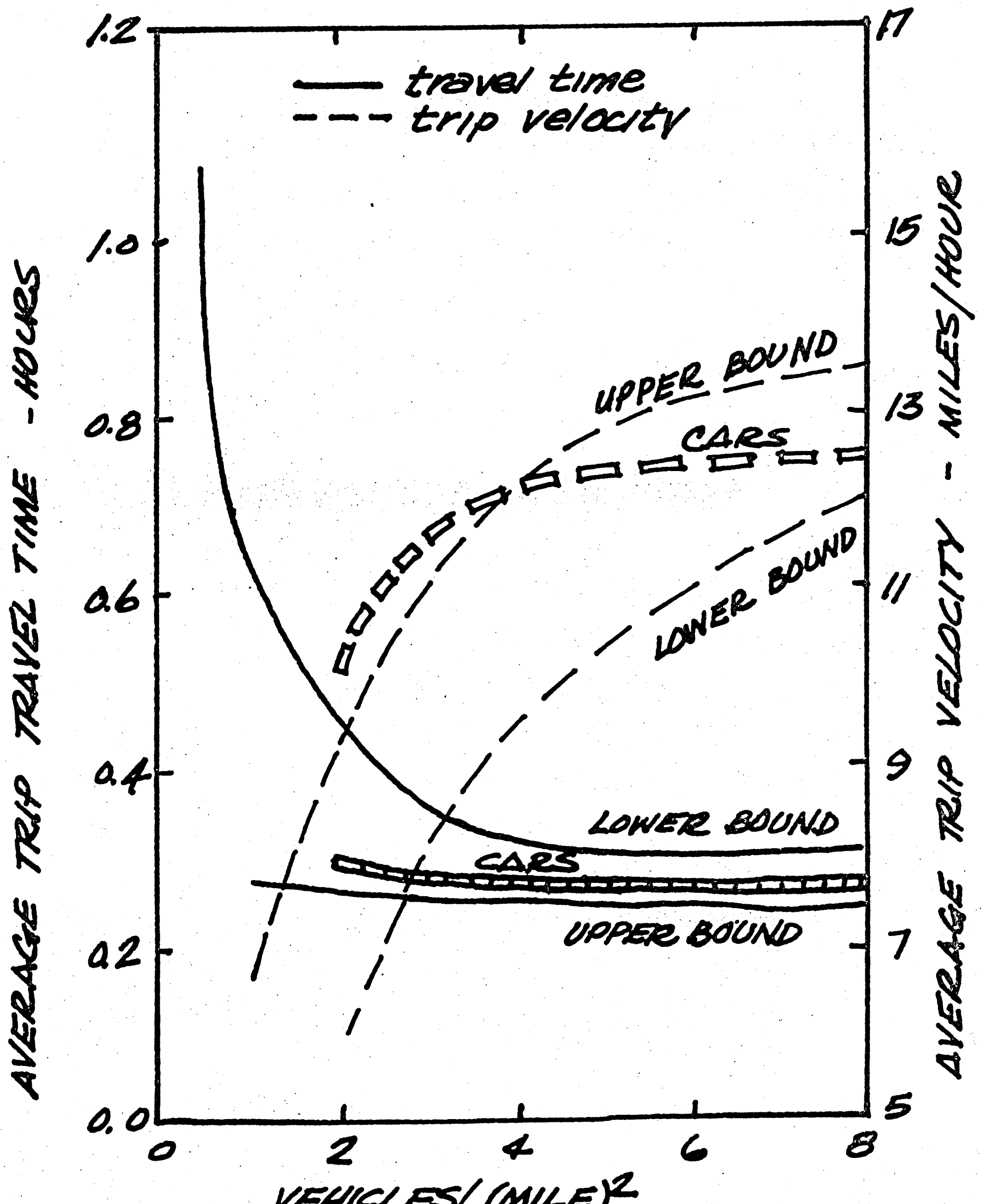
* W.A.B.C.O used 5x5 mi. area @ 20 demands/hour

** N.U. used 1x1 mi; area @ 100 demands/hour

*** RATIO of mean DIAL-A-RIDE service time and the mean direct driving time

SOURCE: reference 32

FIGURE IV-11
COMPARISON OF THE M.I.T. SIMULATION (CARS) AND GARCIA'S ORDER OF MAGNITUDE ESTIMATES OF VEHICLE NEEDS



SOURCE: reference 32

than those developed by the other authors. Thus at a mean level of service of 4, Northwestern required 6 buses and M.I.T. (1970) required 3.5 buses, approximately 40 percent fewer. The advances in efficiency of the routing algorithms appear to have approached the point of diminishing returns. The W.A.B.Co., simulation used the G.P.S.S. (General Purpose System Simulator) computer programs and rather crude sets of street geometry, priorities and service policies. The amount of money invested by W.A.B.Co. was minimal. The Northwestern analysis was the master thesis project of a number of students writing their own simulation. Finally the M.I.T. algorithms are essentially the doctoral dissertation of N. Wilson which was preceded by considerable preparation in the METRAN studies of Call-A-Ride (CARS). This set of studies involved a few hundred thousand dollars. Any further advances in the area of writing algorithms will be equally expensive.

A comparison of the estimates made by Garcia and M.I.T. are shown in Figure IV-11. The CARS average travel time favours the upper estimates mode by Garcia. This is reinforced by the trip speeds. The M.I.T. estimates are higher than Garcia's when the number of buses falls below 4 vehicles per square mile. This relatively minor discrepancy does not detract from the similarity of results obtained by the two studies which were approached in entirely different methodologies; Garcia with analytical equations and M.I.T. with computer simulation.

The conclusion that may be drawn is that the computer algorithms to guide buses through a network exist and are probably sufficiently efficient to operate an actual bus system. This provides a potential solution for large centers having access to computers.

Towns under 100,000 probably will not have easy access to computers and any demand bus system will probably be manually dispatched. The results of these studies do indicate the magnitude of costs in men and materials a community should be prepared to expend if Demand Bus service is desired. The models do not consider the influence of the increased service on ridership and a possible failure of the transit system by being too successful. That is, the demand for service exceeds the supply. This happened in Columbia, Maryland on the first day of operation.

Conclusion

The major conclusion that is forthcoming from the preceding sections of this chapter is: the weakest link in the entire transit planning (simulation) process is an adequate demand model which relates the important and measurable individual time and cost elements of trip-making of the competing modes.

The early work in modal choice modelling recognized the need to describe the trip-maker's origin-destination characteristics and the relative merits of the transportation system linking the two locations. The difficulties of latent demand have been addressed through the Kraft model but they are beyond the scope of succeeding discussions. The model considered acceptable for this study assumes the trip demand for any origin-destination pair is known. The increase in ridership resulting from improvements to the transit system can be estimated by providing a transit accessibility value in the trip generation and/or distribution phase of the transit planning process. The validity, or at least acceptability, of economic based models has been shown to be quite satisfactory in explaining ridership on "normal" transit situations but is not sufficiently sensitive to duplicate the ridership experiences of demand bus. Similarly the various economic authors have shown that the value of time for most work trips is from 1/4 to 1/3 of the annual hourly income but may vary with time saved and the person's income. The authors who explicitly looked at the value of travel time found excess time to be between 2.5 to 3.0 times more important than time riding in a vehicle. Gross excess time does not tell the entire story. Further investigation showed that transfers were prevalent even in large efficient systems and that such transfers had a significant impact on the mode choice of commuters.

Pursuing the question of transfers further, data for Toronto showed a relationship between transferring and waiting time. For completeness in this analysis of excess time the acceptance of walking time was studied. This walking time indicated that transit riders were very sensitive to walking up to a distance of 600 feet. Transit fare elasticity was also shown to be fairly uniform and reasonably estimated at 0.25 to 0.33 percent ridership loss per one percent rise in fare. Based only on the descriptive analysis, revised transformation weights

Chapter IV

REFERENCES

1. Creighton, R., J. Hamburg, "Data Requirements for Metropolitan Transportation Planning", NCHRP Report 120, Highway Research Board. Washington, D.C., 1971.

2. Dueker, K.J., J. Stover, Mass Transit Technical Study: Iowa City; Iowa City, Iowa, May 1971.

3. Kraft, G., "Economic Aspects of Urban Passenger Transport", Highway Research Record 285, Washington, D.C., 1969.

4. Charles Rivers Associates "Analysis of Free Transit", Prepared for the U.S. Department of Transport, 1970.

5. Hoel, L., et al, "Latent Demand for Urban Transportation", Transportation Research Institute Report No.2, Carnegie-Mellon University, 1968.

6. Golob, T.F., "A Survey of User Choice of Alternate Transportation Modes", General Motors Research Laboratories, Warren, Michigan, 1970.

7. Shunk, G.S., Bonchard, R.J., "An Application of Marginal Utility to Travel Mode Choice", Highway Research Record No.322, Highway Research Board, Washington, D.C., 1970.

8. "Working Paper on Modal Split Model Development", South Central Transportation Study, Philadelphia, Pennsylvania, November 1970.

9. Pratt, R.H., Schultz, G.W., "A Systems Approach to Sub-Area Transit Service Design", Presented at 50th Annual Meeting of the Highway Research Board, Washington, D.C., 1971.

10. Navin, F.P.D., "The Interaction Between Personalized Rapid Transit and Demand Activated Bus Transit", Personal Rapid Transit, University of Minnesota, Institute of Technology, November 1972.

11. Pratt, R.H., "A Utilitarian Theory of Travel Mode Choice", Highway Research Record No.322, Highway Research Board, Washington, D.C., 1970.

12. Beesley, M.E., "The Value of Time Spent in Travelling: Some New Evidence", Economica, Vol.32, pp.174-185, 1965.

13. Stopher, P.R., "A Probability Model of Travel Mode Choice for the Work Journey", Highway Research Record No.283, Highway Research Board, Washington, D.C., 1969.

14. Thomas, T.C., Thompson, G.I., "The Value of Time for Commuting Motorists as a Function of Their Income Level and Amount of Time Saved", Highway Research Record No. 314, Highway Research Board, Washington, D.C., 1970.

15. Lisco, T.E., "The Value of Commuters' Travel Time: A Study in Urban Transportation", 1967, Ph.D. Thesis, Department of Economics, University of Chicago.

16. Quarmby, D.C., "Transportation Planning and the Choice of Travel Mode", Summary Report to the Transport Committee of Leeds City Council, Leeds, England, 1966.

17. Pratt, R.H., T. Deen, "Estimation of Sub-Modal Split within the Transit Mode", Highway Research Record 205, 1967.

18. Bock, F.C., "Factors Influencing Modal Trip Assignment", NCHRP Report 57, Highway Research Board, Washington, D.C. 1968.

19. Toronto Area Transportation Study, unpublished data acquired by the author.

20. Lessieu, E.D., J. Zupan, "River Crossing Travel Choice: The Hudson River Experience", Highway Research Record 322, 1970.

21. Petersen, S.C., "Walking Distances to Bus Stops in Washington, D.C., Residential Area", Traffic Engineering, December, 1968.

22. Nelson, G., W. Fowler, "The Relationship Between Transit Ridership and Walking Distances in a Low Density Florida Retirement Area", Presented at the 51st Annual Meeting of the Highway Research Board, Washington, D.C., January 1972.

23. Clearwater Demonstration Bus Project, First Interim Report, for the Florida Department of Transportation by A. M. Voorhees & Associates, Inc., June 1971.

24. "Coordinated Transit for the San Francisco Bay Area - Now to 1975", Simpson and Curtin, Inc., October 1967.

Chapter V

EXISTING DEMAND RESPONSIVE TRANSIT SYSTEMS

Introduction

At the time this study was formulated (January 1971) only three locations in North America were known to have demand responsive transit systems. The systems existing at the time of this study were in Columbia, Maryland; Bay Ridges, Ontario; and Mansfield, Ohio. Since that time a number of additional locations have started such service in a suburb of Regina, Saskatchewan; Ann Arbor, Michigan; and Clearwater, Florida.**

The purpose of this chapter is to explain the operational plan used by each of the three demand bus systems, their scale of operation, and the critical operational characteristics. The study of the existing situation is needed to uncover limitations that may not be apparent in any theoretical model because of the difficulty of predicting the interaction of people with an operating transit system. People quickly learn how to use systems to their maximum benefit which may not be in the manner devised by the planners and operators.

Critical Elements in Demand Bus Systems

The elements that are common to all demand bus systems are

**See Appendix A for a list of operations existing in May 1973.

shown in Figure V-1. The following explains the usual steps needed to obtain service.

Step 1. The customer must communicate his demand to the controller giving as minimum information the origin, destination and any unique systems constrains. (This assumes the operator has a set policy of time and level of transit service.)

Step 2. The controller ascertains the status of the system.

Step 3. The potential transit user is informed of how well his demand may be filled. (That is when he will be picked up or delivered to the destination).

Step 4. The potential user accepts or rejects the service as a result of the information the operator supplied in Step 3.

Step 5. The bus is informed at the appropriate time that he has a "pick-up" at a particular location specified by the customer in Step 1.

Step 6. The bus and customer meet for the journey.

Step 7. The customer arrives at the destination.

The key elements in this system are:

1. customers,
2. telephones (private, public or free lines),
3. a transit controller (dispatcher),
4. radio link from bus to controllers.

All the systems to be discussed have these four common elements in one form or another. Using the transit service criteria of routing flexibility and level of service in time, the four systems fall in the space as noted in Figure V-2. Columbia provides a maximum of service while Mansfield provides a minimum demand service. The two systems, as will be shown, emphasize different elements of the steps in the transit trip.

FIGURE V-1
INFORMATION FLOW FOR CUSTOMER - DEMAND BUS INTERACTION

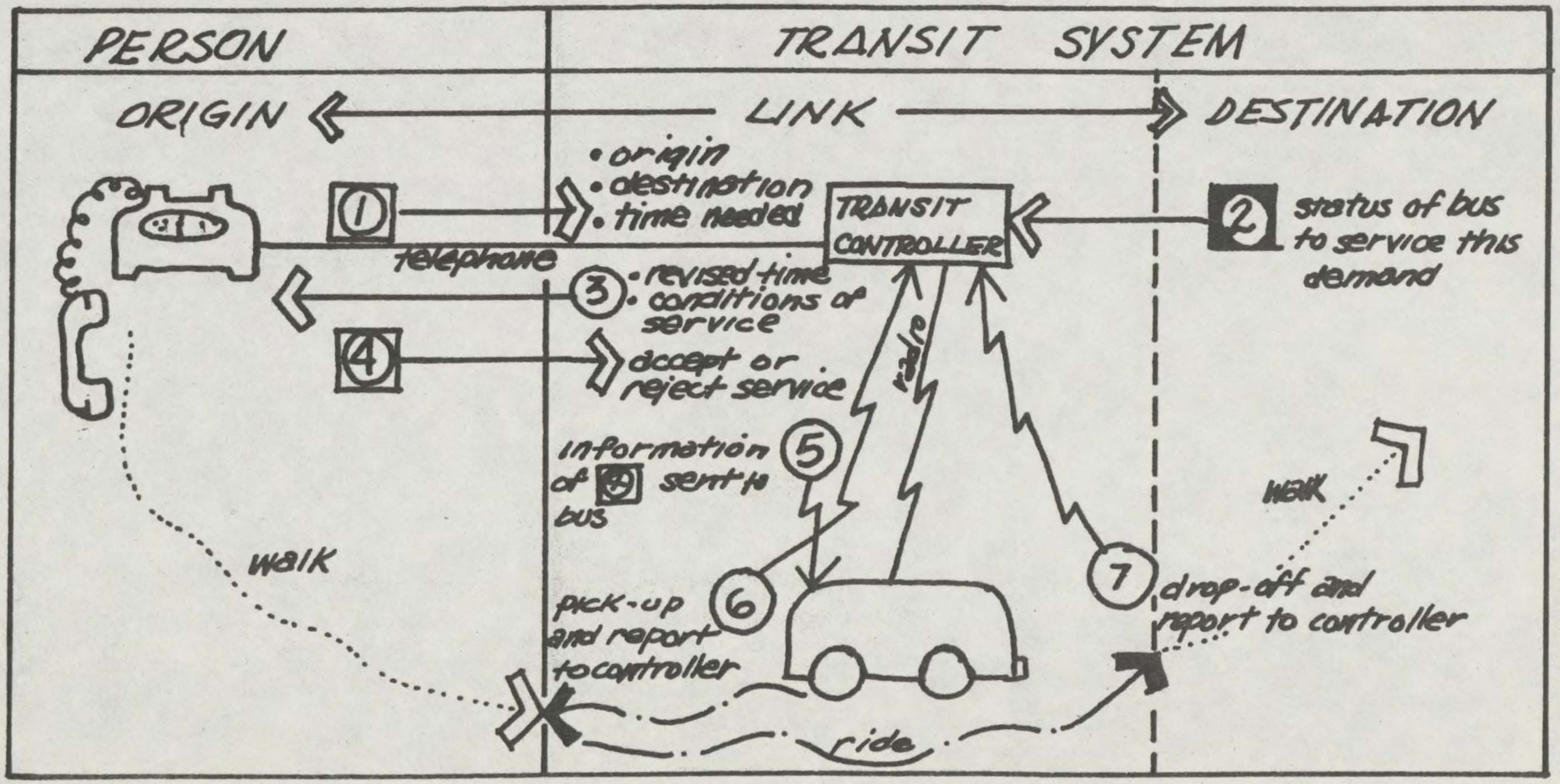
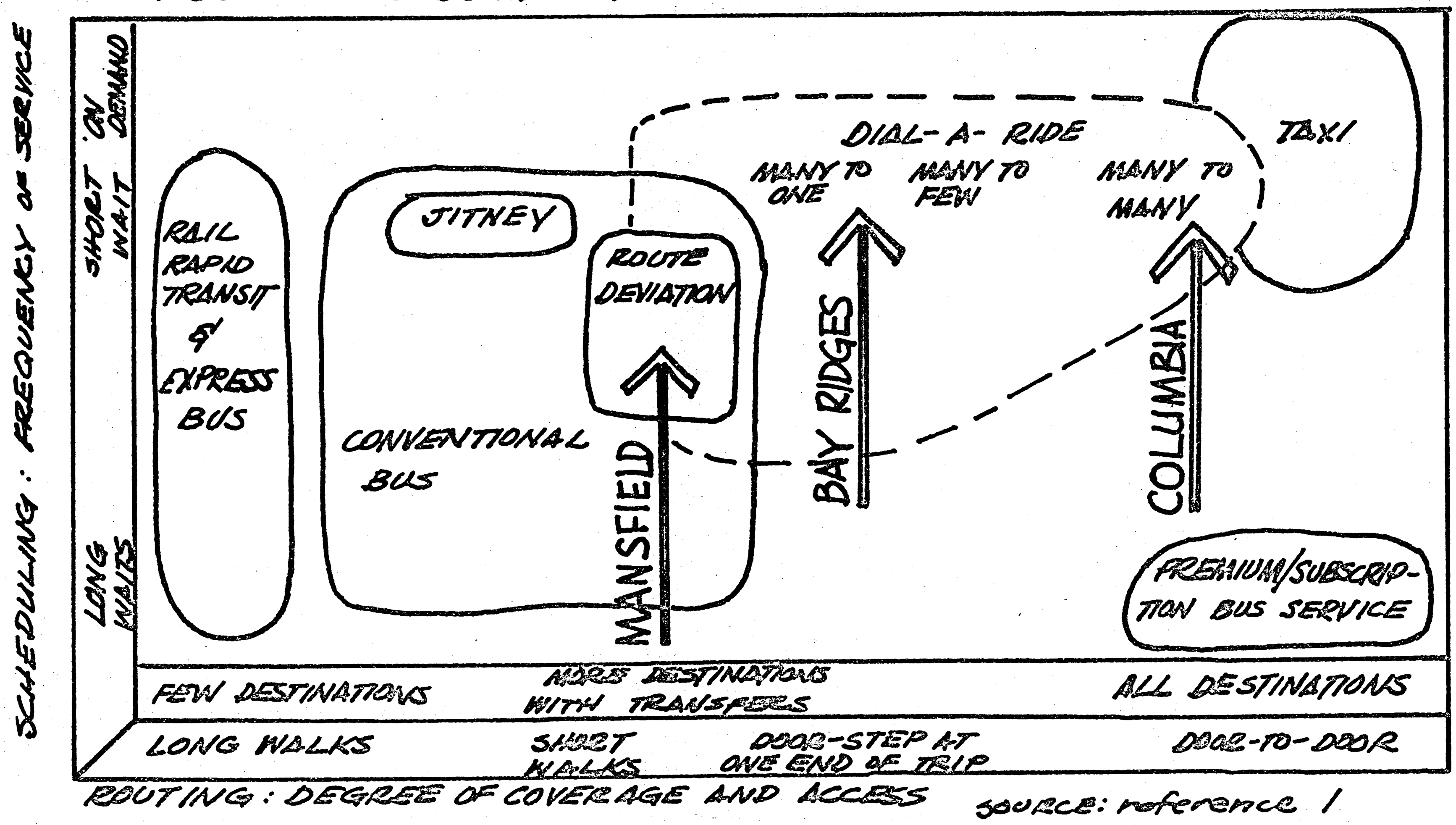


FIGURE V-2

ROUTING AND SCHEDULING SCHEMATIC FOR PUBLIC TRANSPORT SYSTEM



source: reference 1

These systems range from a "many-to-many" arrangement in Columbia, Maryland through to a "many-to-one" in Bay Ridges, Ontario, plus a route deviation from a scheduled route system in Mansfield, Ohio. The many-to-many service is very similar to a shared taxi. The "many" refers to possible origins and destinations. Many-to-one again is similar to taxi service except there is one location to which all trips either start or terminate such as a railroad station. Route deviation refers to a bus operation which allows a bus to leave the main route to pick up or drop off a passenger. Figure V-2 relates the various demand bus service to other public transit modes. An important aspect of the demand bus service is its attempt to fill the service gulf existing between taxis and conventional buses. The following sections will discuss the actual operation of the three types of demand bus operations.

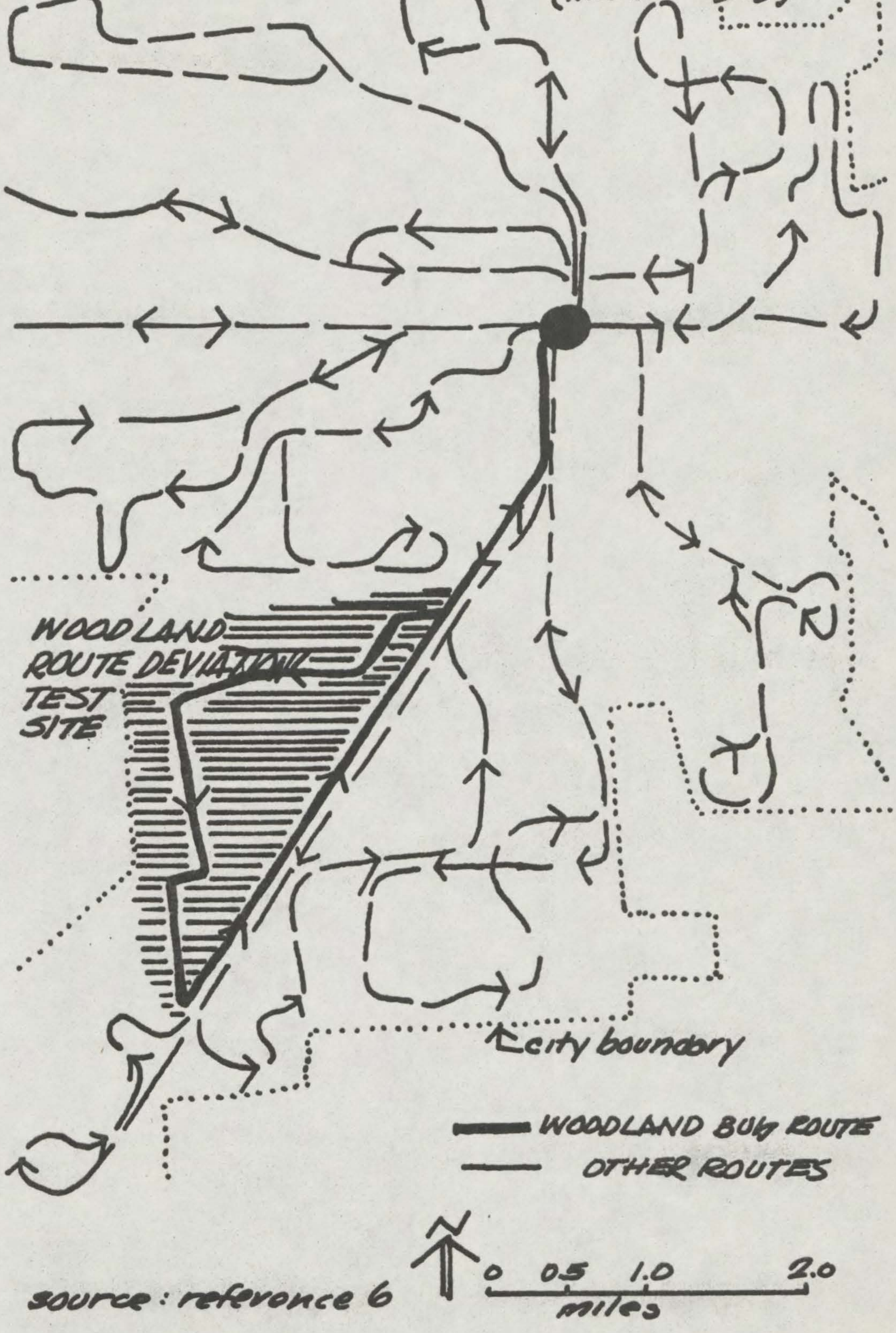
Route Deviation(8)

The Mansfield, Ohio Bus Company, with the assistance of the Ford Motor Company, placed one vehicle in demand bus service along a route that was losing money. The scale of operation is shown in Figure V-3.

The Mansfield Bus System had a high quality bus routing, using small buses (Econovans and 20 passenger Flexets) having 30 minute headways. The buses were in service from 6 a.m. to 6 p.m. on weekdays and 8 a.m. to 3 p.m. on Saturday. All the buses met for a minimum 5 minute layover at the Town Center. During the

FIGURE V 3

MANSFIELD OHIO BUS ROUTES (MARCH 1969)



source: reference 6

peak hours an extra bus was provided to insure a high quality of service in case of a late arrival or breakdown. The route deviation bus line in the Woodland corridor had slack in the schedule and thus provided a good test site. The slack, or free time, allowed the bus to deviate from the main route and still arrive at the town center at the scheduled time.

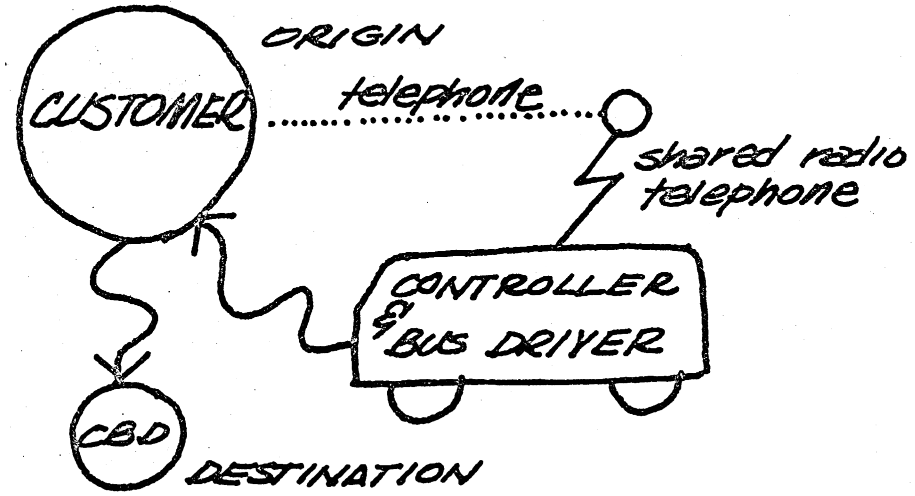
The Operation

The dial-a-ride operation was superimposed on the existing fixed route, fixed headway service. This type of operation is usually called route deviation. The communication network and routing operation is graphically shown in Figure V-4. A special Ford Courier was equipped with a radio telephone permitting the driver to also act as the controller. As controller, the driver advised pick-ups as to his expected time of arrival at their door. The driver could tell the customer the time of pick-up because of the accuracy needed on fixed schedule systems. This feature, the fixed schedule, makes this type of service self-correcting, in time and space. The connection with other buses at the central business district must be made to keep the entire system operating properly and the driver has this scheduled time to which he must regulate all the other elements of the service.

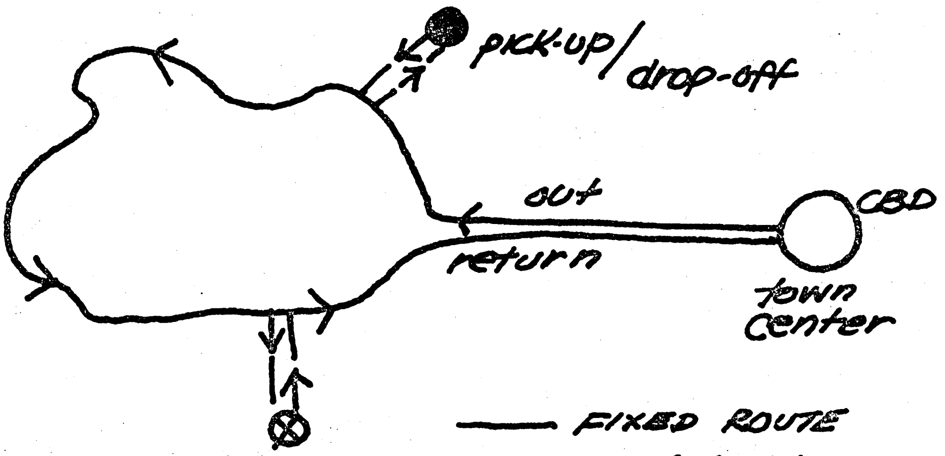
A person boarding at the city center merely told the driver they wanted doorstep service. Patrons were delivered to or picked up at the door for an additional cost of 15¢, thus the adult fare for dial-a-bus was a base of 35¢ plus 15¢ to give a total of 50¢.

The intended service area is the shaded area of Figure V-3.

FIGURE V-4
ROUTE DEVIATION
(MANSFIELD OHIO)



GENERAL OPERATION



BUS ROUTING SYSTEM

Only 17.5% of the 1045 households used the service at least once during the period January, 1970 through June, 1970. Those persons who lived directly on the route (they number 395 households) had almost 25% of the households using transit.

Walking Influence

The influence of walking distance on dial-a-bus in Mansfield is shown in Figure V-5. This figure also shows the influence of walking on regular bus service users in Clearwater, (3) Florida and Washington, D.C. (4)(who live in apartments adjacent to the bus lines). The decrease in usage with distance beyond 300 feet (approximately one block or 1.5 minutes walk)* is dramatic in all cases. This may be a case of "out of sight, out of mind" i.e. if the bus was more visible one would be more likely to use it. What is most likely the case is that people dislike walking to transit and thus at distances beyond 300 feet, start seeking alternatives. The Mansfield, Ohio dial-a-ride usage tends to confirm this suspicion. The percentage of dial-a-ride usage increases as distance from the fixed route increases. The numbers of patrons in Mansfield also holds a warning that deviation far from the fixed route may operate on the principle of diminishing returns.

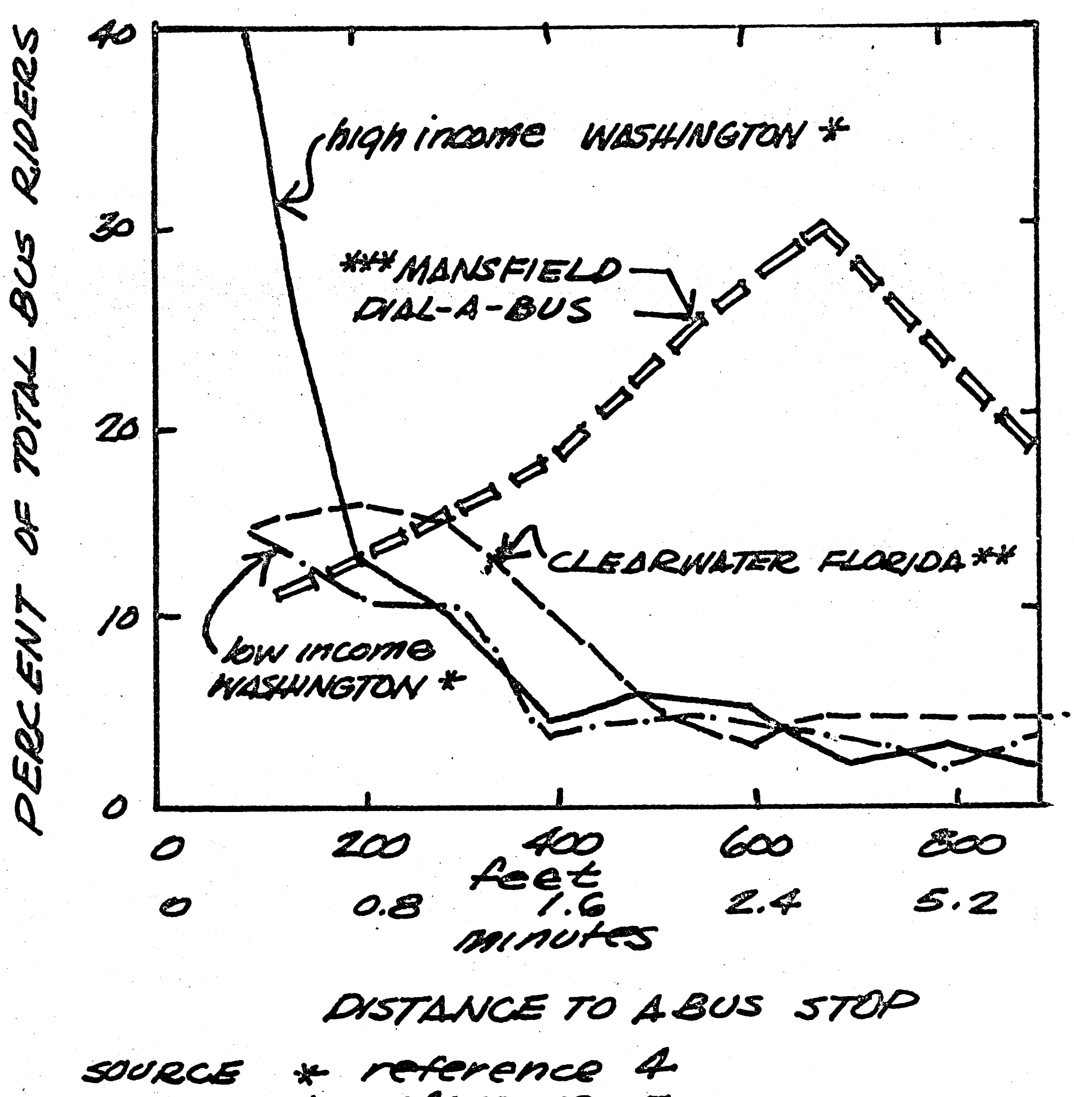
Another view of the influence of distance may be gained

---

*If the walking speed is assumed to be between 3 and 4 feet per second (5) then the walking time for the 300 feet is between 1.7 and 1.5 minutes.

FIGURE V-5

INFLUENCE OF WALKING ON BUS RIDERSHIP AND DEMAND BUS USE



DISTANCE TO A BUS STOP

SOURCE * reference 4
** reference 5
*** reference 6

from a factor called transit productivity.* Using combined data from Clearwater's regular bus service and Mansfield's fixed time schedule demand bus service, a relationship was developed to show the importance of route deviation bus. The results are shown in Figure V-6. The major observation is that a route deviation bus removes the influence of distance in the first quarter of a mile. This first quarter of a mile from a fixed route has traditionally been considered the "domain" of regular bus service. The transit productivity, rather than being extra sensitive to distance is only moderately sensitive. From Figure V-6 the ridership for regular bus and demand bus appear to be additive. If this is correct then the following equation applies.

$$P_t = P_r + P_{dr}$$

P_t = total productivity

P_r = regular service productivity

P_{dr} = demand service productivity through route deviation

A maximum (or minimum) exist if:

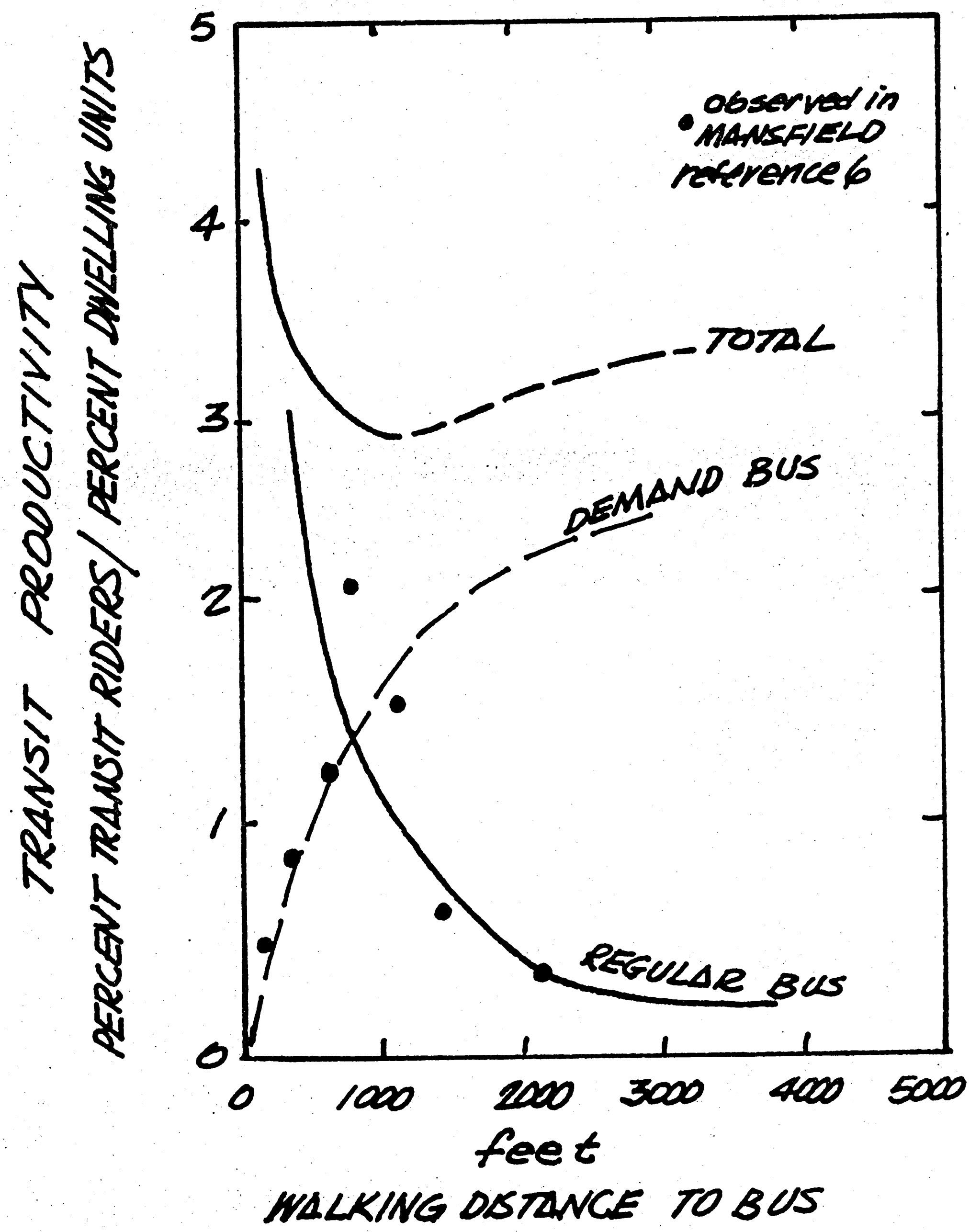
$$\frac{\partial P_t}{\partial x} = 0$$

$$\frac{\partial P_r}{\partial x} + \frac{\partial P_{dr}}{\partial x} = 0$$

*Author's terminology. This term has been coined by the author to explain a unit of transit demand. Transit productivity is defined as the ratio of percent of total transit and the percent of the total number of households within a small slice from a service area. For example, assume that the service area has 500 houses and within a strip from 100 to 200 feet of a bus stop, 20 percent of the houses occur. Similarly within this strip 30 percent of the total transit ridership occurs, for this case the transit productivity is 30/20 = 1.5.

FIGURE V-6

INFLUENCE OF DEMAND BUS ON RIDERSHIP AWAY FROM A FIXED ROUTE



From observation we know $\frac{\partial P_r}{\partial x}$ always diminishes, thus $\frac{\partial P_{dr}}{\partial x}$ must incorporate either: 1. a continually increasing equation or 2. an equation that has a maximum.

Service Area

The next area of interest needed to assess the success or failure of the Mansfield experiment is to compare the Woodland area to Mansfield (Woodland is the suburb where the demand bus operated). Woodland is more than twice as wealthy as the city of Mansfield and 96% of the homes have at least one car and 53% have two. Most of the persons are "white collar" employees with a large domestic work force and many school children. Mansfield has the national average of car-less homes which is approximately 20% and is roughly evenly divided between "white" and "blue" collar workers with very few homes employing domestics. These statistics, while average, point out the fact that Woodland would itself be a low transit using area except for the domestics transported into the area. Thus if a rise in ridership was experienced in this suburb then more dramatic results should be noticed elsewhere where there is more tendency to use transit.

Users of Service

The persons who use the Woodland bus service in Mansfield are primarily captive to the bus in that 63% do not have driver's licences and 32% do not have an automobile in the family. Only

18% felt they could drive an automobile as an alternate method of travel and only 33% felt they could get someone to drive them. Only 8% said they would not make the trip if the bus service did not exist. Forty-five percent of the riders were either under 20 or over 50 years of age and a full 83% of the transit users were women.

The most frequent users of the doorstep service were housewives who accounted for 55% of all users followed by domestics who accounted for 27%. This also explains why 91% of all doorstep service users are women.

Operating Costs

The operating costs for Mansfield may be divided into two parts: those allocated to the fixed schedule and the other to the route deviation. The operating costs associated with Mansfield are summarized in Table V-1. The economics of the route deviation show an interesting and encouraging financial result. The average week day showed 14.4 requests for route deviation, this represents 24 percent of the fixed route clientele. The doorstep service at 15 cents yielded \$2.16 (14.4 x 15¢) daily revenue. To obtain this revenue a radio telephone in the bus cost \$2.00 per day and the total additional mileage was 4.4 miles costing 27¢*. Thus the

* Only short run out-of-pocket operating costs are considered. In Table V-1 gasoline cost is 3.31 cents per mile, allow 2.83 cents per mile for maintenance, oil and tire wear. This gives a total cost of 6.14 cents per mile. Note that since no additional work time for the driver is needed, his wage is considered a fixed cost. The 6.14 cents per mile operating cost yields an additional bus operational daily cost of (6.14¢ x 4.4) .27¢ or \$0.27.

Table V-1

DIAL-A-RIDE COSTS IN MANSFIELD

FIXED COSTS		ANNUAL COST
Bus purchase (approx. $7,400, 5 year life, 8% interest)		$1640
Radio telephone (cost covered by incremental service $50/month)		$ 600
Washing $9.00/week		$ 468
Gas (@ 30¢/gal.) 9.06 miles/gal. 1.4 gals./hour		$1189
Maintenance* 1.14¢/mile		$ 407
Wages (Driver @ $2.25/hour)		$5737
COSTS		$10,041
Revenue		
deviation	$0.15	$ 551
adult fare	$0.35	$5355
TOTAL COST		$4135

Source: Reference 6

*New vehicle and true maintenance costs are not available.

additional operating cost was $2.27 per day. The difference between the operating cost and revenue is a deficit of 11¢ per day. Attracting one new passenger per day with 35¢ fare would give a net profit of 24¢ per day. The responses indicated that approximately eleven trips per day were made because the demand bus system was available. Thus the daily revenue from this ridership due to demand bus actually increased the net profit to the operator by $3.68.* This outcome is rather encouraging especially when one considers the poor quality of the shared radio telephone communications and the lack of publicity of the service in the Mansfield operation.

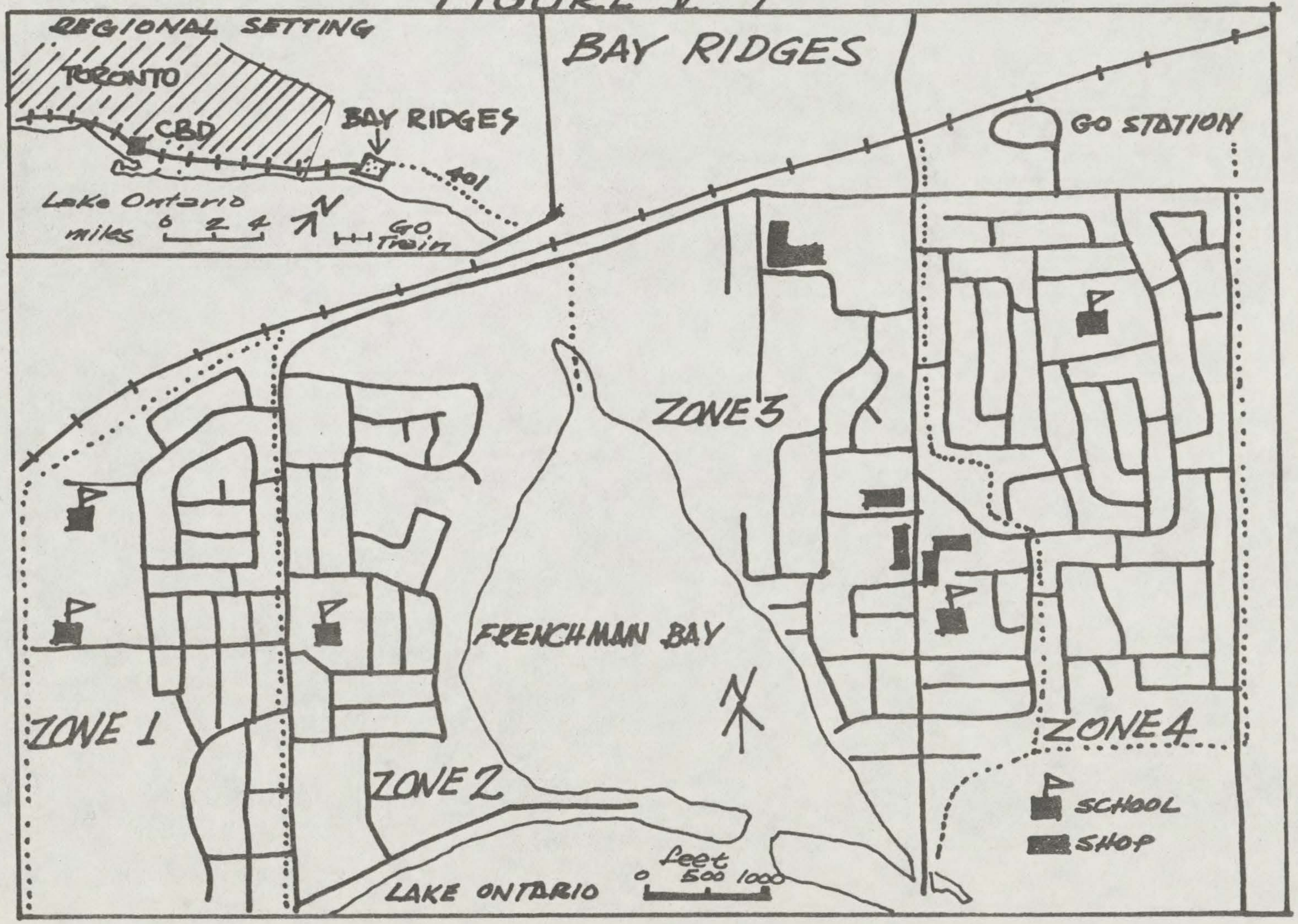
Many to One

The Area

Located 20 miles east of Toronto is Bay Ridges, a commuter suburb on the shores of Lake Ontario as shown in Figure V-7. It is at the Eastern Terminus of the GO (Government of Ontario) Train System which gives high speed service to downtown Toronto. The demand transit started as an experiment (this avoided all legal difficulties with taxis and unions) because a fixed route, fixed schedule bus system, had failed to produce any additional ridership for the GO Train System. The reason for the experiment was to test dial-a-ride (specified in the original GO Train feeder

*Eleven trips gives a daily revenue of (11 x 0.50) $5.50 and three additional doorstep stops yields $0.45. Service of the demand system has a total cost $2.27. The net profit given by this is (5.95 - 2.27) $3.68.

FIGURE V-7



REGIONAL SETTING
TORONTO
CBD
BAY RIDGES
401
Lake Ontario
miles 0 2 4
N
GO Train
BAY RIDGES
GO STATION
ZONE 3
FRENCHMAN BAY
ZONE 1
ZONE 2
ZONE 4
N
SCHOOL
SHOP
feet 0 500 1000
LAKE ONTARIO

bus system) as a feeder bus, realizing that a fixed routed rail system needed good feeder service. The system started July 1970 under the direction of the Ontario Department of Highways, Transit Planning and Operations Section.

The Vehicle

The service started with five Ford Econolines, Series 200 Window Van with V8 engines and an automatic transmission. The major modifications were:

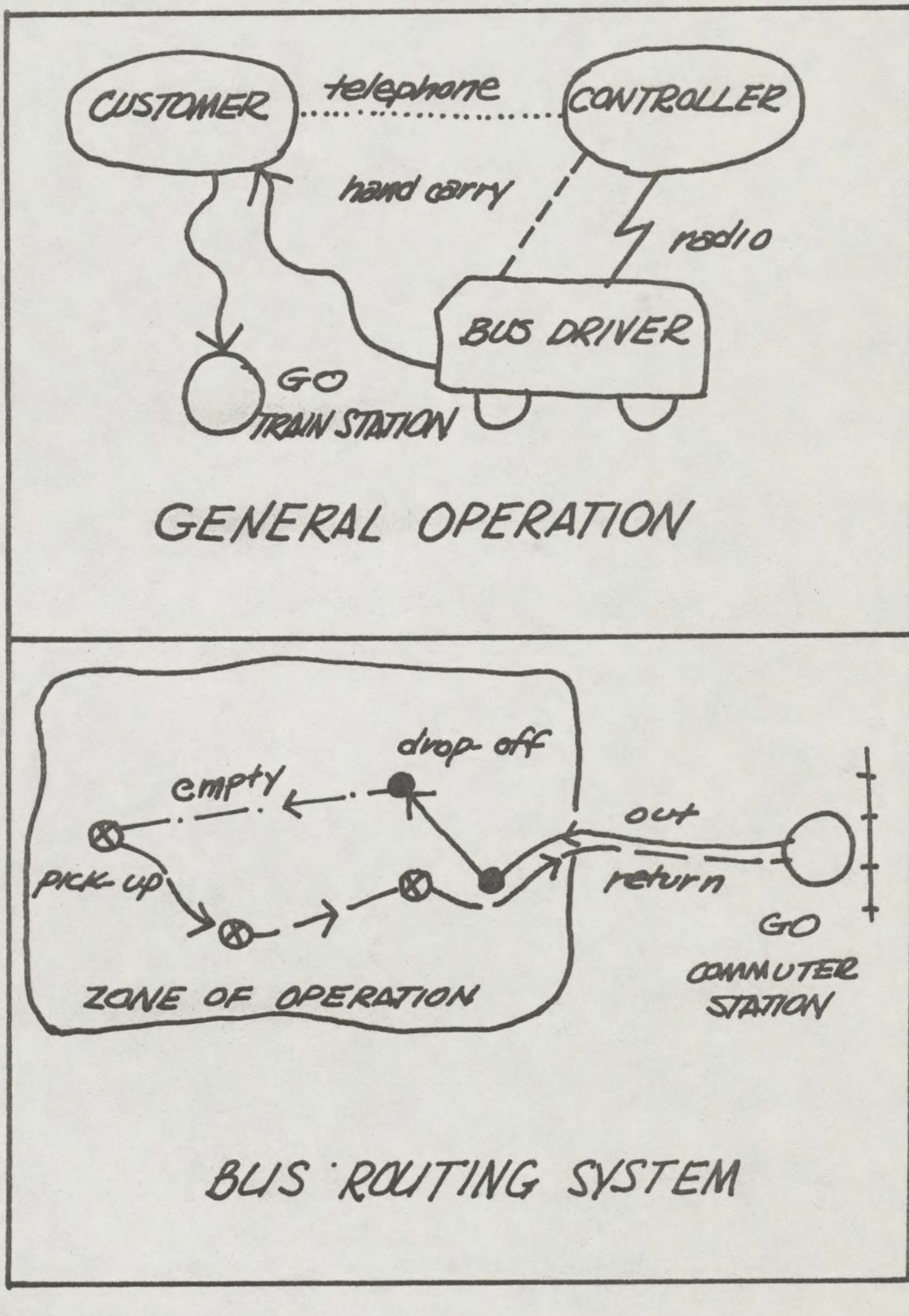
1. raised 6'3" fiber-glass roof,
2. 11 seats (+4 standees),
3. oversized door operated by driver,
4. luggage rack,
5. heater, and
6. two-way radio.

Operations

The operational procedure had two modes of operation, one for the peak hours and another for the off-peak hours. The schematic operational modes are shown in Figure V-8. The operation is very similar to the Mansfield system in that the person arriving from the "GO" Train gets on the properly designated bus and states his destination which the driver logs on a map of his area*. When the bus is loaded it travels out

*It is interesting to note that persons identified with the bus driver and not the zone number on the bus as was discovered during one rush hour. Drivers had been switched to other buses so they would learn new areas, transit patrons went to the bus with "their" driver, no other experiments of this type were run.

FIGURE V-8
MANY-TO-ONE
(BAY RIDGES, ONTARIO)



(at this time the pick-up request log sheet has been given to the driver) dropping off persons at their destinations. When empty, the bus goes to the furthest pick-up and proceeds back to the station in a path considered best by the driver.

Since the primary purpose of the bus system is to service the GO Train, the bus system must meet each and every train. This imposes a time constraint on the bus's running time and also limits the service area. The limit is that trains arrive every 20 minutes in the peak hour, thus in 20 minutes a bus must: load all passengers, deliver them, pick-up new passengers and be back to the station to unload. This places considerable pressure on the drivers during the peak hours.

During the off-peak, the scheduled time between trains is 60 minutes and both buses meet at the shopping center for a 5 minute layover. The operation in the off-peak also allows a modified many-to-many option within a zone, or through a transfer at the shopping center.

Communications

The customer telephones the dispatcher for service one hour before the time the bus is needed.* The dispatcher verifies that service is available and notes the demand on a map of the appropriate zone for the appropriate time. This may also have any "standing" (requests made the evening before or regular

*This technique allows for rejection of service when the requests for service exceed the bus capacity, or the spare bus may be pressed into service.

service for a week) calls transferred to the appropriate location. This map of requests is handed to the driver prior to his departure from the GO station. Any request for service that arrives after the bus departs may be transmitted to the bus via a radio link between the dispatcher and bus operator.

Service Levels

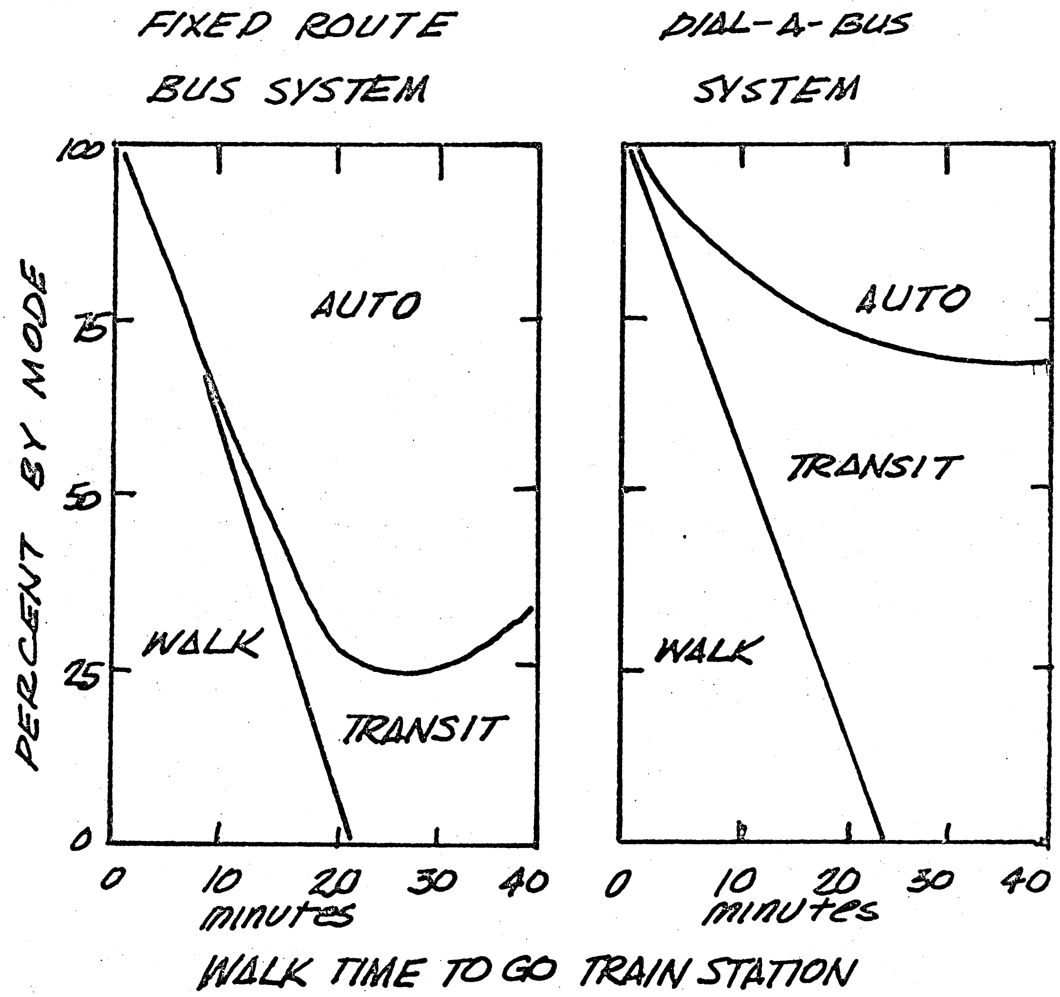
The dial-a-bus service area is divided into 4 zones as shown in Figure V-7. During the peak hour a bus is assigned to each zone. Zones 1 and 2 are combined as are 3 and 4 during the off-peak with each area being serviced by a single bus. The bus frequency is 20 minutes from 6.30 a.m. to 7.30 a.m. and 4.50 p.m. to 6.10 p.m. and at hourly intervals during the off-peak.

Walking Distances

Fortunately for this study extensive data exist for Bay Ridges and they are well reported (8). This discussion shall be divided into three parts. First walking to the GO station will be considered, then walking by transit users to transit service and finally their relationship to non-user walking habits.

The walking distance of patrons who walk to the GO train, appears to be independent of the available access modes. The relative stability of the influence of distance on the use of alternate modes is shown in the walk curves of Figure V-9. The approximate rate of loss of patronage is 3.7% with each minute increase in time. The influence of distance on the use of alternate modes is shown under the AUTO and TRANSIT headings.

FIGURE V-9
ACCESS MODE TO GO TRAIN FOR FIXED ROUTE AND DIAL-A-BUS TRANSIT SERVICE



SOURCE: reference 8

Climatic influence of Dial-A-Ride on shifting persons from the automobile to the bus is obvious. With fixed bus routed systems, the rate of use of the bus increased by approximately 0.9% for each minute increase in distance. The rate of using the Dial-A-Ride was 2.5% increase per minute to approximately 20 minutes and approximately 0.6% per minute beyond 20 minutes. This break in the curve at 20 minutes may give the distance domain (approximately 4000 feet) of maximum Dial-A-Ride use in small urban areas. The drop in automobile usage was reflected by an increase in the bus usage, thus there was a shift from the auto mode. The approximate influence of distance on bus usage in January was 0.6% usage increase per one minute increase in time.

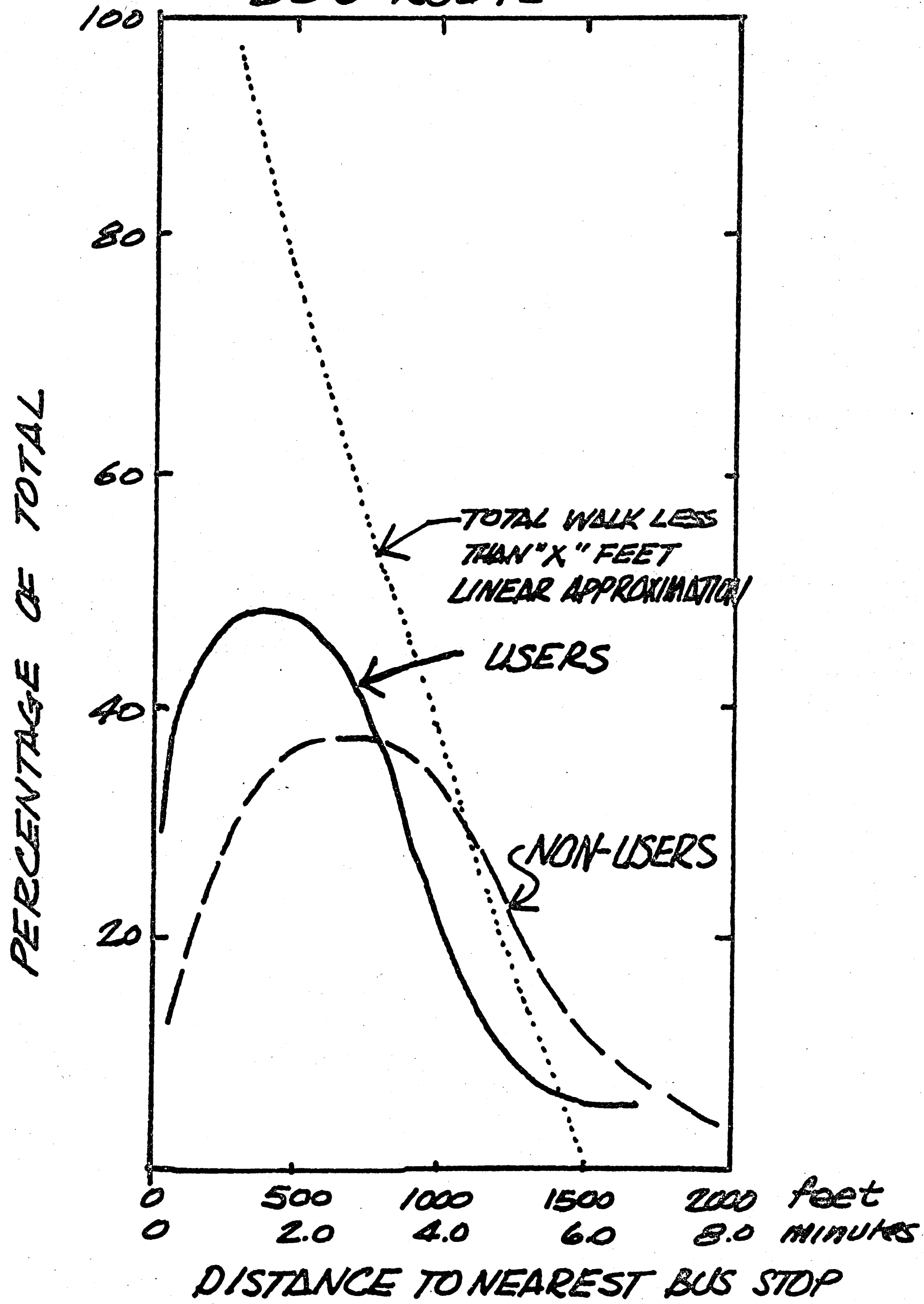
This observation, plotted in Figure V-9 dramatically shows:

1. Persons will walk to fixed facilities and are quite predictable in their actions in this respect.
2. Persons may, in special circumstances, be shifted from their automobiles to high quality bus service.

Feeder Bus

The influence of a walk to a feeder bus service to the GO train is shown in Figure V-10, a cumulative curve. The comparison of the cumulative curve in Figures V-10 and V-9 indicates that persons are approximately 5.4 times more sensitive to distance: walking to a feeder bus to get to the facility as opposed to walking directly to the facility. This observation indicates that in approaching a facility a person must evaluate time, thus

FIGURE V-10
WALK DISTANCES TO A FEEDER BUS ROUTE



SOURCE: reference 8

a person may walk to the GO Train but would not consider spending that much time walking to a feeder bus service. The rate of change of percentage of transit users versus distance is approximately 0.047% decrease per foot increase in distance, this corresponds very closely to the observations in Clearwater and low income groups in Washington, D.C.

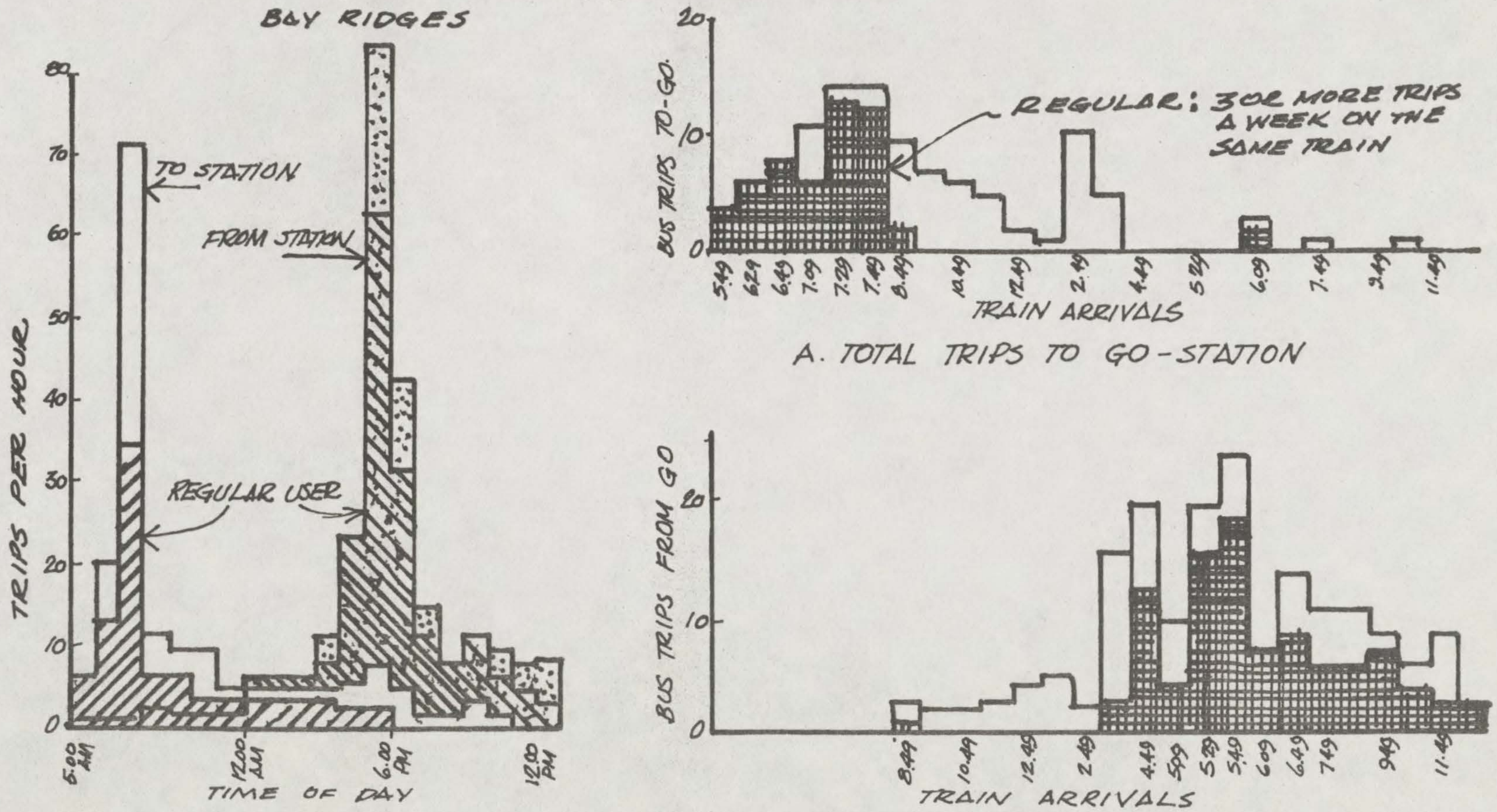
It implies that if it is possible to establish the impedence of walking to riding time, it is then possible to compare the value of riding with walking time.

Demand

Demand by time. The demand for the bus service essentially reflects the time demand for commuter train service and is shown in Figure V-11. The very high peak is characteristic of commuter railroads (or subways). The low weekend usage is also characteristic of railraod transit service. The demands serviced directly by the dispatcher, i.e. answering the telephone etc., are indicated by the broken line. The dispatcher directly services a maximum of some 20 trips per hour in the a.m. peak and there is a low but steady flow of traffic on the weekend. (The weekend might be the time for a radio telephone type service since commercial usage would be low.)

Demand by purpose. The demand by trip purpose is shown in Table V-2 and of the 723 replies to the survey, (covering 1786 trips) 67% were work purpose and 33 percent were non-work trips. As is indicated by the columns for Dial-A-Bus usage in Table V-2, 43% of all work trips claim to usually use dial-a-bus and 57%

FIGURE V-11
TRIP DEMAND OVER TIME



DIAL-A-BUS TRIPS TO & FROM GO.
AVERAGE WEEKDAY
SOURCE: REFERENCE 7

B. TOTAL TRIPS FROM GO-STATION
DIAL-A-BUS REGULAR RIDERS
WED. SEPT. 16 1970

Table V-2

DIAL-A-BUS USAGE BY TRIP PURPOSE

Purpose	Access	Frequency of use of Service						
		Usual		Occasional		Rare		Total
Work	Use Go Train	254	52%	85	18%	145	30%	484
	Use Dial-A-Bus	143	43%	80	24%	113	33%	336
Non-work	Use Go Train	111	43%	154	24%	436	33%	701
	Use Dial-A-Bus	114	42%	76	29%	75	29%	265

Source: Reference 8

Table V-3

ANNUAL OPERATING COST FOR BAY RIDGES
(Canadian Dollars)

FIXED COSTS	
oBus purchase (5 @ $7,389 replaced each 5 years, 8% interest)	$8,190.00
oRadio (6 @ $1,000, replace each 5 years, 8% interest)	786.00
oRadio maintenance (bus units @ $6/month base unit @ $12/month)	504.00
oTelephone (3 lines)	840.00
oBase Terminal	1,220.00
oLicences (5 @ $84)	420.00
oInsurance (5 @ $408)	2,040.00
oBus Cleaning (5 @ $5/each/week)	1,300.00
TOTAL FIXED	$15,309.00

VARIABLE COSTS	
o3544 IMP. Gallons Gasoline	$1,664.55
o65 IMP. Quarts Oil	68.54
oNon-Warranty Maintenance*	366.91
oDrivers** @ $3.14/hour	
weekdays	31,537.00
weekends	7,110.00
oDispatcher @ $3.25/hour	
weekdays	16,600.00
weekends	6,800.00
TOTAL VARIABLE	64,147.00
TOTAL FIXED	$15,309.00
TOTAL COST	$79,447.00

*This is a "new" bus fleet and much of the maintenance came under the new vehicle warranty.

**The system is non-union and operates for 3,134 hours annually for 30,363 miles.

Source: Reference 8.

Table V-4

INFLUENCE OF DISPATCHER COSTS
(Bay Ridges, Ontario)

TIME OF DAY	ON THE COST* PER TRIP		
	With Dispatcher (cents)	Without Dispatcher (cents)	%
Peak**	50	44	12.0
Mid-day off-peak			
Feeder	66	35	47.0
Local**	48	48	-
Evening off-peak	75	40	46.7
Saturdays	87	43	50.6
Sundays & Holidays	136	72	45.5
Average	60	43	28.3

$$\text{Cost*} = \frac{\text{fixed + semi-variable}}{\text{average patronage}}$$

**Local service is provided but is not the main function, feeder service to GO Train, thus no dispatcher cost is assigned to this type of trip.

costs.

This set of cost figures indicates that the pressing need in small city demand bus systems is the elimination of, or modification of, the dispatcher function to reduce this cost.

Conclusion

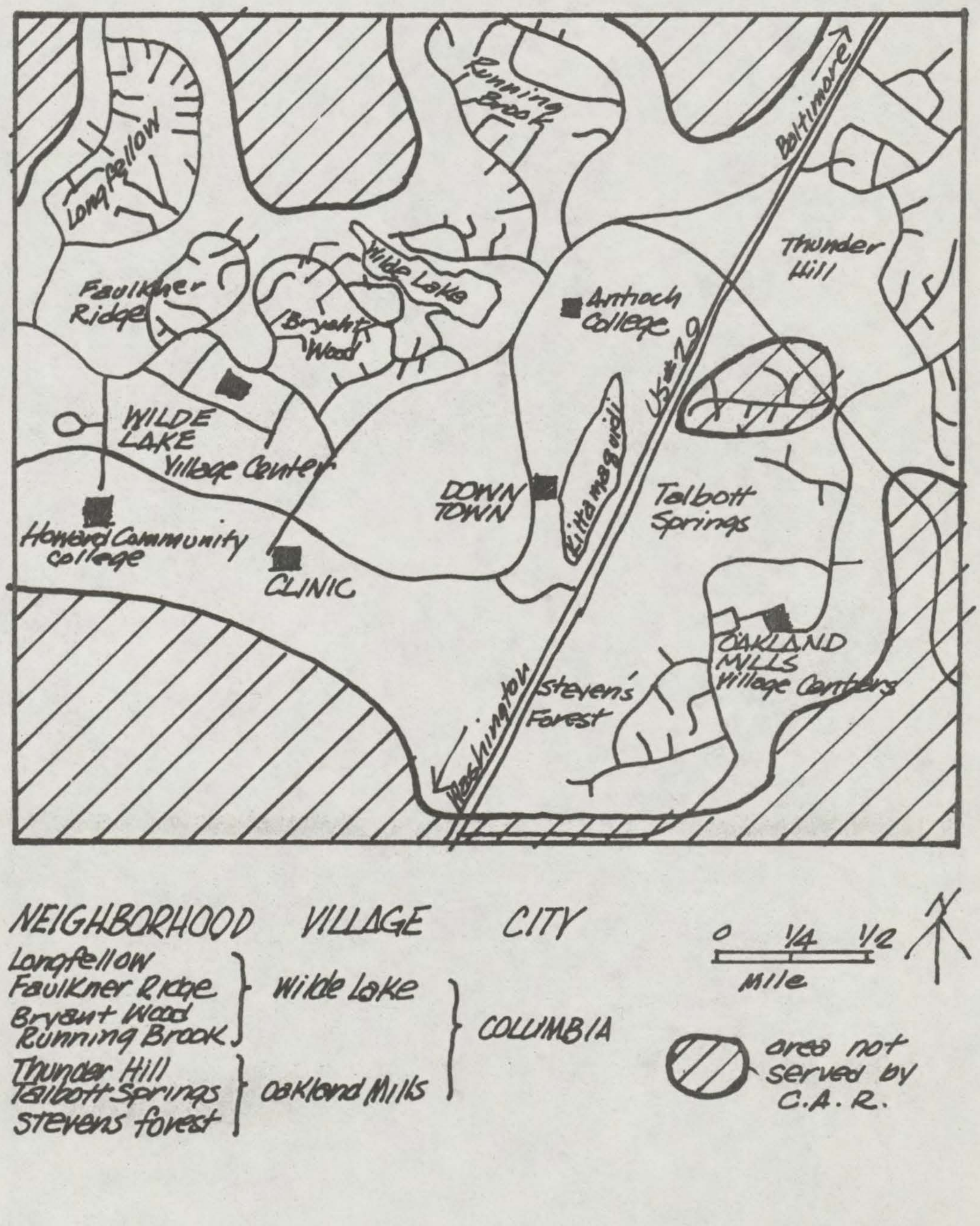
The Bay Ridges experiment indicates that persons will use a high quality transit service if it is dependable and competitive with the automobile. The data shows that while persons are willing to walk considerable distances to the principal destination, (the GO train station) they are not willing to undertake the same walk to a feeder bus system. The dramatic change in ridership from a rather unreliable fixed route system to a reliable demand-bus system was shown in the shift of auto users. The growth factor of 4.2 was experienced by demand-bus over the fixed route system.

The demand for the Bay Ridges Dial-A-Bus service directly reflects the needs of the GO Train commuter. The very low off-peak transit demand is a direct result of the system's success. The commuter uses Dial-A-Bus and thus frees the family automobile for use during the off-peak period.

Finally, the operating cost shows that the cost of a single person to do the dispatching in a small system tends to increase the per trip costs to a very high level. The dispatcher accounts for an average of 30% (17¢ per trip) of the costs. The dispatcher costs range from a low of 12% (6¢ per trip) in the peak hour, to a high of 50% (44¢ per trip) and 45% (60¢ per trip) on Saturday and Sunday respectively.

FIGURE V-12

COLUMBIA MARYLAND DEVELOPMENT CONCEPT AND CALL-A-RIDE SERVICE AREA



Columbia employing over 8000 persons.

Operation Data

The bus operation had two modes, one being a set of buses called "Easy Rider" that serviced the residential employment linkages in the peak hour, and Call-A-Ride (CAR) which serviced the remainder of the time from 8.30 a.m. to 11.00 p.m., six days a week.

The CAR System

The only restriction on the bus operation is it must stay within the area of Columbia as shown in Figure V-12. This represents the area under the control of the Columbia Corporation.

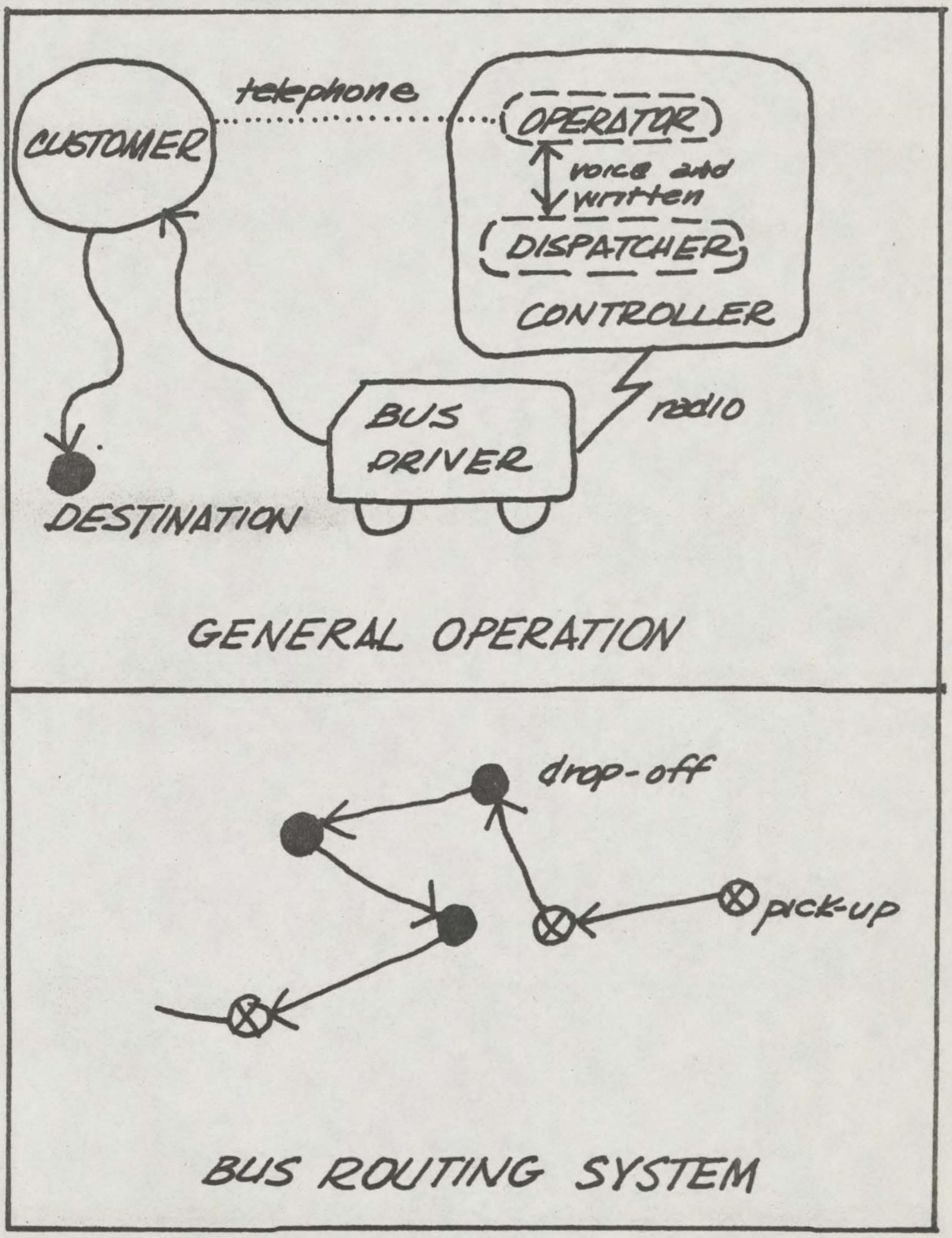
Operation

The CAR service consisted of radio-dispatched vehicles, linked to the requester through a central dispatcher as shown in Figure V-13. Those desiring transportation dialed 730-RIDE giving the dispatcher his address of origin and desired destination. The dispatcher checked the location of the vehicles against the caller's location, considered the time of pick-up, and so informed the caller. If the time of pick-up was agreeable, the caller accepted the service and the dispatcher radioed the information and instructions to the driver of the appropriate vehicle at the appropriate time.

The dispatcher also tood advance calls, such as "every day at 10.30 a.m.", or "Monday and Thursday at 2.30 p.m." This capability allowed the dispatcher to plan vehicle routing more

FIGURE V-13

MANY-TO-MANY
(COLUMBIA MARYLAND)



effectively and freed the passengers from calling each time service was needed.

The dispatcher kept track of the location of the vehicles, as well as the number and destinations of all passengers in each vehicle. It was also the dispatcher's responsibility to determine the vehicles' routes, sequence of pick-up and drop-off, and all other operating details.

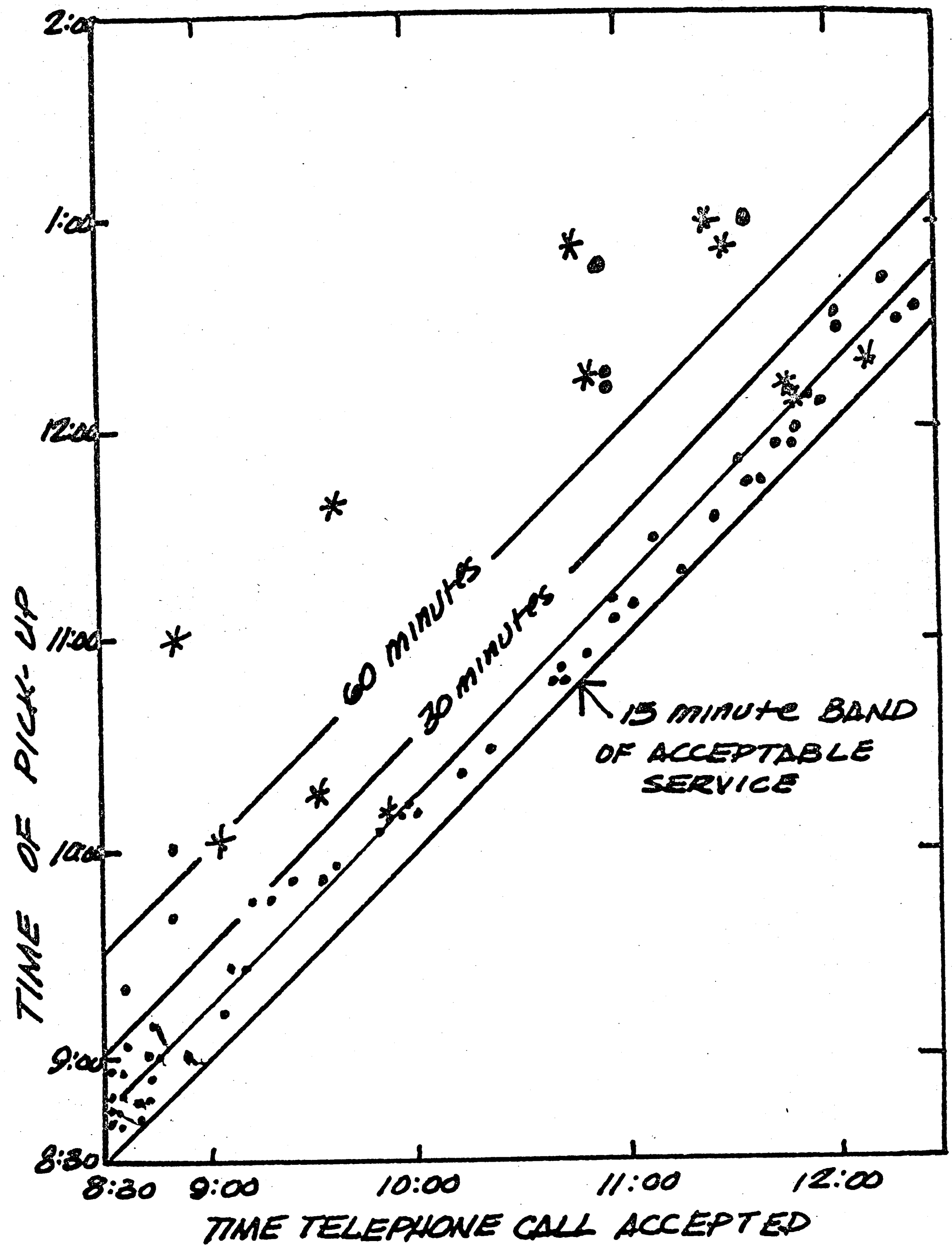
Level of Service

The only way to measure the level of service being provided by a demand bus system is to check on the actual time of pick-up versus the time the call was received. Figure V-14 provides a graph of the response time. As may be seen the majority of calls, 65% in fact, are serviced within 15 minutes. The total time devoted to the expected time of pick-up, drop-off, and riding is shown in Figure V-15. Fifty percent of the patrons spend less than 5 minutes on the bus and have an estimated total travel time of 12 minutes. Seventy-five percent spend less than 12 minutes riding and have a total of 25 minutes travel time.

This is a high level of service and the loss of ridership due to long waits works out to be a relatively simple relationship. The relationship between those requesting services, then either cancelling immediately, later, or not appearing (no-show), is shown in Figure V-16 as a function of the pick-up time (or time that the bus arrived and could not locate the patron). The rate of loss to the transit system for short waits, 10 to 30 minutes, is approximately 1% loss per minute of waiting time. For wait times beyond

FIGURE V-14

COLUMBIA CALL-A-RIDE PICK-UP SERVICE
(WEDNESDAY MARCH 3, 1971)



● fare paying dispatch
* cancel or no-show dispatch   source ref. 9

FIGURE V-15

COLUMBIA C.A.R

TIME BETWEEN EXPECTED TIME OF ARRIVAL AND TIME OF DROP-OFF

(TUESDAY JANUARY 19, 1971)

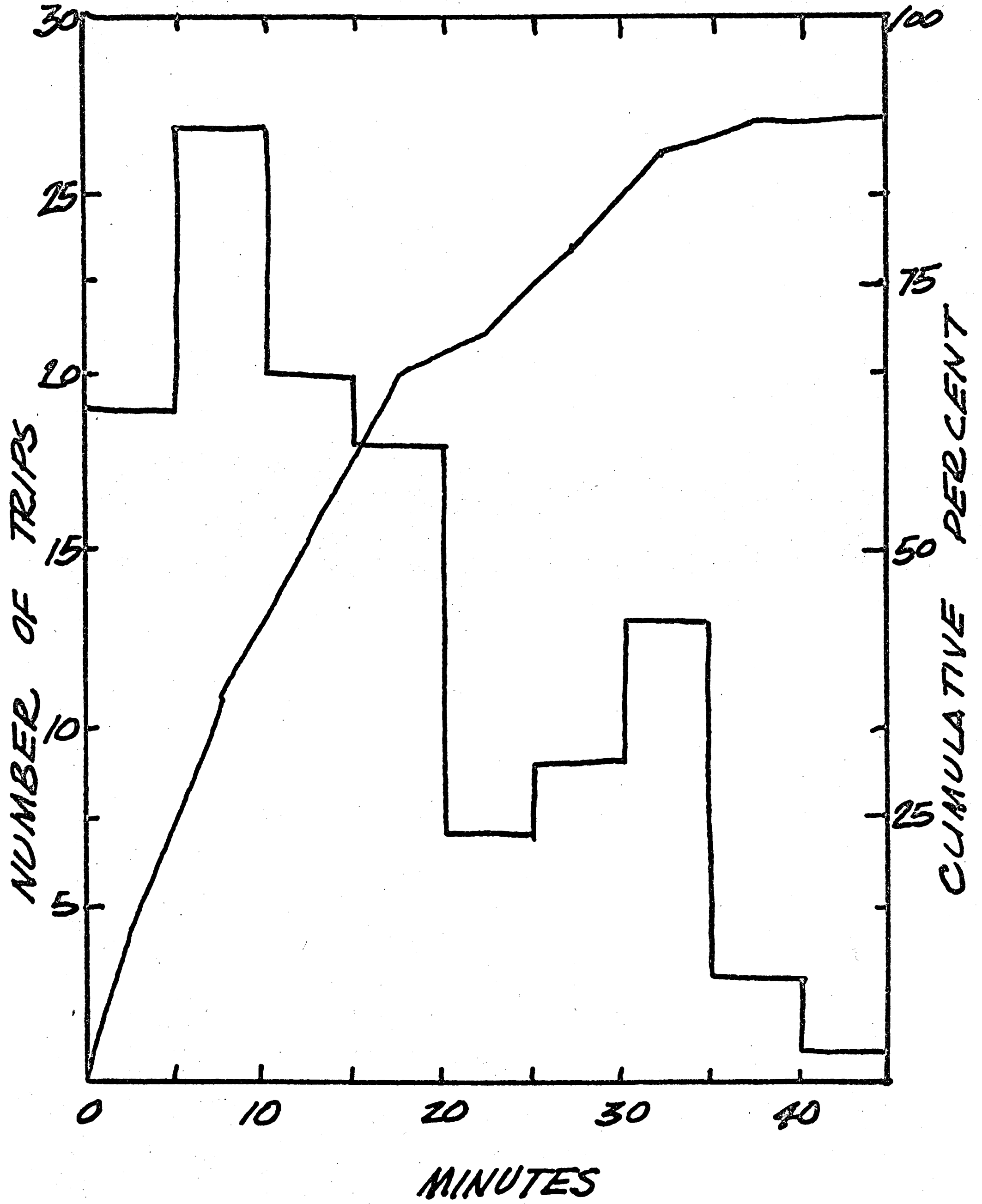


FIGURE V-15 continued

COLUMBIA C.A.R

TIME SPENT ON BUS
(WEDNESDAY JANUARY 20, 1971)

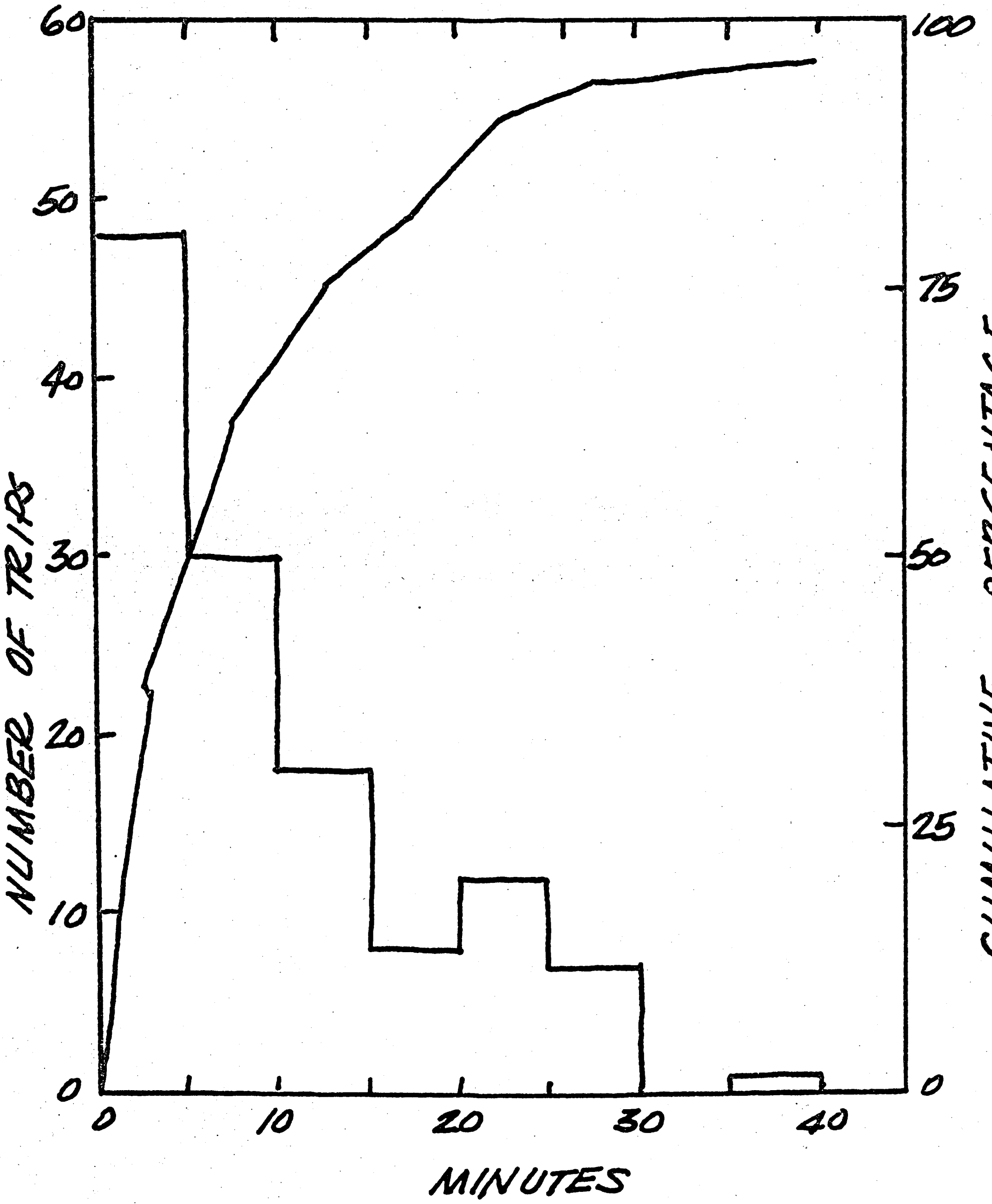
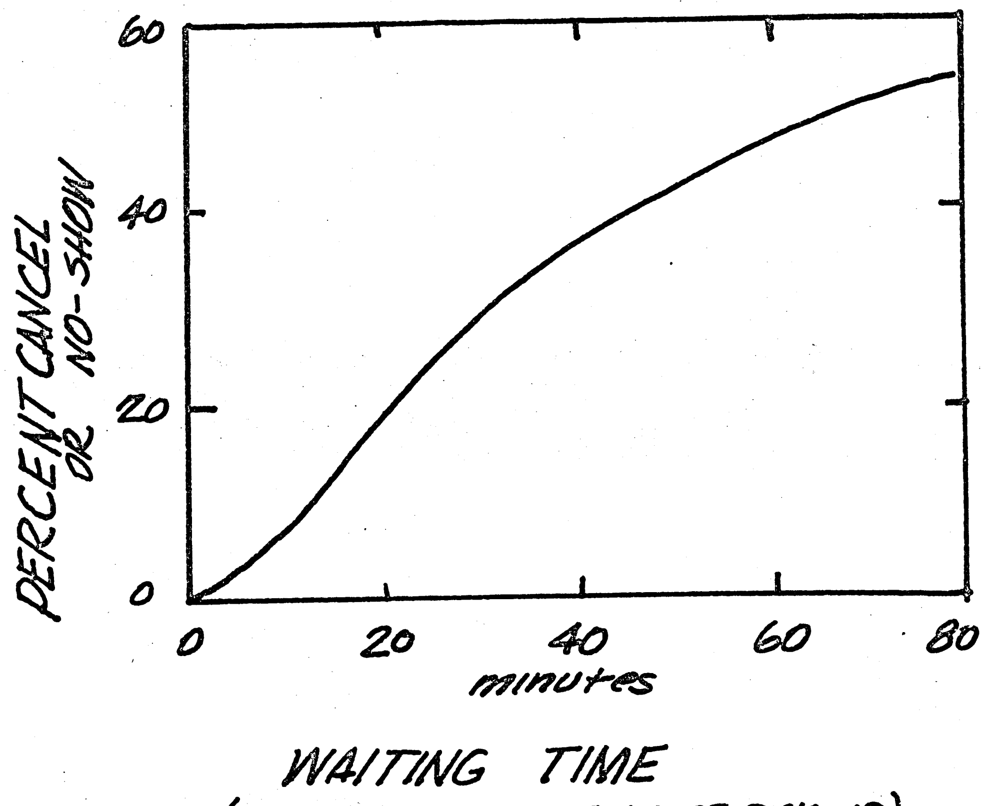


FIGURE V-16

INFLUENCE OF WAITING TIME ON THE ACCEPTANCE OF C.A.R. SERVICE (COLUMBIA, MARYLAND)



source: C.A.R LOG BOOK DATA

30 minutes the rate of loss is less but the absolute loss to the system is from 30 to 50 percent of the requests.

As was observed the chances for a wait time less than 12 minutes and a total travel time of 25 minutes, is 75 percent. This means if one used the service to go to work each day of the week, then 1.25 days per week of the total travel time would be longer than 25 minutes.

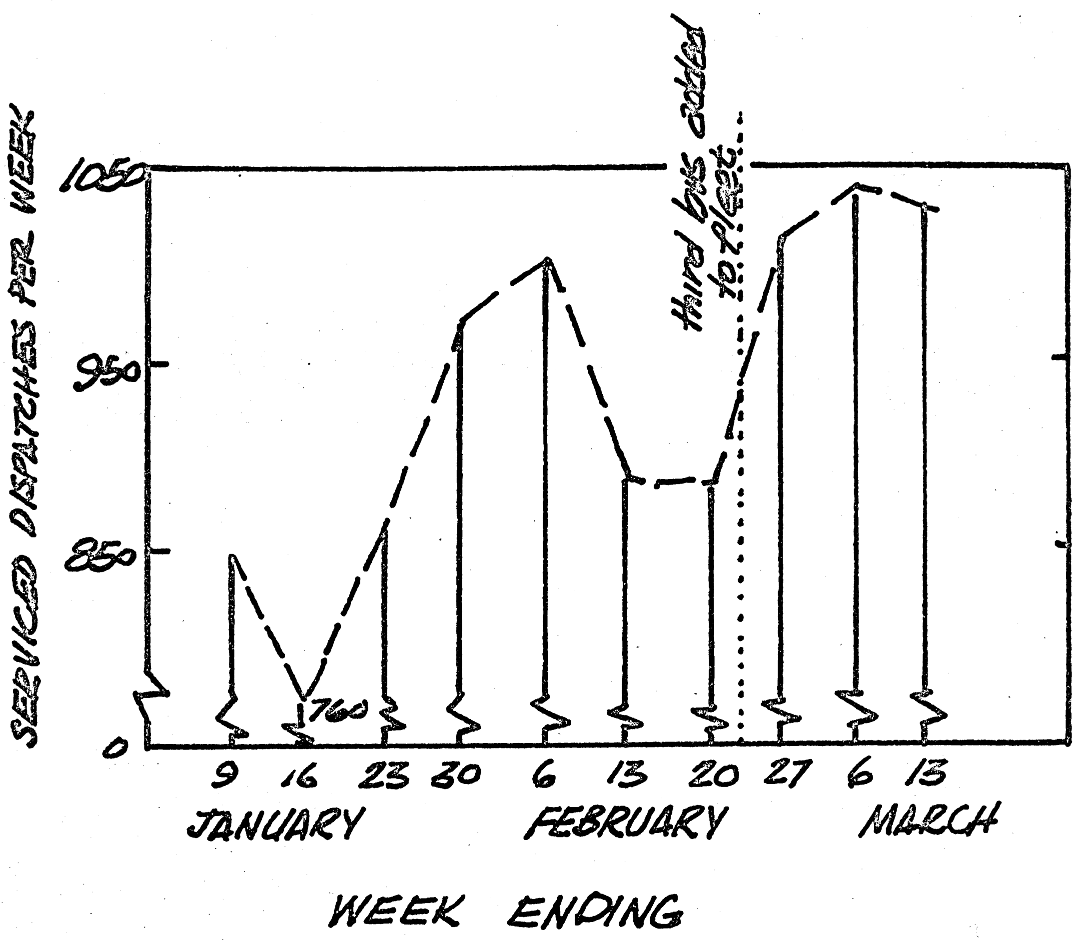
The on-board survey asked people to state how early or late they expected to arrive at their destination. On the average they expected to be late by two minutes, the standard deviation was 9.7 minutes. Thus sixty-six percent of the patrons "expect" to arrive between 8 minutes early or 12 minutes late. This situation is not very reliable in meeting the requirements for a given arrival time. Trips such as work or medical purpose form the vast majority of the transit demand in Columbia. This observation was confirmed in the on-board bus survey where 50 percent of the work and 70 percent of the medical trips thought the dependability of pick-up and delivery was not reliable.

Demand for Call-A-Ride

Time. Prior to January 1971 the Columbia Transit System with 3 buses on fixed routes at 60 minute headways, carried approximately 50 people per day or approximately 320 people in the average week (November, December 1970). The growth in patronage of the CAR system is shown in Figure V-17. The rate of use has not fallen below 750* requests per week, or allowing

*This was as of the first 5 months of operation.

FIGURE V-17
RIDERSHIP INCREASE WITH CALL-A-RIDE
(COLUMBIA, MARYLAND)



SOURCE: COLUMBIA CAR LOG BOOK

approximately 1.5 persons per request, equals 1130 individual trips. This 1130 persons presents a 3.5 growth factor in transit usage. The March values indicate a balance at approximately 1040 requests or 1560 patrons and represent a growth of approximately a multiple of five. (This result corresponds with the values observed in Bay Ridges, Ontario). Because of demand and service difficulties, the original 2 vehicle bus fleet was augmented with another bus on February 22, 1971.

The peak-day hourly demands are shown in Figure V-18. The graphs indicate that demand over the peak days is quite similar and averages about 18 requests per hour during the day or approximately 5 to 6 per bus per hour*. The demands over the daytime indicate that the system is operating fairly close to its capacity from 9.30 a.m. to approximately 6.30 when ridership falls off dramatically to only 5 or 6 calls per hour.

A Chi squared goodness of fit test on hourly demand distribution of the five peak days in Figure V-18 indicated that the hourly distributions were similar with 95 percent significance. The calculated Chi squared value was 30.9 and the tabulated value for 42 degrees of freedom at 95 percent significance is 57.3. Since the calculated value is less than the tabulated value, the hypothesis that all the hourly distributions by day are similar, is accepted.

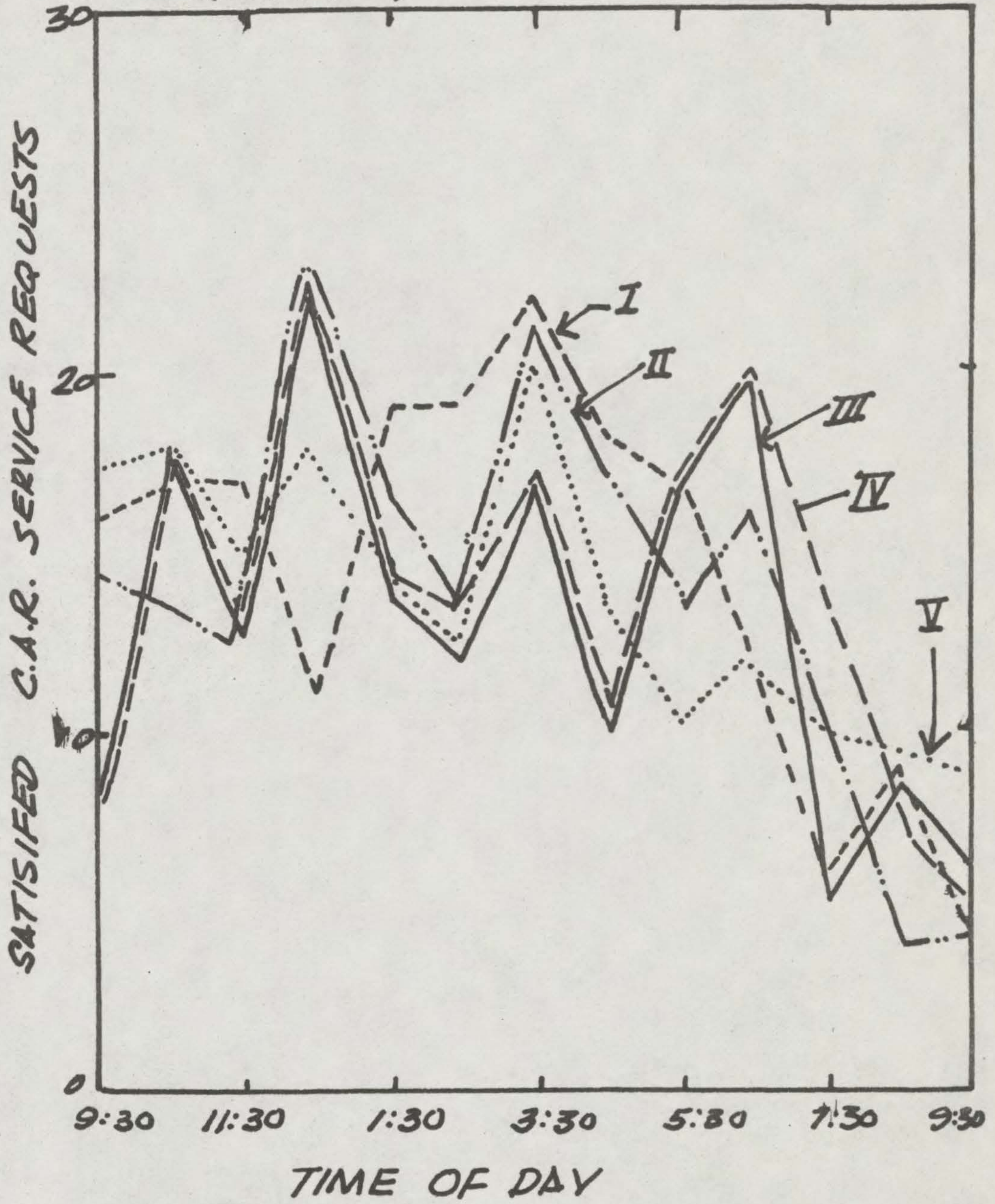
Using the peak days of the week as a guide to a design day,

---

*The CAR system proposed by MIT indicates a productivity of approximately 10-12 responses per hour with manual dispatching.

FIGURE V-18

PEAK DAY OF SELECTED WEEKS
CALL-A-RIDE
(COLUMBIA, MARYLAND)



I — 8-13 MARCH
II — 25-30 JANUARY
III — 1-6 MARCH
IV — 1-6 FEBRUARY
V — 22-27 FEBRUARY
SOURCE: COLUMBIA C.A.R LOG BOOK

transit demand results in the following general formula:

$$d_p = \bar{d}_p + \lambda \sigma_{\bar{d}_p}$$

where d_p = design day requests

$\bar{d}_p$ = average peak hour requests over the hours

$\sigma_{\bar{d}_p}$ = standard deviation of d_p expected week to week

λ = a factor by which one expects to service persons: it represents a probability

This formula may lead to a method of setting up the required command and control for a bus system to service clients with a certain probability of success. Using this approach with the data of Figure V-18 the mean hourly demands and standard deviations were calculated and summarized in Table V-5. The mean of the mean, peak weekday hourly satisfied demand is 15 or 5 demands satisfied per bus. The mean of the means displays a rather stable nature between 8.30 a.m. and 5.30 p.m. The supply of buses needed to satisfy the peak-day mean hourly demands is given by $\bar{d}_p + 2\sigma_{\bar{d}_p}$ and $\bar{d}_p + 3\sigma_{\bar{d}_p}$. Assuming that the distribution of the hourly demands is normal about $\bar{d}$, then at $\bar{d} + 2\sigma_{\bar{d}_p}$ about 90 percent of all hourly demands during any given hour will be satisfied. Assuming a possible productivity of 10 serviced demands per hour per bus, from Table V-5, the minimum number of buses needed is 2 and a maximum of 3. Similar bus needs are obtained for $\bar{d} + 3\sigma_{\bar{d}_p}$ except at 11.30 a.m. when the bus needs rise to 3.3 vehicles. Considering the Columbia operation in the light of peak day

Table V-5

PEAK DAY OF THE WEEK HOURLY DEMAND STATISTICS

HOUR STARTING AT	MEAN HOURLY DEMAND $\bar{d}$	STANDARD DEVIATION σ	$\bar{d} + 2\sigma$	$\bar{d} + 3\sigma$
8:30	12.2	4.9	22.0	26.9
9:30	17.0	1.7	19.4	20.1
10:30	12.2	5.2	22.6	27.8
11:30	19.0	4.8	28.6	33.4
12:30	15.4	2.2	19.8	22.0
1:30	14.6	2.5	19.6	22.1
2:30	19.4	2.3	24.0	26.3
3:30	13.8	3.8	21.4	25.2
4:30	15.0	3.1	21.1	24.3
5:30	16.2	3.8	23.8	27.6
6:30	9.6	3.0	15.6	18.6
Mean of the MEAN	15.0		21.5	24.9
σ	3.0		3.4	4.2

hourly demands and the probability of servicing that demand, a somewhat different view on the operating efficiency is obtained. If $\bar{d_p} + 3\sigma_{\bar{d_p}}$ demands are assumed to be an "ideal" design demand for a dial-a-bus service, then Columbia is operating at slightly over 80 percent efficiency on the maximum demand day given by $\bar{d_p} + 3\sigma_{\bar{d_p}}$. The use of this method of demand analysis is well suited to demand-bus systems and in particular for use on service reliability. In the case of Columbia, it represents the extreme value of requests at which the system is beginning to faulter.

Purpose. The purpose for using transit in Columbia is summarized in Table V-6. The work purpose accounts for only 27 percent of all the trips. There is a high portion of non-work trips and in particular a large percentage of "visit a friend" and "recreation" trips when compared to other transit systems. This many-to-many system serves (and was so designed) a different rider than the Bay Ridges system which serves over 50% of the commuters or Mansfield which serviced mainly domestics.

Spatial. The spatial distribution of transit trips is summarized in Figure V-19. The division of trip purpose gives an indication that the major generators are the two village centers of Wild Lake and Oakland Mills. The interchanges indicated on the map, Figure V-19, account for almost 60% of all the transit demands during the last week of January 1971.

The downtown was a good attractor of trips, but, as it is mainly an office complex, was restricted principally to work trips. The village centers, as explained earlier, have shops, some office

Table V-6

TRIPS BY PURPOSE

PURPOSE	NUMBER	PERCENT
Work	36	27
Shop	24	18
School	3	2
Clinic	10	7
Visit a Friend	5	4
Recreation	11	9
Other	42	32
No Response	2	1
TOTAL	133	100

Survey May 1971, Columbia, Maryland.

function, and a major recreation facility as well as selected community services and are the major users of the transit service. The majority of the "work trips" are destined to these centers.

An interesting event that stands out in Figure V-19 is the low interchange rate of Thunder Hill with any center other than Oakland Mills. This results from a long trip between the two developed areas of Columbia. The dispatchers always quoted at least one hour service to the Thunder Hill and Stevens Forest residents unless a bus was already on its way over to the Eastern side of Highway 29.

Operating Costs

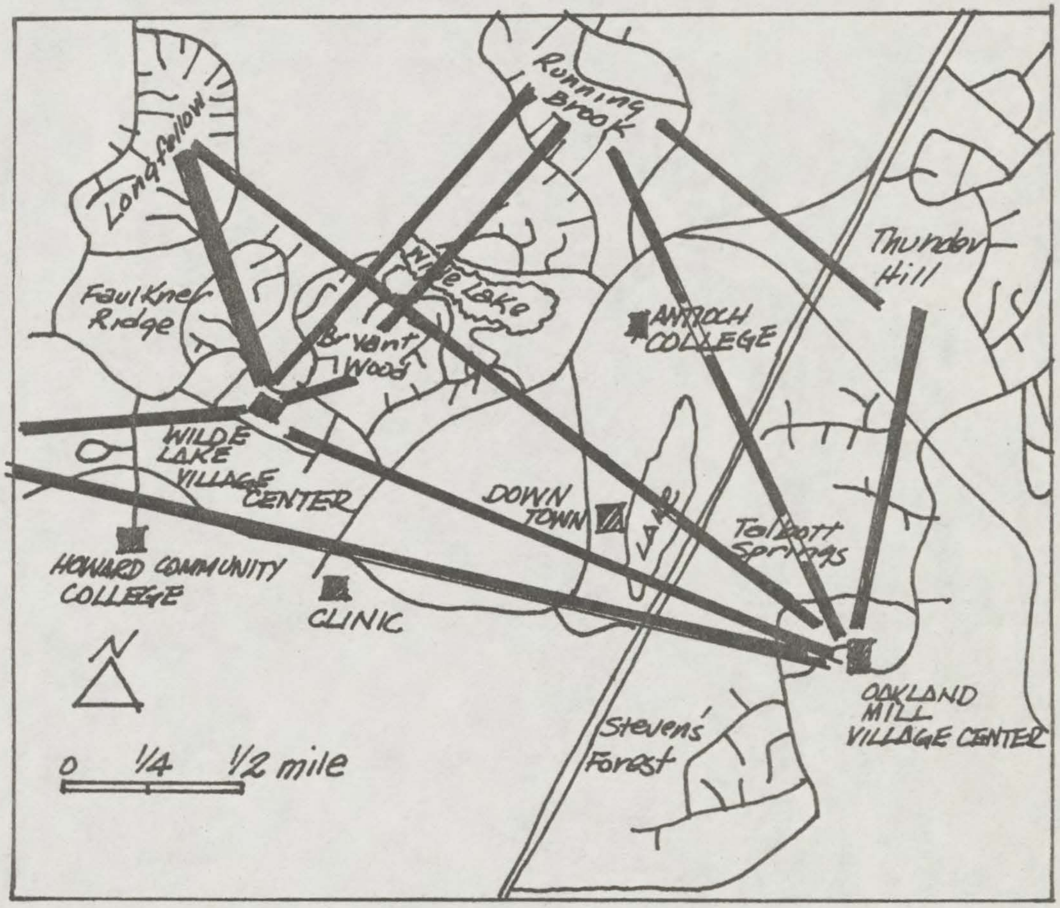
The Columbia experience with operating costs is summarized in Table V-7. The point of interest is that the dispatcher costs are approximately the same as in the Bay Ridges project. Labour costs of both account for 75% of total costs. The Columbia dispatchers accounted for 21% of total costs, while in Bay Ridges they accounted for 29%. Part of the difference in operating costs between Columbia and Bay Ridges may be accounted for by the fact that supervision and start up cost was not included in the Bay Ridge's data*.

*If such costs are excluded from the Columbia data, the cost per ride is $1.36.

FIGURE V-19

MAJOR TRANSIT INTERCHANGES*

COLUMBIA MARYLAND



═══ 20 trips (2x10 one-way trips)**

*marked interchanges equal 56% of all trips

**daily average for 28-29-30 January 1970
total trips counted were 447

Table V-7

CALL-A-RIDE
COLUMBIA, MARYLAND
PROJECTED ANNUAL OPERATING EXPENSES
(As of July 1, 1971)

ITEM		EXPENSES
Vehicles (POL, Maint.) 120,000 miles (Ford) @ 10¢/mile 30,000 miles (Minibus		$20,700
Drivers 11,725 hours @ $3.15/hr. (including fringe benefits)		36,950
Dispatchers 7,025 hours @ $3.25/hr. (including fringe benefits)		22,800
Communications Depreciation, Maintenance		1,000
Overhead		
Supervisory	$19,850	
Insurance	3,250	
Taxes	550	
Rent	2,500	
Telephone	1,250	
Misc.	2,200	
		29,600
TOTAL EXPENSES		$111,050
REVENUE (66,240 trips @ 25¢)		16,040
LOSS		$95,010

Comparison of the Three Systems

A summary of selected parameters is presented in Table V-8. The original dial-a-ride experiment was undertaken by Karl Gunther of the Ford Motor Company and Mr. Burkhart, owner of the transit company in Mansfield, Ohio. The Mansfield bus company went out of business over general financial problems and not due to the expense of the Dial-A-Ride. The Bay Ridges experiment by the Ontario Government used Karl Gunther as a consultant and thus gained from the Mansfield experience as well as the Dutch BUXI System (10). The Bay Ridges experiment was taken over by the municipality of Pickering during 1972. The Columbia system was initiated by Robert Bartolo of the Rouse Company, the builder of Columbia. It was styled after the transit systems suggested by Dr. D. Roos of the Massachusetts Institute of Technology. Columbia now operates only an evening hour Call-A-Ride.

An estimate of the potential dispersion of transit demands is given by the population density. The lower the population density the lower the probability of having two demands occur close to each other. The fifth row of Table V-8 shows that Columbia had the lowest population density with 2900 persons per square mile and Bay Ridges the highest with 9800 persons per square mile. The passenger productivity rates are not fully compatible because Mansfield only operated from peak hour to peak hour while Columbia and Bay Ridges went beyond the peak hour. The Dial-A-Ride demands per day, per square mile is given in Row 11 of Table V-8. The

Table V-8

COMPARISON OF THREE DEMAND BUS SYSTEMS

Item	MANSFIELD*** OHIO	BAY RIDGES ONTARIO	COLUMBIA**** MARYLAND
Type	Route Deviation	Many-to-One	Many-to-Many
Started	1/69	6/70	1/71
Population	3000	13700	17800
Served Area (miles^2)	.7	1.4	6.0
Density $\left(\frac{\text{People}}{\text{mile}^2}\right)$	4300	9800	2900
Service	7:15 a.m. 6:15 p.m.	5:00 a.m. 1:00 a.m.	8:30 a.m. 11:00 p.m.
Base Fare (¢)	35 +15 to route deviate	25 (35/1972)	25 (50/1972)
Daily Passengers	75 (14.4 use route deviation)	460	250-300
Vehicles			
Peakhour	1	5	0
Base	1	3	4
Dial-a-Ride			
*demands/mile^2/day	21 (107 total)	345	50
*vehicle hours/day	11	41	124
*passengers/vehicle hour	9.8**	11.3	4.4
*passengers/total labour hour	9.8**	7.6	3.0

*Average daily values

**Total for dial-a-ride plus fixed route

***Out of business 1972

****Evening Call-A-Ride service as of June 1972.

maximum demand density for service occurs in Bay Ridges and the least in Mansfield.

The total transit demand density in Mansfield is increased considerably when the fixed route demand is added to the demand resulting from route deviation. The difference in demand density between Columbia and Mansfield is probably due to the high income and auto ownership in Columbia and not just the inefficiencies of many-to-many dial-a-bus.

The unit variables in the transit industry involve the passengers per vehicle hour or total labour hour since the dispatcher's wages must be included. Bay Ridges experienced the highest productivity per vehicle hour at 11.3 passengers per vehicle hour. Columbia was one third that at 4.4 passengers per vehicle hour. The productivity per labour hour was the highest for Mansfield, Ohio at 9.8 total passengers per labour hour while Columbia was one third this value at 3.0 passengers per labour hour.

There are two conclusions which may be drawn from this comparison of the three systems. The first marginal improvement may be experienced by providing a radio telephone and using the driver as the dispatcher. This provided a productive combination of conventional fixed transit with the attraction of dial-a-bus service at a premium price. The many-to-few transit system of Bay Ridges proves equally attractive since there is a trade off between the high vehicle productivity and the somewhat lower productivity per labour hour.

Chapter V

REFERENCES

1. Gunther, K., "Incremental Implementation of Dial-A-Ride Systems", Highway Research Board, Special Report 124, Washington, D.C., 1971.

2. Gunther, E., "The Mansfield Dial-A-Ride Experiment", 11th Annual Transportation Research Forum, New Orleans, Louisiana, October 1970.

3. "Clearwater Demonstration Bus Project", State of Florida, D.O.T., June 1971.

4. Petersen, S.G., "Walking Distances to Bus Stops in Washington D.C., Residential Area", Traffic Engineering, December 1968.

5. Navin, F.P.D., R. Wheeler, "Pedestrian Flow Characteristics", Traffic Engineering, June 1970.

6. "The Mansfield, Ohio, Dial-A-Ride Experiment". Richland County Regional Planning Commission and Ford Motor Co., August 1970.

7. Bonsall, J.A., "The Bay Ridges Dial-A-Bus Experiment", Department of Highways, Ontario, Downsview, Ontario, Canada, January 1971.

8. "Dial-A-Bus, The Bay Ridges Experiment", Ontario Department of Transportation and Communications, Downsview, Ontario Canada, August 1971.

9. Bartolo, R., Navin, F., "Demand Responsive Transit: Columbia, Maryland's Experience with Call-A-Ride", Annual National Meeting, American Institute of Planners, San Francisco, October 1971.

10. Hupkes, G., "BUXI, Demand Responsive Bus Operation in the Netherlands", Traffic Engineering and Control, March 1971.

Chapter VI

TRANSIT ATTITUDES

Introduction

The purpose of this chapter is to investigate the universality of the attitude of urban dwellers towards transit service. A review of the observed attitudes towards the automobile and transit was undertaken considering factors such as: city size, sex of the patrons, and trip purpose.

In the past several years numerous studies of consumer attitudes toward public transportation systems have been conducted. The studies have concentrated on particular areas for specific transportation system concepts. Early studies by McMillan and Assall (1969), (1),(2), Paine, et al., (1967), (3,4,5,) and Brock (1968), (6) concentrated on large cities with conventional bus service. A more recent study has been undertaken in Lafayette, Indiana (7) with conventional bus service (1971). The General Motors Research Laboratories implemented a series of surveys, (8, 9,10), concentrating on local demand transit for Warren, Michigan. The G.M. methodology was utilized in determining consumer attitudes toward demand transit in Columbia, Maryland (11,12,13). Appendix B has the details of the survey design. The attitudinal surveys used in the various studies employed similar techniques to estimate attitudes suggesting that relevant comparisons of the studies could reveal important insights concerning the differences in the populations surveyed. General Motors, Navin and Purdue all employed the techniques of paired comparisons and semantic scales. The surveys referenced in Paine, et al. (1967) and McMillan and Assall (1969) used a combination of the paired comparisons and semantic scales as well as the more elementary technique of binary choice in a yes/no arrangement. The principal product from this chapter is a listing, in order of user preference, of the attributes of an "ideal" demand transit system.

Attitudes Towards Existing Transit Service

Satisfaction with Modes

The automobile is a positive value in the lives of eighty-five percent of the inhabitants of the U.S.A. and worth all the pollution, disruption and destruction associated with its use (1). Increase in automobile usage over a one year period was reported by 52 percent of the people while only 8 percent reported a decline. The majority of persons considered the automobile the best available mode of urban travel.

Against this overwhelming acceptance of the automobile, public transit is often asked to compete and be an economically viable entity. The value people placed on public transit is less than that of the automobile. Only twenty percent of the population reported an increased use of transit over a one year period and 10 percent reported a decrease. People were neutral in their attitude towards transit use for work and considered it a disadvantage for shopping. Twenty percent of the total urban population are dissatisfied with transit whereas only one percent of the population are dissatisfied with automobile.

Mode Selection

The reason people select one mode of travel is a complex inter-relationship of attitudes between the person and the attributes of the mode*. The principal reported factors considered in selecting a mode of work travel in Chicago (6) are given in Fig. V1-1. On the average, "time" is the major consideration. "Comfort" and "car necessity" are then grouped together, followed by a miscellaneous group of "other" and "cost". The least frequently cited reasons for mode selection involve walking, parking cost, or the availability of parking. The average value does not tell the whole story as may be seen by the ordering of the variables by males and females. Men consider the need for a car as determining the mode of travel 23 percent of the time while for women this is not a determining factor. The two factors that determine the use of the automobile for most women are comfort and time. Obviously the reasons for mode selection may vary considerably between men and women. The data does not allow pursuit of this line of questioning but it does indicate that any analysis of the subsequent data should at least investigate the needs of women since they tend to be the majority of present transit users.

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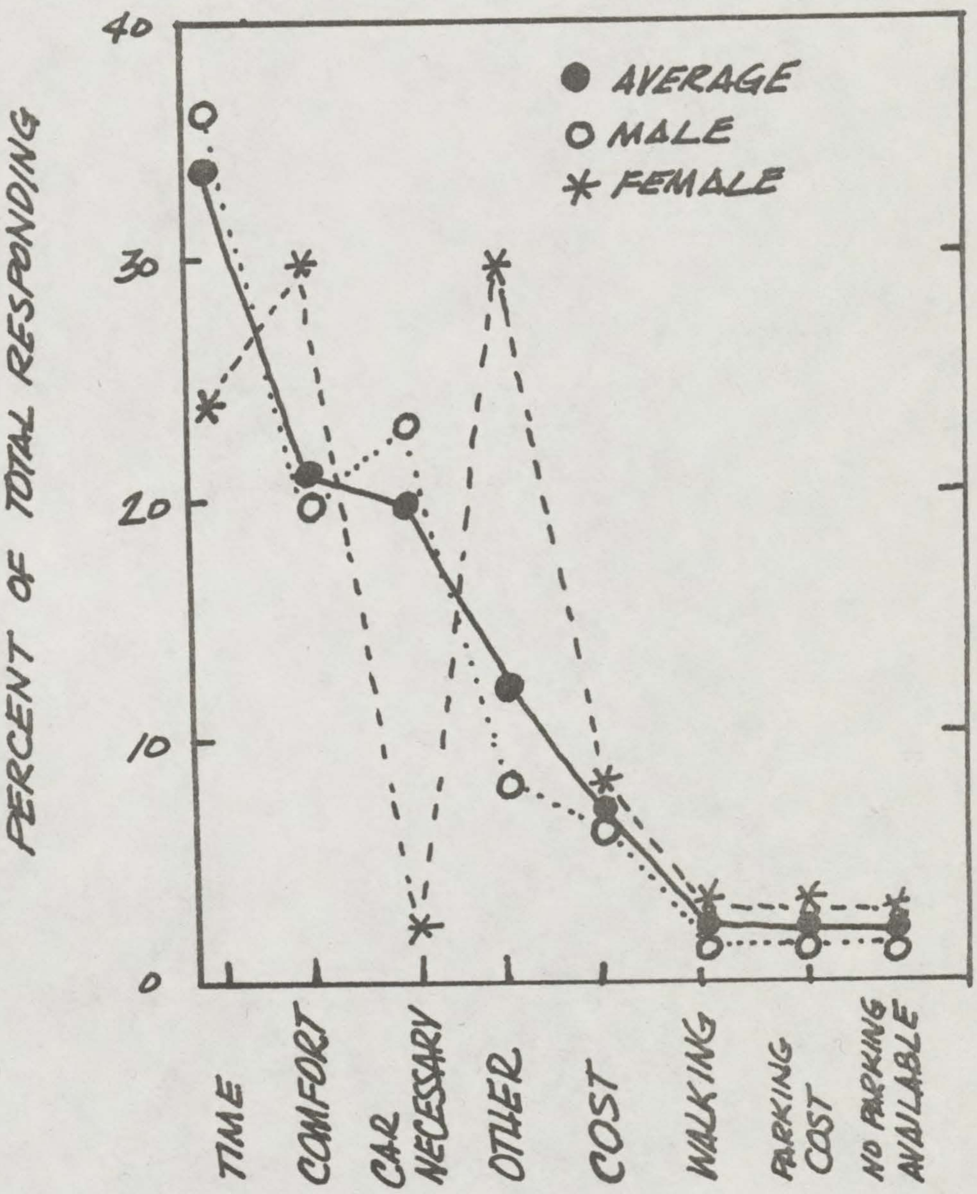
*See Chapter IV, Sub-Heading - Economic Mode Choice Models, for discussion on the potential theoretical combination of a person's attitude and a mode's attributes for mode selection models.

FIGURE VI-1

CAR EITHER ACTUAL OR BEST ALTERNATE MODE OF TRAVEL FOR WORK TRIP



SOURCE: reference 6

Attitudes Toward Modes

The factors, reported by Bock (6), that determine the use of the automobile in the view of the traveller, are the travel time and cost as shown in Table VI-1. Travel time and cost are considered favourable by 50 and 63 percent of the auto travellers respectively. The public transit user* generally consider their travel time unfavourably. Transit convenience is considered favourable by one fifth of the transit users. The automobile is faulted only on strain (not surprising for Chicago commuters) and high cost.

Bus transit, in particular, is singled out as being unfavourable by 29 percent of bus users in the reliability of travel time and double that number as to the effects of weather.

The commuter in Chicago has a rather low opinion of transit for most of the selected urban travel time parameter. The automobile users appear to be unanimous in their favourable opinion of the car.

Reasons for Mode Switching

The two major influencing factors that determine the selection of the transit rather than the auto mode are travel cost and the lack of parking (note, not the cost of parking as in Figure VI-1). To check for a possible relationship between the

*The definition of a transit user is anyone using either the bus, subway, commuter rail or a combination of these modes with or without automobile access. A bus user is a person using only the bus mode with or without the automobile as an access mode. This distinction is necessary in large cities such as Chicago with a multiplicity of vehicle types in their total transit system.

Table VI-1

ATTITUDE TOWARDS SELECTED TRAVEL PARAMETERS
BY PERSONS MAKING WORK TRIPS
(Percent of all trips in a mode)

Travel Parameter	Mode* Determined By			Favorable			Unfavorable		
MODE	Car	Bus	Rail	Car	Bus	Rail	Car	Bus	Rail
Travel Cost	1	-	1	15	10	20	8	-	4
Door to door time	6	-	-	49	2	10	1	18	25
Travel Time Variability	1	-	-	1	-	3	8	29	5
Convenience	11	2	2	63	15	20	1	4	2
Comfort	-	-	-	29	2	14	2	8	39
Effort/Strain	-	-	-	-	6	15	39	+	1
Safety	-	-	-	2	7	30	9	3	2
Weather	3	20	35	1	3	4	6	58	35

Source: Reference 6, Tables 22 through 25.

*The numbers in this column represent the percent of people who said a particular factor or group of factors, determined the mode by which they travelled. Thus of those using the car as the mode to go to work, 11% said convenience was the factor that determined the use of the car over other modes.

ordering of travel parameters the reasons for switching modes, as reported in Chicago and ordered by importance, is shown in Table VI-2. A relationship between the two sets of reasons was studied with a Spearman Rank Correlation*. The correlation (r_s) is only 0.306 and at a significance level of 95 percent, the hypothesis that the two orderings are similar, is rejected. The low correlation coefficient indicates that the reason for switching to and from the transit mode are almost independent. A removal of reasons 3,4,5,9 and 10** gave similar results with a correlation coefficient of 0.45.

Table VI-2 gives insight into the factors that are probably necessary to get persons to switch to the transit mode. The more positive aspects of transit needed are:

- o ease of access,
- o availability of the mode,
- o cost, and
- o convenience.

The negative aspects of transit use is the existing travel time and a loss of the transit habit (general preference, item 5).

These results support the need for an area wide transit system with considerable coverage (i.e. close to the source of

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*Spearman Rank Correlation is a parametric statistical method to test the similarity of the ordering of sets of data such as that presented in Table VI-2. The value of the coefficient of +1 or -1 indicates an identical ordering of the sets of data. A value of zero indicates an unrelated ordering. A negative value indicates a reverse ordering relationship, and a positive number indicates a one to one correspondence.

**These are difficult to measure and were removed to see if the remaining reasons for switching modes could be related.

Table VI-2

RANKING OF
REASONS FOR SWITCHING MODES

Reason	From Auto To Public Transit*	From Public Transit To Auto
1 Availability of Mode	2	1
2 Time to Travel	7	2
3 Convenience	4	3
4 Comfort	5	4
5 General Preference	10	5
6 Cost	3	6
7 Ease of Access	1	7
8 Weather	9	8
9 Auxiliary	6	9
10 Safety	8	10

Source: Reference 6

*This means all the workers who switched from the automobile <u>to</u> public transit, either bus, subway, commuter rail or any combination, ordered their reasons for switching modes as numbered in this column.

revenue, the customer in his home) while keeping the costs reasonable. Specially tailored service should be provided when possible (i.e. express bus, etc.) since this type of service can reduce travel time as well as being convenient to the origin and destination.

Influence of City Size

Large Cities. Studies conducted by Maryland University (3, 4,5) investigated consumer attitude towards transportation. Factors* by Trip Purpose. The factors ordered by importance for two types of trip purposes are shown in Table V-3. The first four factors indicate that the urban traveller desires:

1. reliability of arriving at the destination,
2. good travel time (considerable difference between purposes).
3. protection from the elements, and
4. reasonable cost.

The non-work trip purpose placed comfort and convenience before the travel time or cost. These are the factors that the urban traveller wishes to visualize in a mode.

Factors by Mode of Travel

The Maryland study also considered the relative satisfaction of urban travellers with transit and auto. They defined a group of system attributes as convenience factors. Convenience

*Factors as used in this section only, are a set of attitudinal questions grouped with the use of factor analysis, a statistical method of data analysis. This definition does not apply to earlier usage of the word factor.

Table VI-3

DIFFERENCE IN PHILADELPHIA FACTORS BETWEEN TRIP PURPOSE
ARRANGED ON BASIS OF RELATIVE IMPORTANCE

FACTOR	WORK/SCHOOL	NON-WORK	Δ***
Reliability	6.39*(1)**	6.34 (1)	.05 (5)
Travel Time	6.14 (2)	5.26 (4)	.88 (1)
Weather	5.99 (3)	5.98 (2)	.01 (8)
Cost	5.50 (4)	5.52 (3)	-.02 (7)
State of Vehicle	5.13 (5)	5.10 (5)	.03 (6)
Unfamiliarity	4.62 (6)	4.56 (6)	.06 (4)
Self Esteem	4.61 (7)	4.25 (8)	.36 (3)
Diversions****	4.01 (8)	4.45 (7)	-.44 (2)

*Highest score = 7.00

**(x) order of relative importance, rank

***Difference between the purposes, thus (6.39 - 6.34) = 0.05

****Radio, scenery, etc.

Source: Reference 4

factors were those factors associated with a comfortable and pleasant trip. The two convenience factors widely separated between the two modes*, transit and auto, are "protection while waiting" and "uncrowded vehicle". There was a grouping of items called "the level of service". The service level factors were concerned primarily with measurable events such as "waiting", "fare", "transfers" and the like. The three factors with appreciable difference are:

- o avoid long waits,
- o avoid walking more than one block, and
- o avoid transfers.

Table VI-4 indicates the relative ranking of the service level items. Note that the service level factors are mainly time and cost related attributes. Workers are concerned primarily with getting to their destination at a certain time and will subordinate everything to this criteria including walking and transferring. Thus work trips are probably adequately served by transit focused on the central business district. The non-work trip attitude expresses no overwhelming emphasis but rather a generalized concern for the least effort (i.e. no transfer, short walk, and arrival when planned) and minimum cost of the trip. These criteria are usually not met by a transit system focused on the central area.

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*The factor separation difference mentioned here measures the difference in relative importance, thus if the difference is zero the two populations view the factor as having the same relative importance. A large difference means that the relative importance of that factor differs considerably between the two sampled populations.

Table VI-4

RELATIVE ORDER OF SERVICE LEVEL ITEMS

WORK Rank	SYSTEM ATTRIBUTE	NON-WORK Rank
1	Arrive without accident	1
2	Arrive at intended time	4
3	Shortest distance	(9)
4	Fast as possible	(11)
5	Avoid changing vehicles	2
6	Shortest time	(13)
(8)*	one way cost of 25¢ rather than 50¢	3
(10)	avoid walking more than a block	5
(9)	one way cost of 25¢ rather than 35¢	6

*The six most important service level attributes differ between the purposes. The number within brackets is the order beyond six of the attribute in question.

Source: Reference 4

Small Cities. The attitudes of persons towards transit in small urban areas has been sparingly studied, and thus the data is rather limited and any conclusions, tenuous. A reliable study undertaken by Heathington, Satterly et al in Lafayette, Indiana during 1971 studied attitudes towards fixed route transit service (7). They found approximately sixteen percent of the persons in Lafayette making work trips selected the automobile because they preferred the comfort and convenience. Most auto passengers (27%) used the auto because a ride with someone was available. The reasons for using the bus were for the most part negative. Twenty-three percent of the transit users had no driver's licence and only thirteen percent thought transit was more convenient. The comparison of bus user and the public's attitudes towards the bus service indicated that the general city population's attitude towards transit is much more negative than that of the bus user. The level of service characteristics that bus users consider disagreeable are:

60% found transfers difficult,
70% claimed the buses did not follow scheduled times,
80% wanted adequate shelter from the weather,
55% thought the bus stops inadequately marked,
51% considered bus breakdowns too frequent, and
70% claimed that bus schedules were difficult to find.

The general public and bus users do not agree completely in their attitude towards the system attributes of the service. The non-user feels that the bus does not go where they need to go*.

A Spearman Rank Correlation indicated that the ordering of the two group's (transit users and all others) desired destinations are similar. The destinations may be grouped into four general categories with various desgrees of desirability.

Location 1. downtown, very desirable** to all.

Location 2. the hospitals and universities, desirable to transit users, indifference by the non-users.

Location 3. the shopping centers, generally desired by transit users and indifference by non-users.

Location 4. the industrial sites, generally not desired by anyone.

The results for location 4 must be interpreted with discretion since the needs of captive transit workers may not be fully represented. Work trips account for 43% of the transit use of which almost 90% are full time members of the work force. The listing indicates that the downtown must be serviced by transit, as well as major social services (hospitals, universities, etc.) and probably major shopping centers. The only element that may not now be gaining its fair share of service are the shopping centers.

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*This indicates a weakness of a bus survey to uncover the demand for bus service, because bus service is not a ubiquitous commodity and users have accommodated their travel patterns to the bus service.

**This is used as a relative measure of where in the city people thought bus service should be provided. Thus, a bus service to downtown was considered "very desirable" by all people while a bus service to the industrial sites was at the other extreme and considered "not desirable". One might replace "desirable" by <u>necessary</u> or <u>needed</u>.

Conclusion

The average auto commuter considers mainly time to travel, comfort and the need for the automobile when selecting his travel mode. The positive aspects of transit which encourage its use are: ease of access, cost and convenience. The systems that presently service both large and small urban areas are usually not tailored to off-peak service. The systems are not satisfactory when compared to the automobile and only a small minority use public transit because of any positive advantage over the automobile.

Inefficiencies attributed to the transit system (but not necessarily true) by the potential users are:

1. does not go where desired,
2. must walk long distances,
3. often not reliable due to the age of the equipment,
4. the operation is not convenient, i.e. waiting in the elements, relatively poor schedule adherence, transfers necessary.

Probably a major problem is the poor image the general public holds of the total service offered by transit. Small transit systems, if profit is the only motive, are doomed to failure*. Large systems usually have a sufficiently large number of truly captive riders, no driver's licence or automobile, to sustain a base ridership with almost any level of service. One must realize that transit service under these conditions in effect "skims the cream" and leaves those in areas without "sufficient" captives to fend for themselves.

*If such systems have charter rights or a school bus contract they will stay in business but the public transit service is subsidized by the charter and school contracts.

Attitudes Toward A New Transit Operation

The main purpose of this section is to report on two surveys of the attitude of persons towards selected demand transit attributes. The experimental details are contained in Appendix B explaining the questionnaire, sample selection, and survey controls.

Most of the previous studies had indicated an almost complete dissatisfaction with transit on the part of the general public and not a much better opinion on the part of the bus user. The studies had also pin pointed the various attributes of the transit system considered most important and those for which there was the least satisfaction. These factors help in the design of a new transit system but the studies lacked a key ingredient: no small cities under 100,000 were studied. The prior studies reflect the attitude of medium sized cities of 100,000+ population and the results may not be directly transferable to small cities. The inability to transfer the data analysis is mainly as a result of city size difference. The studies indicated that an ideal type of urban transit system would be one that:

1. arrived at the destination on time,
2. reduced walking at both ends of the trip,
3. kept one out of the weather,
4. was reasonably fast and comfortable, and
5. adapted to peak and off-peak operations.

A system that fits this description is demand-responsive bus service. Demand responsive bus service is in many ways similar to a shared taxi service and operates as follows:

1. the transit user telephones a controller and requests service,
2. the controller assesses the service status of the system, tells the user, (who may reject the service) and dispatches the bus, then
3. the bus arrives at some estimated time and picks up the user, and
4. the bus then travels in the general direction of the destination picking up and delivering persons until finally the user in question is delivered to destination.

This system assures a bus arriving (you can't miss it), eliminates the need to wait outside, the need to transfer, and finally the need to walk great distances at the origin or destination end of the trip. The use of operational constraints may fix delivery time to ensure the most desirable attribute of a system which is to arrive at a destination on time.

To refine the details of such a system and to estimate the feasibility, the Research Laboratory of General Motors in Warren, Michigan undertook an extensive attitude survey. The Warren, Michigan population studied by General Motors had no experience with demand transit and were evaluating it without having used such a system. To confirm or reject the results of the General Motors study, the author undertook a similar but somewhat smaller attitude study of the general public and transit users in Columbia, Maryland during May 1971. Columbia was selected because at that time a true many-to-many demand bus system was in operation. The bus users in Columbia would be answering the attitudinal survey with a certain amount of experience.

General Motors Survey

The General Motors Survey was conducted during 1970 in Warren, Michigan. Warren is an industrial suburb of Detroit. The population is mainly blue collar workers with an income range of $10,000 to $15,000 annually.

The survey had two different questionnaires: paired questions and semantic scaled questions*. The paired questions are used to measure the relative importance of the attributes one to the other. Semantic scaling measures the degree of opinion ranging from "very desirable to very undesirable". The General Motors Survey surveyed 1300 people: 600 completed the paired questionnaires survey and 700 took part in the semantic scaling survey.

The paired questionnaire considered thirty-two system characteristics. Ideally the technique of paired questions requires each question to be asked against every other. The thirty-two system characteristics would then require 32 x 32 or 1024 question pairs of the form:

A. Less waiting at the origin

or

B. Assurance of having a seat

To reduce the number of questions the designers of the Warren survey divided the characteristics into three functional sub-groups and sub-groups. The sub-groups were:

*See Appendix C for a brief description of the Columbia questionnaire format and the tie-in with the GM study. An example of the paired question and semantic scaled analysis is included in Appendix D.

1. level of service characteristics
2. convenience factors, and
3. vehicle design characteristics.

Due to the length of the remaining questionnaire persons were asked portions of the questions but never the total number. Reliability checks on the consistency of selected question pairs confirmed the acceptability of this technique.

The semantic scaling questionnaire has 54 questions which evaluated the desirability of design alternatives for 15 system characteristics.

Both sets of questionnaires had the ordering of groups of questions and/or groups of possible responses to questions arranged in a random fashion.

Columbia Survey

Columbia, Maryland is located on a transportation corridor approximately halfway between Baltimore, Maryland and Washington, D.C. Columbia has a more diversified population than Warren. A greater portion of the residents earn more than $15,000 in Columbia with about the same portion as Warren in the lower income brackets. The educational level is considerably higher in Columbia than in Warren. The Columbia population density is higher than Warren but the total population is less: 10,000 as opposed to 200,000 in Warren. The major difference between the two locations was the existence of the Call-A-Ride system in Columbia.

The original thirty-two paired questionnaire system characteristics used by General Motors was reduced to fifteen as listed in Figure VI-2. "Lower fare" is the link with the General Motors results. If the relative positioning of the remaining system characteristics could be shown significantly similar then the inference is "the results were transferable". "Lower fare" and "assurance of a seat" and "shorter travel time" tied the survey questions together. These three characteristics were paired with all other questions to develop a general preference scale.

The Columbia semantic scaling questionnaire was designed to extend the General Motors survey. Again budget constraints necessitated a reduction in the number of system characteristics dealing with vehicle design and concentrating on service and

FIGURE VI -2

SYSTEM CHARACTERISTICS USED IN THE COLUMBIA PAIRED COMPARISON QUESTIONNAIRE

1	arriving at your destination when you planned to	SET #1 LEVEL OF SERVICE
2	making a trip without changing vehicles	
3	a shorter time spent waiting to be picked up	
4	a lower fare for passengers*	
5	less time spent walking to a pick-up point	
6	a shorter time spent traveling in the vehicle*	
7	being able to make a direct route	
8	small variation in travel time from one day to the next . .	
9	the assurance of getting a seat	SET II CONVENIENCE
10	calling for service without being delayed	
11	more protection from the weather at public pick-up points	
12	being able to select the time when you will be picked up . .	
13	convenient method of paying your fare	
14	freedom to turn, tilt, or adjust seat	VEHICLE DESIGN
15	more chance at being able to arrange ahead to meet a friend	

convenience attributes. The semantic scales questionnaire survey obtained 100 responses. These 100 people were different from the 131 of the paired questions. Appendix B has a fuller explanation of the survey methodology.

Paired Questionnaire Survey Results

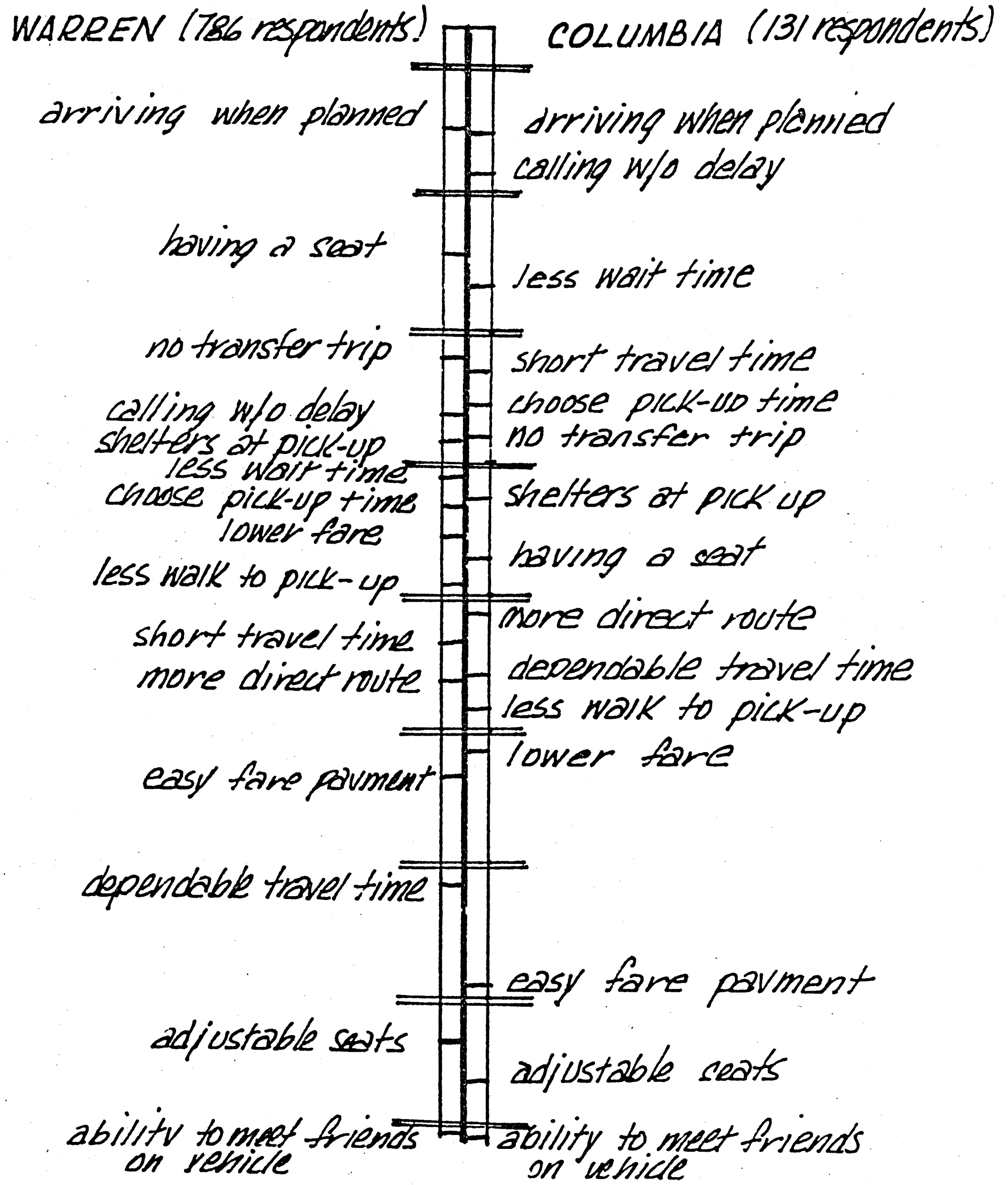
Comparison of Columbia and Warren. A summary of the scaled rank ordering of system characteristics for Columbia and Warren is shown in Figure VI-3. The method of paired questions allows the ordering of variables as well as estimating the relative "importance separation" between the ordered variables. The methodology is outlined in Appendix C. The rank ordering* is essentially similar at the 95 percent significance level. Thus the general attitudes of the two populations towards demand transit can be assumed similar. The vehicle design features are the least important in both areas. Similarly "arriving when planned" is the most important. Between these two extremes the remaining variables are clustered.

The selection of the second and third most important variables reflect the transit system existing in each area. The difficulty of transferring in a conventional system is reflected by the Warren residents. The experience with Call-A-Ride is forcefully exhibited by the Columbia residents. The buses used in the Columbia service were swamped with requests from the first day of service. The waits during peak demands often went to an

*All the rank ordering analysis was undertaken with Spearman Rank Correlation. This method was used since it lends itself to easy manual computational procedures and gave results of sufficient accuracy for the data involved.

FIGURE VI-3

PAIRED COMPARISON RESULTS FOR WARREN AND COLUMBIA



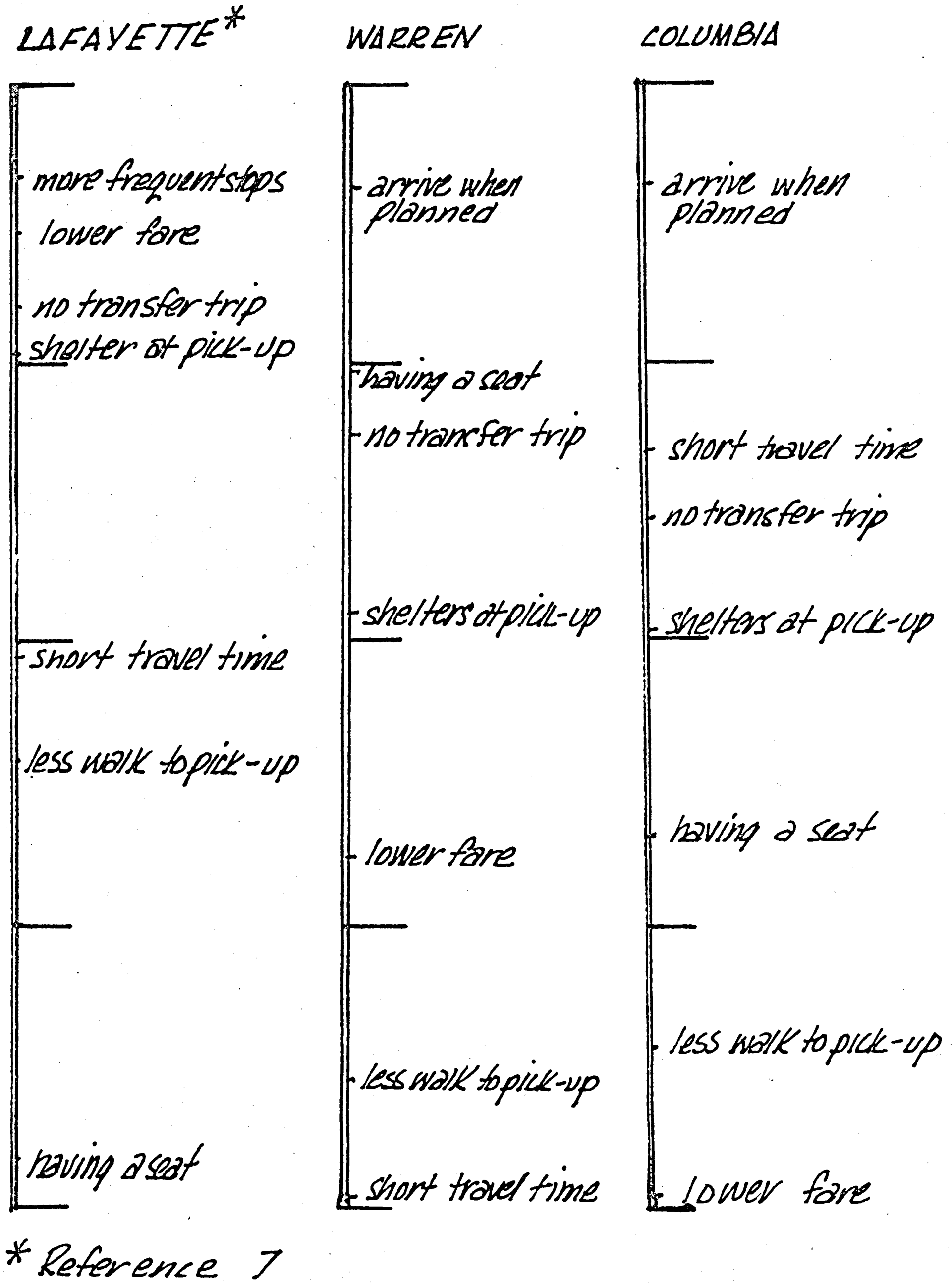
hour and difficulty in reaching the dispatcher was common. People very quickly become familiar with the system and planned around these time constraints though they were never entirely satisfied with the service during heavy demands.

The relative positioning of the importance of "lower fare" may be due partly to the higher incomes in Columbia and/or the lower fare. The fare in Columbia at the time of the survey was 25¢ a ride and 35¢ in Warren. It is probable that the Warren residents believed that any demand responsive transit system would, out of necessity, cost more than 35 cents.

The general conclusion from this is that the residents of both locations, Warren and Columbia, have essentially the same preferences for demand responsive transit.

The differences between a city with poor conventional transit and the demand responsive systems is shown in Figure VI-4. The study by Purdue used "more frequent service" which may be assumed to be in the same dimension as "arriving when planned". This is a valid assumption in that more frequent service would allow the transit user to arrive at his destination at a time more closely approximating a desired time. The striking difference between the three areas is the relative ranking of "lower fare". "Lower fare" is very important in Lafayette and considerably less important in Warren and Columbia. The Lafayette and Warren populations consider fare more important than travel time, Columbia residents reverse this order. The potential explanation of this lies in the relative income levels of the communities.

FIGURE VI-4
PAIRED COMPARISON RESULTS FROM SURVEYS IN THREE COMMUNITIES



* Reference 7

The higher incomes of Columbia allows for more emphasis to be placed on the time to travel rather than the "out-of-pocket" cost of the ride. The shortcomings of conventional transit is indicated by the relatively consistent rating of "no transfer trip". The Lafayette residents who use a poor quality existing transit system are also aware of the shortcomings by the importance they place on such characteristics as "shelter at pick-up" and "less walk to pick-up".

The results of the attitude surveys conducted by the University of Maryland and presented earlier also lend validity to the Warren and Columbia results. A rank ordering of selected transit system characteristics is shown in Table VI-5. The similarities in all the populations is quite striking and may be stated as follows:

> A desire to arrive at a destination when planned, with no transfers, plus shelters from inclement weather provided fairly close to the origin of the trip.

Columbia's Sub-Populations

The Columbia survey did not consider the purpose of trips since this was part of the Warren survey and if transferability was shown to be true then the Warren results would be accepted. A simple Spearman Rank Correlation of the relative ordering of the 15 variables, common to Columbia and Warren, indicated that the ordering was similar at the 95 percent significance level, for any of the six sub-populations listed in Table VI-6. The generalized rank ordering of variables does not tell the whole story, and the

Table VI-5

RANK ORDER OF TRANSIT SERVICE CHARACTERISTICS

CHARACTERISTIC	COLUMBIA, MARYLAND	WARREN, MICHIGAN	BALTIMORE + PHILADELPHIA	LAFAYETTE, INDIANA
Arriving when planned	1	1	1	1
Short travel time	2	7	2	6
No transfer to another bus	3	3	3	3
Protection from weather	4	4	4	4
Have a seat	5	2	N.A.	8
Short walk to pick-up	6	6	5	7
Lower fare	7	5	6	2
Longer hours of service	N.A.	8	N.A.	5

Source: Columbia, Figure VI-4
Warren, Reference 10
Baltimore, Reference 3
Lafayette, Reference 7

Table VI-6

SUMMARY OF PAIRED COMPARISON RESULTS FOR SELECTED SUB POPULATIONS OF COLUMBIA

ATTRIBUTE	TOTAL	MALE (31)**	FEMALE (97)	FREQ. USER (26)	OCCAS. USER (56)	NEVER USER (47)	USED TRANSIT BEFORE (49)	NEVER USED TRANSIT (71)	1 OR 0 AUTOS (53)	2 OR + AUTOS (56)
1 Arrive when plan	1.59*	1.41	1.67	1.64	1.64	1.65	1.52	1.63	1.49	1.70
2 No transfer	1.07	0.89	1.12	0.76	1.11	1.23	1.01	1.04	0.96	1.18
3 Less wait time	1.35	1.19	1.41	1.30	1.32	1.50	1.38	1.28	1.20	1.40
4 Lower fare	0.61	0.59	0.59	0.35	0.68	0.72	0.51	0.63	0.48	0.63
5 Less walk	0.64	0.51	0.67	0.60	0.62	0.80	0.48	0.71	0.56	0.66
6 Short travel time	1.05	1.02	1.06	1.19	1.04	1.12	1.00	1.08	0.92	1.15
7 More direct route	0.79	0.75	0.81	0.79	0.80	0.91	0.83	0.76	0.75	0.83
8 Dependable time	0.73	0.59	0.79	0.64	0.80	0.77	0.79	0.67	0.58	0.80
9 Have a seat	0.87	0.89	0.88	0.94	0.78	1.06	0.84	0.90	0.86	0.84
10 Call w/o delay	1.50	1.42	1.53	1.40	1.59	1.61	1.56	1.45	1.30	1.63
11 Shelters	0.93	0.78	0.98	0.94	0.90	1.08	0.85	0.98	0.89	1.02
12 Choose pick-up time	1.06	0.91	1.09	1.22	0.98	1.22	0.99	1.12	1.02	1.10
13 Easy fare payment	0.17	0.19	0.17	0.17	0.18	0.26	0.06	0.18	0.15	0.20
14 Adjustable seats	0.04	0.06	0.04	0.05	0.13	0.03	0.06	0.03	0.06	0.00
15 Ability to meet friends	0.16	0.11	0.17	0.12	0.29	0.04	0.13	0.16	0.11	0.18

*This is the value attribute 1, for total population would have on an ordinal interval scale.

**Sample size

relative importance of each variable should also be understood. While the ordering is similar, differences exist in the relative importance of variables. This is shown by the position on the scale of Figure VI-5 and involves the system characteristics of: "arriving when planned", "shorter travel time" and "dependable travel time". Shopping trips allow the operator more leeway in scheduling because arriving when planned is somewhat less important than for work trips. Shopping trips show a preference for convenience characteristics such as shelters and less walking. These conclusions are supported by the general results from the University of Maryland study presented earlier.

A graphical comparsion of the results by sex of the respondent is shown in Figure VI-6. Important differences exist between the two groups and these are graphically portrayed in Figure VI-6. Men are more willing to sacrifice convenience as measured by transfers and choice of pick-up time in order to obtain a fast dependable trip. These conclusions probably result from the fact that men use transit mainly for work purposes and women for work-shopping and other purposes.

Semantic Scaled Questionnaire Results

The semantic scaled attitudinal survey technique allows an analysis of the "degree of opinion" associated with a selected characteristic to be measured. The degree ranges from very unimportant (or undesirable) rated 1 through to a very important (very desirable) rated at 7. The mean of all responses measured the average value of desirability and allows average ratings.

FIGURE VI - 5

PAIRED COMPARISON RESULTS FOR WARREN
STRATIFIED BY TRIP PURPOSE

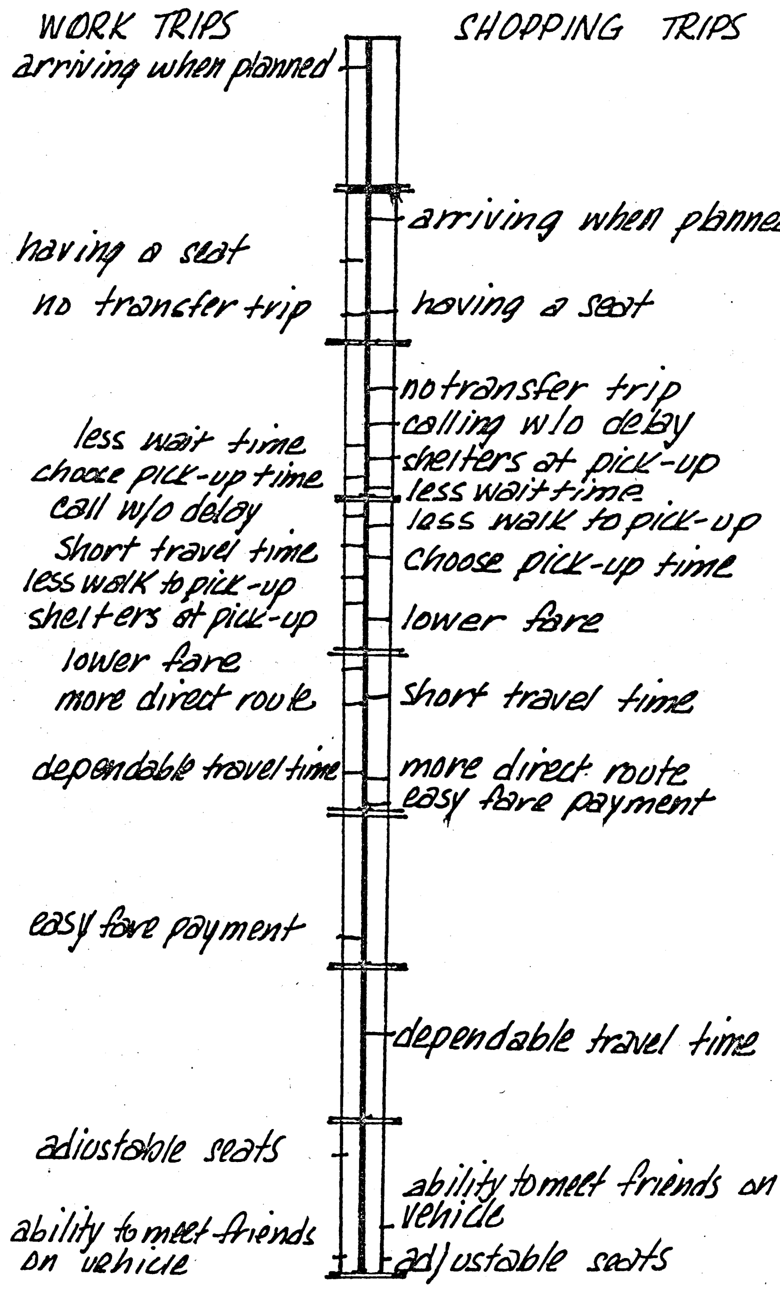
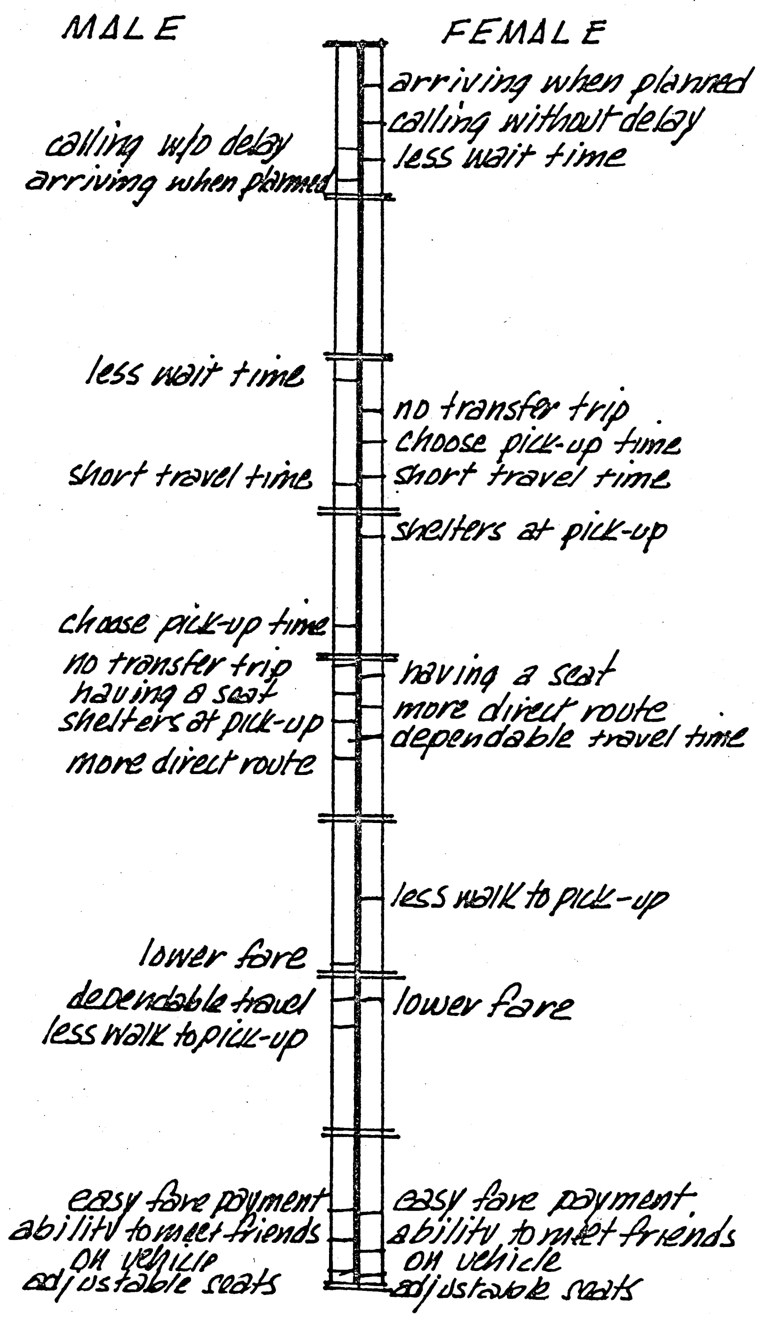


FIGURE VI-6

PAIRED COMPARISON RESULTS FOR COLUMBIA STRATIFIED BY SEX OF RESPONDENT



The standard deviation gives a measure of how unanimous, or similar, the respondents are. The following discussions concern the mean (average) responses but the deviations from the mean are introduced when helpful to the discussion.

Columbia and Warren Comparison. A comparison of 33 of the 54 attributes common* to the semantic scaled questionnaire used in Warren and Columbia is presented in Table VI-7. The opinion profile of Table VI-7 for Columbia (solid circles) and Warren (clear circles) are the plotted values which represent the mean response over the seven point scale as explained above.

The general pattern of the two profiles is quite similar and may be considered the same for the design of the system. A Chi squared test used to judge the similarity of the 33 attitudes for the two cities indicated that the pattern over the seven point scale was essentially similar at the 95 percent level of significance.

Terminal Time. A graph of terminal time sensitivity is shown in Figure V-7 for the data from Warren and Columbia. The attitudes towards terminal time are similar for both cities at the ninety-five percent significance level. The reaction of both populations to either waiting at home for pickup or arriving early (the same as waiting at the destination) is similar. The waiting time desirability drops off more rapidly after ten minutes. The sensitivity of waiting time on ridership is also available from observations in Columbia. The Columbia transit operation control log gives a relationship between the number of requests which

*The 21 omitted attributes concern the response to proposed individual fare charges and relative time inside vehicles. These are presented later in this chapter.

Table VI-7

SEMANTIC SCALED SURVEY RESULTS,
COLUMBIA AND WARREN

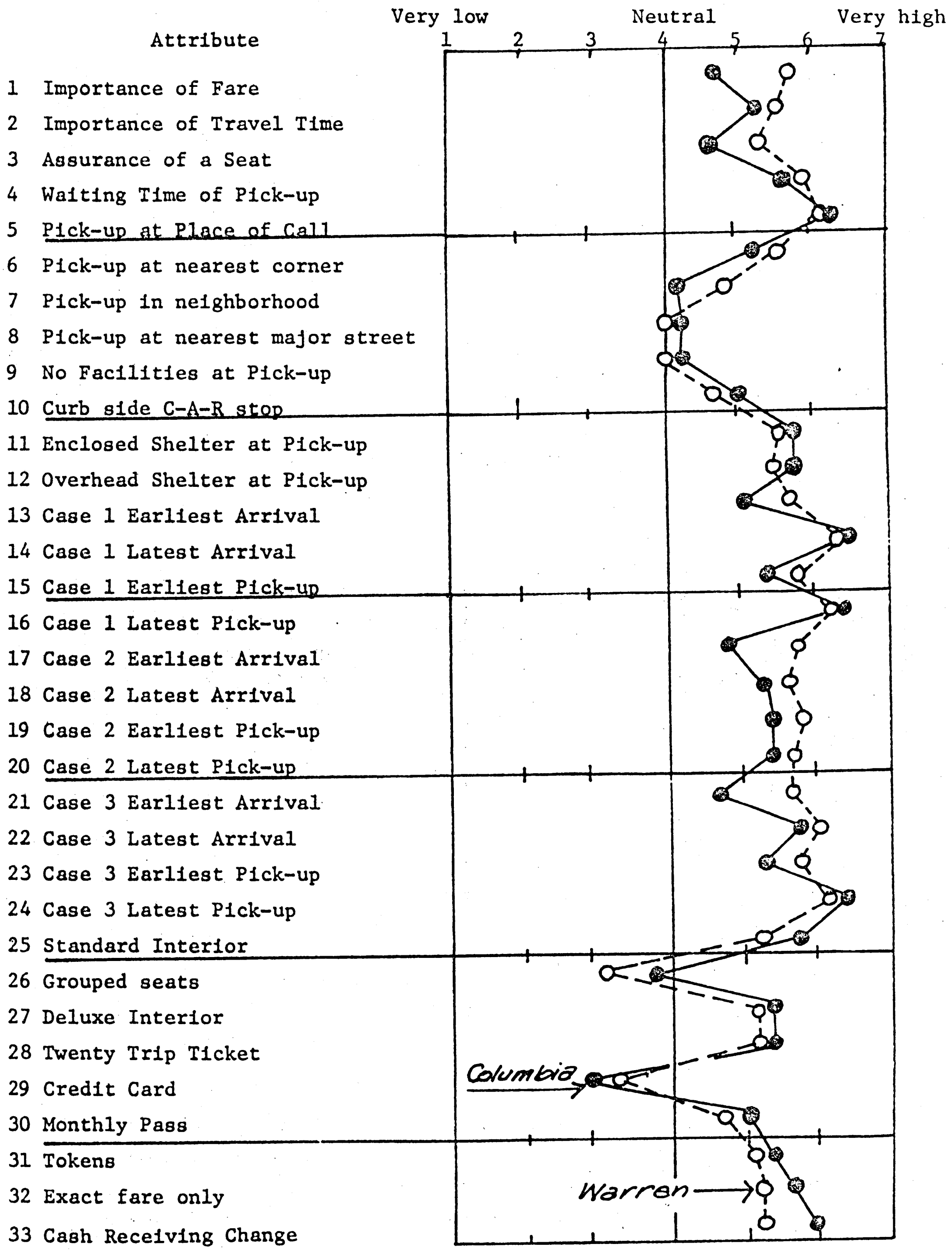
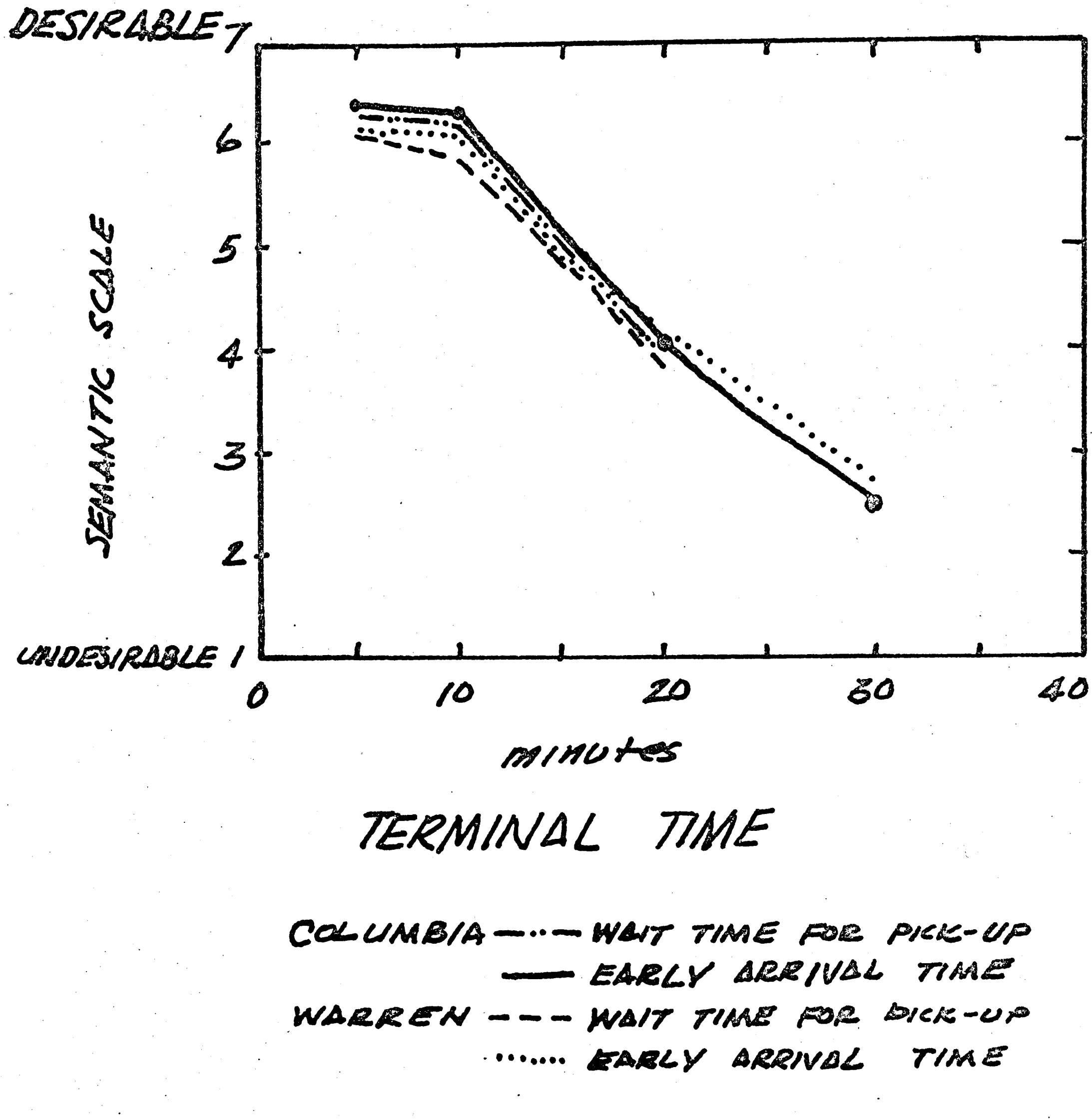


FIGURE III -7

TERMINAL TIME SENSITIVITY



either cancelled or did not show-up, and the length of time required for transit service. The approximate relationship is given by:

- 5% cancel or do not show (no-show) if the wait is less than 15 minutes, and
- 45% cancel or do not show if the wait time exceeds 1 hour.

The relationship between cancellation and no-show is approximately linear between these two extremes. The minimal loss of riders at waits less than 15 minutes tends to confirm the observation of this attitudinal survey.

<u>In-Vehicle Time Comparison</u>. An estimate of the reaction to transit travel time relative to auto travel time is shown in Figure VI-8. The curves are based on a combination of data from Warren and Columbia. The three common questions were tested for similarity with a student t-test. The tabulated statistical values for the three common questions is presented in Table VI-8. The student t-test assumes that the distribution from which the mean and variance is drawn, is normal. In the case considered this is not completely valid, see Appendix E. The calculated student *t* is less than the tabulated value of 1.96 implying that the Columbia and G.M. mean scores are similar for each of the three relative scores. Thus the Columbia mean attitude towards a 10 minute C.A.R. ride and a 5 minute auto ride is similar to that of the sampled population in Warren, Michigan. The fact that the tabulated *t* values are considerably less than the calculated value encourage acceptance of the similarity of means, even though the requirement

FIGURE VI-8

MEAN SATISFACTION CONTOURS FOR IN-TRANSIT AND IN-AUTO TRAVEL TIME

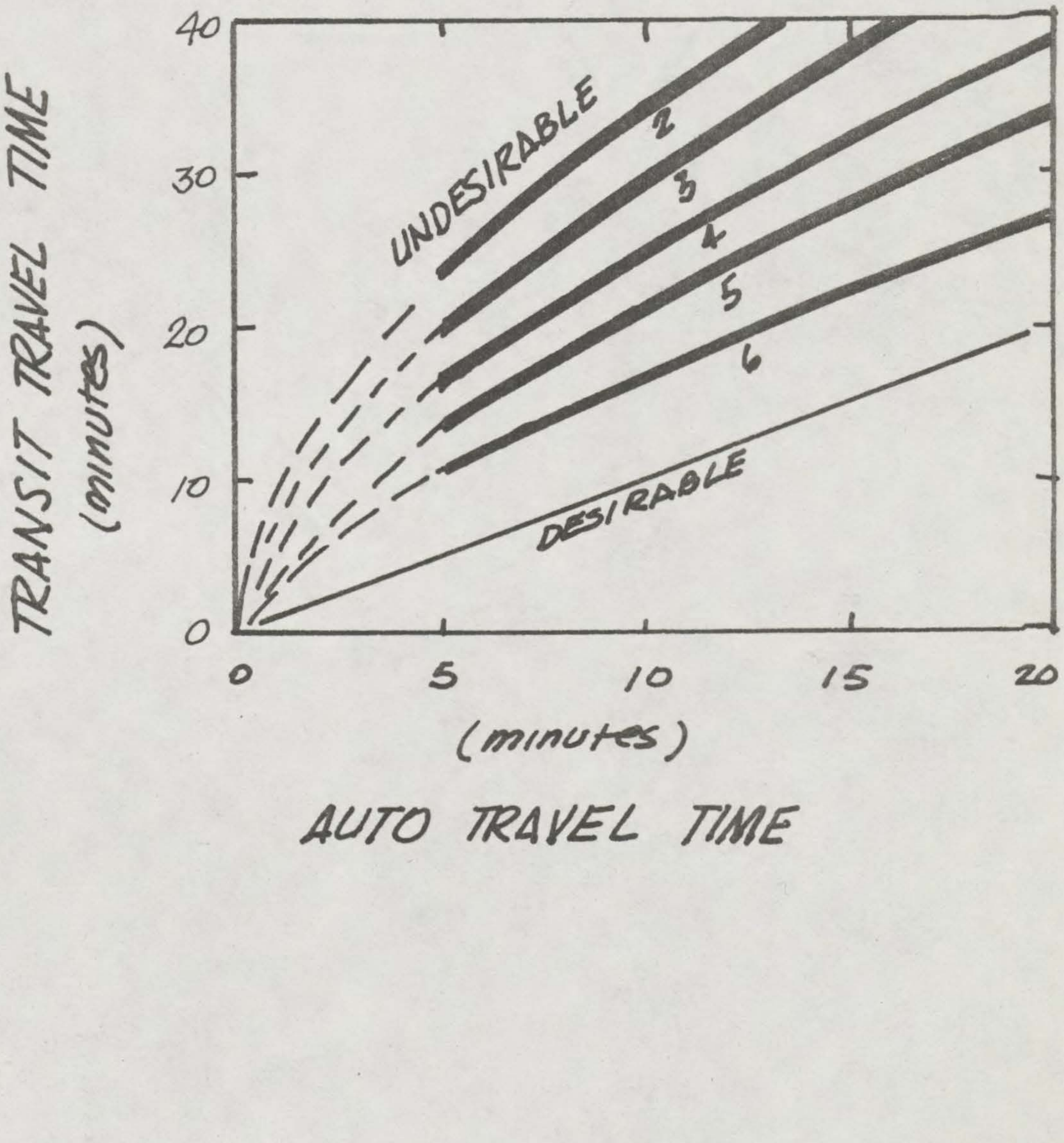


Table VI-8

SIMILARITY TEST FOR IN-VEHICLE TRAVEL TIME FOR COLUMBIA AND GENERAL MOTORS SURVEYS

		COLUMBIA	GENERAL MOTORS		"t"
Time (Minutes) Call-A-Ride	Auto	Mean Score	Mean Score	Score	Calculated*
10	5	6.17	6.00	1.4	0.95
15	5	4.71	4.60	1.8	0.48
15	10	6.10	6.30	1.2	1.32
Sample Size		100	417		

$$t_{515,0.025} = 1.96 = Z_{0.025}$$

*Assume that the distribution is normal and that the variance is similar. The large sample size, 517, has the "t" distribution approaching a normal "Z" distribution.

for a normal distribution is not satisfied. Thus for this analysis it was assumed that the mean scaled response value for each of the three questions was significantly the same for both cities at a confidence level of 95 percent. Based on these three points it was assumed that both populations reacted in a similar manner and thus the results pooled to draw Figure V-8. The relationship between the ratio of the travel time and transit travel time about which persons are indifferent (semantic scale value of 4) is a non-linear relationship*. The nonlinear nature of the relationship equates with the non-linear value of time as discussed by Thomas et al. The approximate ratio of transit travel time to auto travel time at a semantic scale value of 4 ranges from: 3.6 at five minutes auto time, 2.6 at ten minutes, 2.1 at fifteen minutes, and 1.9 at twenty minutes auto travel time. In other words if the "potential demand bus users" were given a choice of a ten minute auto ride or a twenty-five minute "demand bus ride", the choice of mode would be neutral. Under these conditions the split between modes would be 50-50.

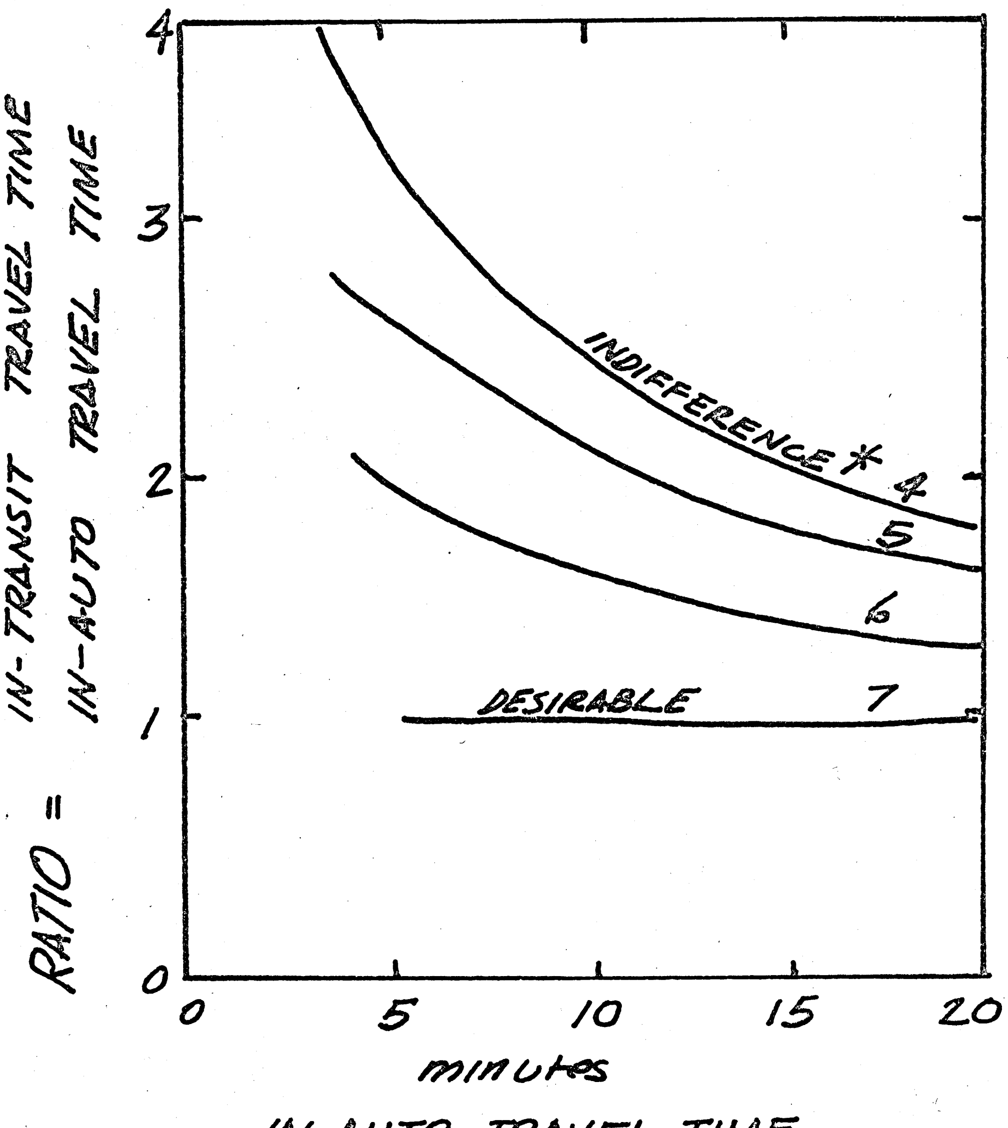
A graph of the in-vehicle travel time ratio, the in-auto time, and the mean satisfaction contours is shown in Figure VI-9.

*The use of the word "indifferent" in this study means the neutral point, or a scale value of 4 on the semantic scale. Thus on the scale below, the value of 4 is neither desirable nor undesirable.

Undesirable 1 2 3 4 5 6 7 Desirable

This has been assumed to be the value at which an attribute would have a "neutral" influence on potential transit users. For example in Figure VI-8, a Dial-A-Bus (in-vehicle) travel time of approximately 25 minutes and an auto (in-vehicle) travel time of 10 minutes have a neutral impact. Thus for these two in-vehicle travel times neither mode would be favoured.

FIGURE VI-9
RELATIONSHIP BETWEEN IN-VEHICLE TRAVEL TIME RATIO AND LEVEL OF SATISFACTION



* LEVEL OF SATISFACTION

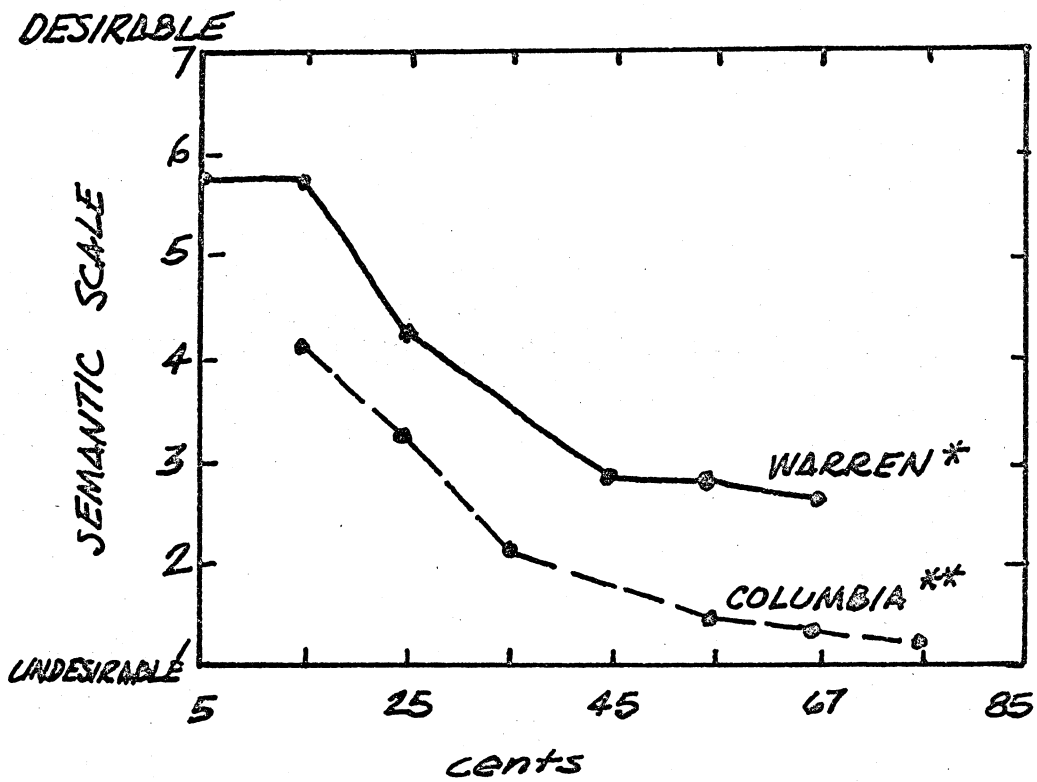
The "ideal" or most satisfactory (desirable) in-vehicle travel time ratio is 1. The ratio value is high for short trips and increases to the curve of indifference (satisfaction contour 4). As the time increases the satisfaction values converge towards a ratio value between 1 and 1.5 (approximately). Thus the relationship between transit and auto in-vehicle travel time must differentiate between the length of trip.

Fare. The average household income for Warren is less than the income for Columbia. One would hypothesize that the Columbia respondents would be less sensitive to fare than the Warren respondents, as was demonstrated for the paired comparisons scales. The semantic scales indicate that Warren respondents have a higher mean scale value for every fare level which would seem to be a contradiction. The existing fare was 25 cents in Columbia and 35 cents in Warren. The reaction of potential transit users toward proposed one-way fares less than the existing fares is shown in Figure V-10. The curve shapes are very similar. The difference between the curves is most likely attributed to the fact that Warren respondents are being offered an improvement in existing service while Columbia is not. The low 25 cent fare in Columbia probably explains why the respondents would rather have other system characteristics satisfied rather than pay a lower than 25 cent fare. These differences indicate that no conclusions can be drawn concerning the effect of income on the preferences.

The Columbia on-board bus survey also inquired about the willingness to pay. To get around the difficulty experienced with

FIGURE VI-10

SEMANTIC SCALING FARE SENSITIVITY



PROPOSED DEMAND BUS FARE LESS EXISTING FARE

* WARREN EXISTING FARE WAS 35¢

** COLUMBIAS EXISTING FARE WAS 25¢

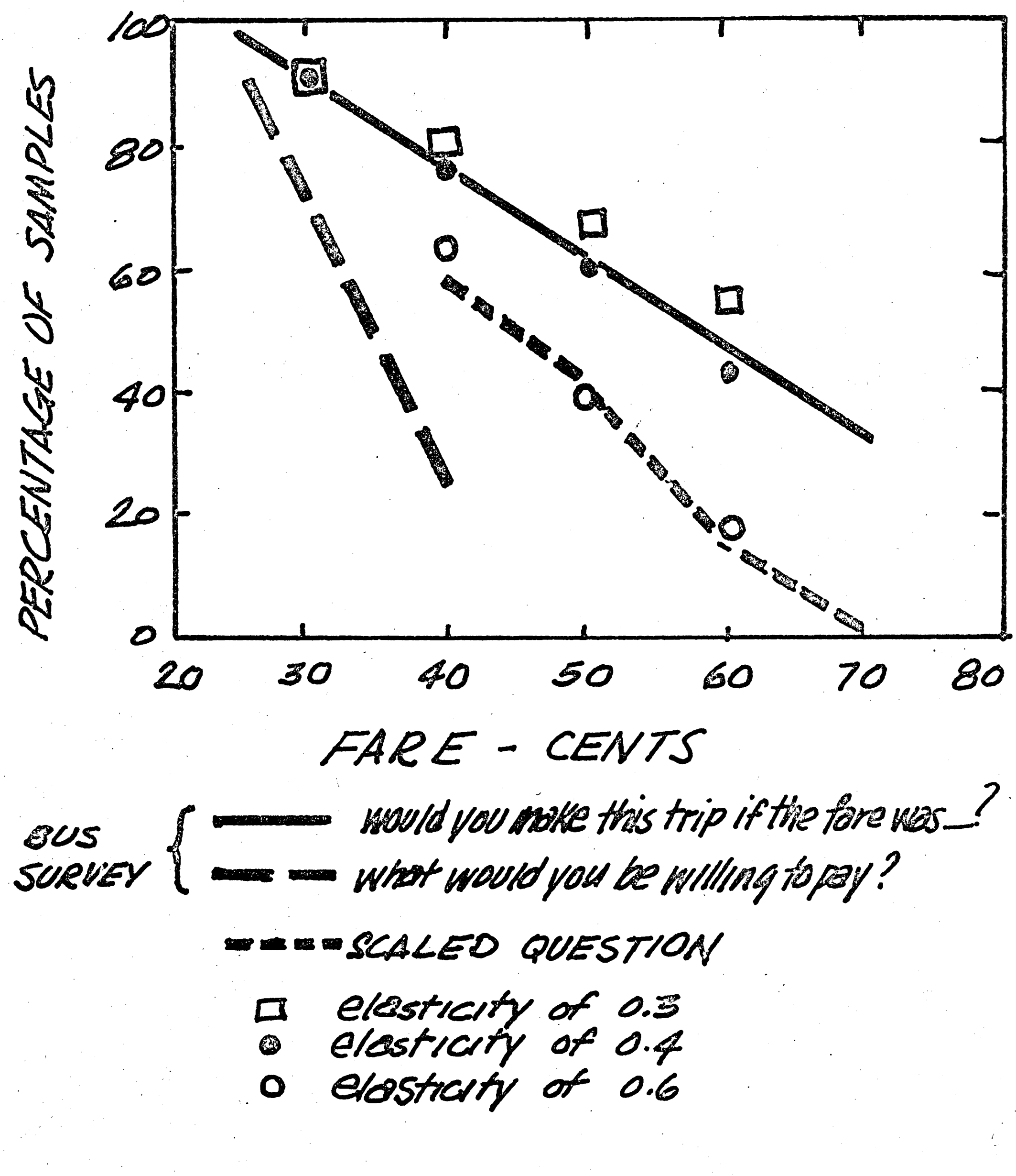
such questions, two phrasings of the question was employed. The first question asked was "Would you make this trip if the fare were "x" cents"? and another asked "What would you be willing to pay?"* The results are summarized in Figure VI-11. Figure VI-11 also includes the loss one would expect if the fare elasticity** ranged from 0.3 to 0.4. This is the elasticity range suggested by the data collected in Clearwater, Florida, see Table IV-5. The average number of Columbia transit users who said they would not make the trip, corresponds with the results of the 0.4 elasticity curve. This lends credibility to use of well constructed attitude surveys to study questions such as fares and service. This analysis implies that the reaction to travel costs may be more universal than usually suspected.

Columbia Sub-Population Reactions. To isolate the influence of selected socio-economic variables on certain attributes of the transit system the Columbia data may be further analysed. A visual comparison of the mean and standard deviation rating of the 33 attributes listed in Table V-7 for the socio-economic sub-populations in Columbia indicated that they were essentially similar. A listing of all the sub-population groups with semantic scale mean and standard deviation is presented in Appendix E. The sub-populations include groups such as: male,

*This question probably leads people to understate their fare as a point to negotiate from with the transit operators. They would then want the operator to set a lower fare since it would then be a gain for them. The "this trip" question is very specific and probably allows for a better evaluation at that moment in time.

**This states that for a one percent increase in fare the ridership will decline by 0.3 to 0.4 percent.

FIGURE VI-11
ATTITUDES: OBSERVED AND SURVEYED TOWARDS SELECTED TRANSIT FARES COLUMBIA



female; no driver's licence, driver's licence; zero or one car, 2 or more cars and a number of others.

The degree of homogeneous or unanimous response is estimated by the standard deviation about the mean of any attribute. Assuming that not having a driver's licence indicates captivity to transit, then transit captives are, on the whole, less opinionated and more unanimous* in their response than those who have driver's licences and assumed not captive to the transit system. In general the same may be said about those who are frequent users: they are less opinionated and more homogeneous in attitudes.

This observation implies that, if a bus system is designed to satisfy the "average" transit captive or frequent user the perceived needs of the choice rider will not be satisfied. If the choice riders attitudes are used in the transit system design the "average" response of the captive or frequent user is well satisfied.

Pursuing the apparent relationship between the terminal time at a trip origin or destination, uncovered Figure V-7, a similar graph was plotted using sub-populations in Columbia. The results for seven sub-populations are presented in Figure V-12. The distribution of responses about the hand fitted line at 5 and 20 minutes appear to be approximately normal. These points have the mix of wait-in home and early-arrival times and were intended to provide common values against which response could be related.

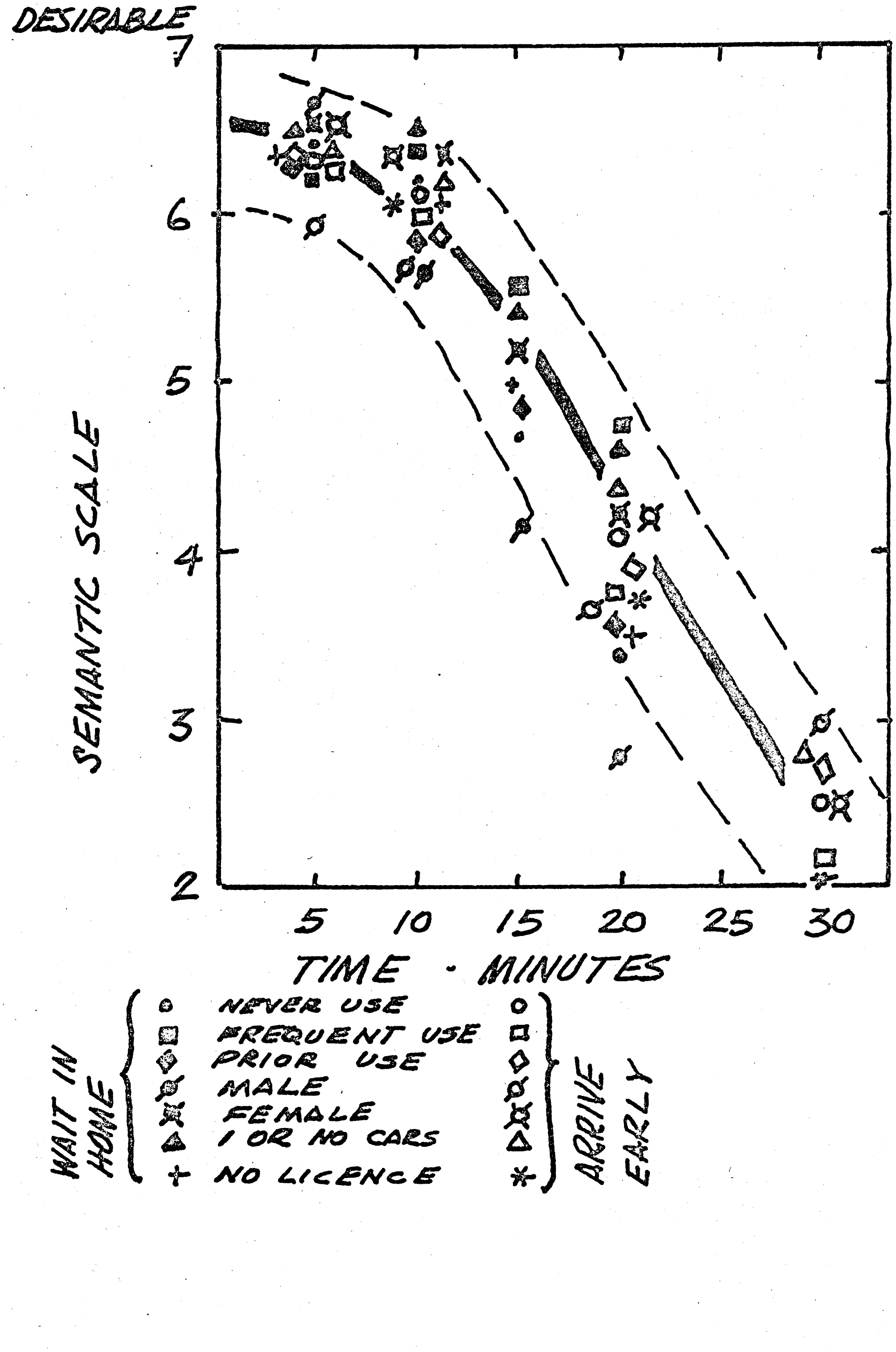
---

*The data used to make these statements are partially included in Figure VI-12, those points far removed from the handfitted "average" line represent the departure from the "average" opinion.

FIGURE VI-12

THE RELATIONSHIP BETWEEN SATISFACTION AND EARLY ARRIVAL AND WAIT TIME

COLUMBIA



Approximately 80 percent of all the mean responses are within +0.5 units of the semantic scale of the hand drawn curve. The two conclusions that may be drawn from Figure V-12 are: first, persons will react to waiting at either end of a trip with similar degrees of satisfaction and, second, 15 minutes would appear to be the maximum desirable wait or early arrival. The satisfaction at a rating of 4 is indifference to the wait of 20 minutes, is this the combined wait at both ends? Thus what is the desirability rating of waiting a total of thirty minutes? This question cannot be answered at this time with the available data.

Conclusion

The study of commuters in Chicago (6) emphasized the point that the availability of parking is a key variable in the mode choice decision. Failing a complete parking ban in a downtown, the positive aspects of transit must be emphasized. The attributes that will cause a switch to transit are:

- availability of the mode,
- ease of access,
- cost, and
- convenience.

The influence of trip purpose on the "idealized transit" emphasized the service differences needed between work and other purpose trips. Work trips are usually well served by conventional fixed-route, fixed-scheduled bus service. The same system offers little to attract other trip purposes.

The attitude survey data from Warren, Lafayette, and

Columbia indicates that the desired transit service characteristics are ordered in a fairly consistent rank. The ranking appears to be independent of the size of the city. Variations in the rank may be explained by the conditions of the local bus system.

The system suggested by this study may be summarized as follows:

- o arrives on time,
- o no transfers,
- o minimum walking time, and
- o protection from the elements.

The analysis of the relative influence of the time elements of a transit trip revealed a relationship between waiting time and riders lost. The relationship is:

- o 5 percent cancel or "no-show" if the wait exceeds 15 minutes, and
- o 45 percent cancel or "no-show" if the wait time exceeds 60 minutes, (Between these two extremes the percent loss is approximately linear with time.)

Also a relationship between the time spent riding in a bus or automobile is presented. The mean satisfaction contours of transit and auto ride times in Figure V-8 provide two contributions to the estimation of transit patronage. First, they conclusively show, for short trips, that to have a time relationship which favours the use of neither system, the in-transit time must be weighted more heavily than in-auto time. Assuming that the satisfaction contour of 5 is a conservative estimate of a useful in-auto to in-transit-time then:

- o in-transit time = 2.5 (in-auto time) for auto trip time 5 to 10 minutes,
- o in-transit time = 1.8 (in-auto time) in-auto trip time 10 to 20 minutes.

The surveyed reaction to potential fare increases in Columbia gave potential ridership losses which corresponded closely to those estimated through ridership fare elasticities observed in other transit systems. The elasticity which best fits the surveyed average ridership loss in Figure VI-1 is 0.4. This implies a possible common reaction of young transit patrons towards increasing transit fares.

An analysis of terminal times for seven sub-groups in Columbia indicated that time spent waiting at either end of the trip is equally important. Thus time spent waiting at home for a bus is considered similar to the time spent waiting at the destination brought about by an early arrival. Thus a 10 minute wait at home is equally satisfactory (or not satisfactory) as a 10 minute wait (early arrival) at the destination.

These conclusions will be used later in the development of a modal choice model sensitive to the service characteristics inherent in this new transit operation.

REFERENCES

1. McMillan, Robert K., Henry Assall (1968). National Survey of Transportation Attitudes and Behavior. Phase I Summary Report. NCHRP Report 49. Highway Research Board, Washington, D.C.

2. McMillan, R.K., H. Assall (1969). National Survey of Transportation Attitudes and Behavior. Phase II Analysis Report. NCHRP Report 82. Highway Research Board, Washington, D.C.

3. Paine, Frank T., A.N. Nash, S.J. Hille, G. A. Brunner (1967). Consumer Conceived Attributes of Transportation: An Attitude Study. Clearinghouse Publication, PB176 485, June.

4. Paine, Frank T., A. N. Nash, A.J. Hille (1969). Consumer Attitudes Toward Auto Versus Public Transport Alternatives. Journal of Applied Psychology. Vol.53, No.6, 472-480.

5. Nash, Allan N., S.J. Hille (1968). Public Attitudes Toward Transport Modes: A Summary of Two Pilot Studies. Highway Research Record, No.233.

6. Bock, Frederick D. (1968). Factors Influencing Modal Trip Assignment NCHRP Report 57. Highway Research Board, Washington, D.C.

7. Purdue University (1971). The greater Lafayette Area Bus Transit Study. Joint Highway Research Project. Kenneth Heathington, Project Director, Lafayette, Indiana. April.

8. Golob, Thomas F., E.T. Canty, R.L. Gustafson and J.E. Vitt (1971). An Analysis of User Preferences for a Public Transportation System. Transportation Research, Vol.6.

9. Gustafson, Richard L., H.N. Curd and T.F. Golob (1971a). User Preferences for a Demand-Responsive Transportation System: A Case Study Report. Highway Research Record No.367.

10. Gustafson, Richard L., H.N. Curd and T.F. Golob (1971b). Survey Data: Measurement of User Preferences for a Demand-Responsive Transportation System. General Motors Research Laboratories, Warren, Michigan, GMR-1057.

11. Navin, Francis P.D., R. C. Bartolo, Demand Responsive Transit: Columbia, Maryland's Experience. Presented at the Annual Meeting of the American Institute of Planners. October 1971.

12. Gustafson, Richard L., F.P.D. Navin (1972). User Preferences for Dial-A-Bus: A comparison of Two Cities. Special Report 136, Highway Research Board, Washington, D.C., (1973), pp.83-93.

13. Navin, Francis P.D., R.L. Gustafson. Attitudes Towards Public Transit: Some Comparisons, Presented at the 51st Annual Meeting of the Highway Research Board. Washington, D.C. January, 1973.

Chapter VII

SPATIAL AND TEMPORAL ANALYSIS

Introduction

The objective of this chapter is to estimate the regularity of demand for Dial-A-Bus in Columbia, Maryland and Bay Ridges, Ontario. If the demand shows any significant degree of regularity then this regularity should be incorporated in the bus operation strategy. The operation strategies to be investigated are many-to-many and many-to-one.

The Data and Analysis

The data for this study comes from the extensive records maintained by the Columbia Community Association and the GO Transit System.* The data was collected such that:

1. A full day's demand was available (for Bay Ridges only 3 hours in the morning),
2. Four days continuous operation. (For Bay Ridges only 3 hours in the morning),
3. A continuous set of Wednesday mornings for a few months.

This stratification of data was needed to allow for possible statistical analysis of days by successive weeks; days within a week.

The analysis for each of the two locations was quite

*Government of Ontario Transit operated the Bay Ridges Dial-A-Ride until 1973, at which time the municipality of Pickering took over the operation.

different. The steps in the analysis are shown in Figure VI-1. Notice that the analysis of the Columbia system is much more extensive than that for Bay Ridges. Columbia's many-to-many operation added a considerable number of variables which had to be investigated. The outcome is a tentative bus operating policy. The policy incorporates the spatial and temporal analysis as well as the general economic experience of each system as presented in Chapter VI.

Bay Ridges

The major trip purpose for the a.m. analysis period, using the Dial-A-Bus, GO Train combination in Bay Ridges, is for work into downtown Toronto. The analysis time was from 8 a.m. to 12 noon. This particular time period should show a regular pattern in space and time if one can be found. The data was not sufficient to provide any comparison between the demand for service between successive hours.

Pattern by Day of the Week

The probability of having a transit demand in a small analysis area during a day of the week is shown in Figure VII-2. The probability of a demand is defined as the sum of the demand indices divided by the number of days analysed. Thus if during each of four days at least one person demanded service on a small zone then for that small area the probability of a demand would be 4/4 = 1. Similarly if demands occurred on only two days the

FIGURE VII-1

TEMPORAL AND SPATIAL ANALYSIS

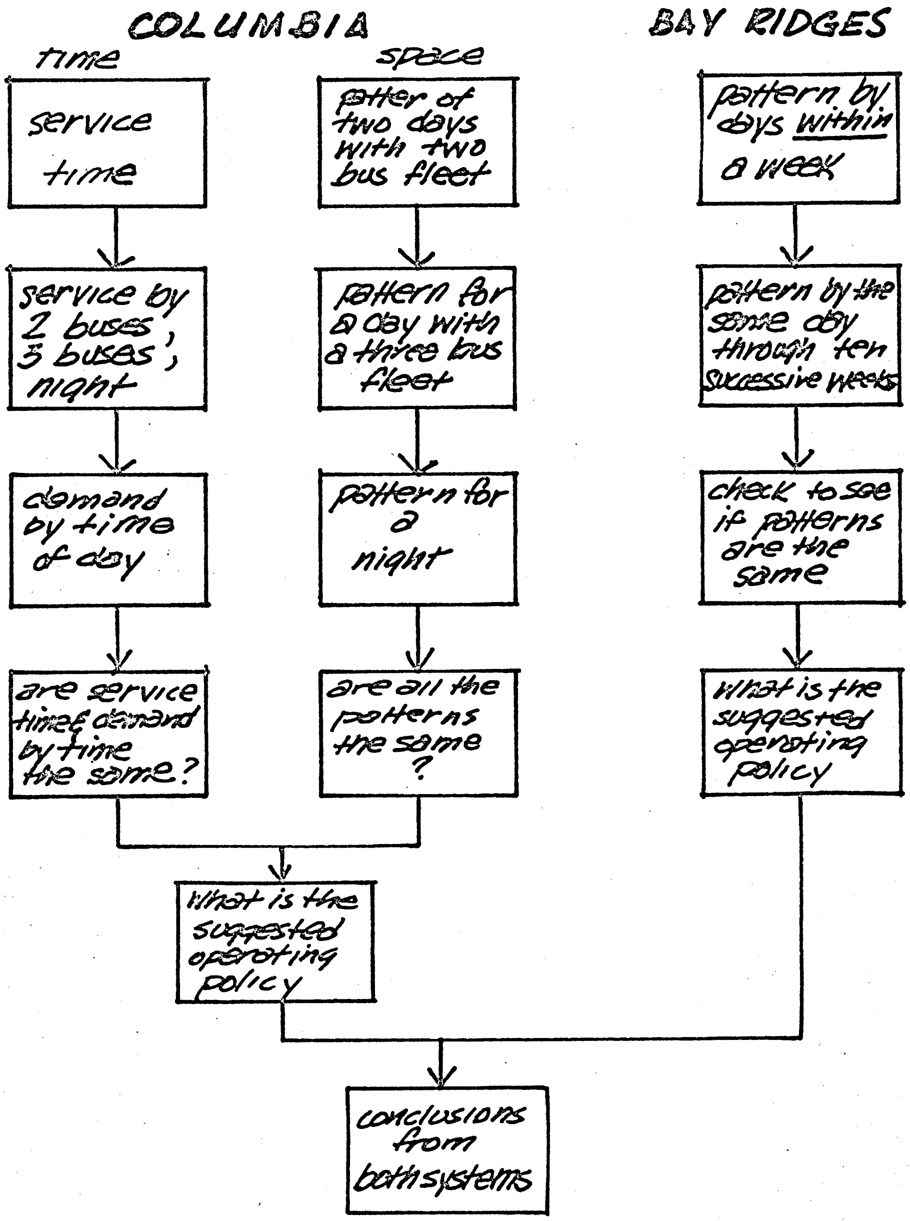
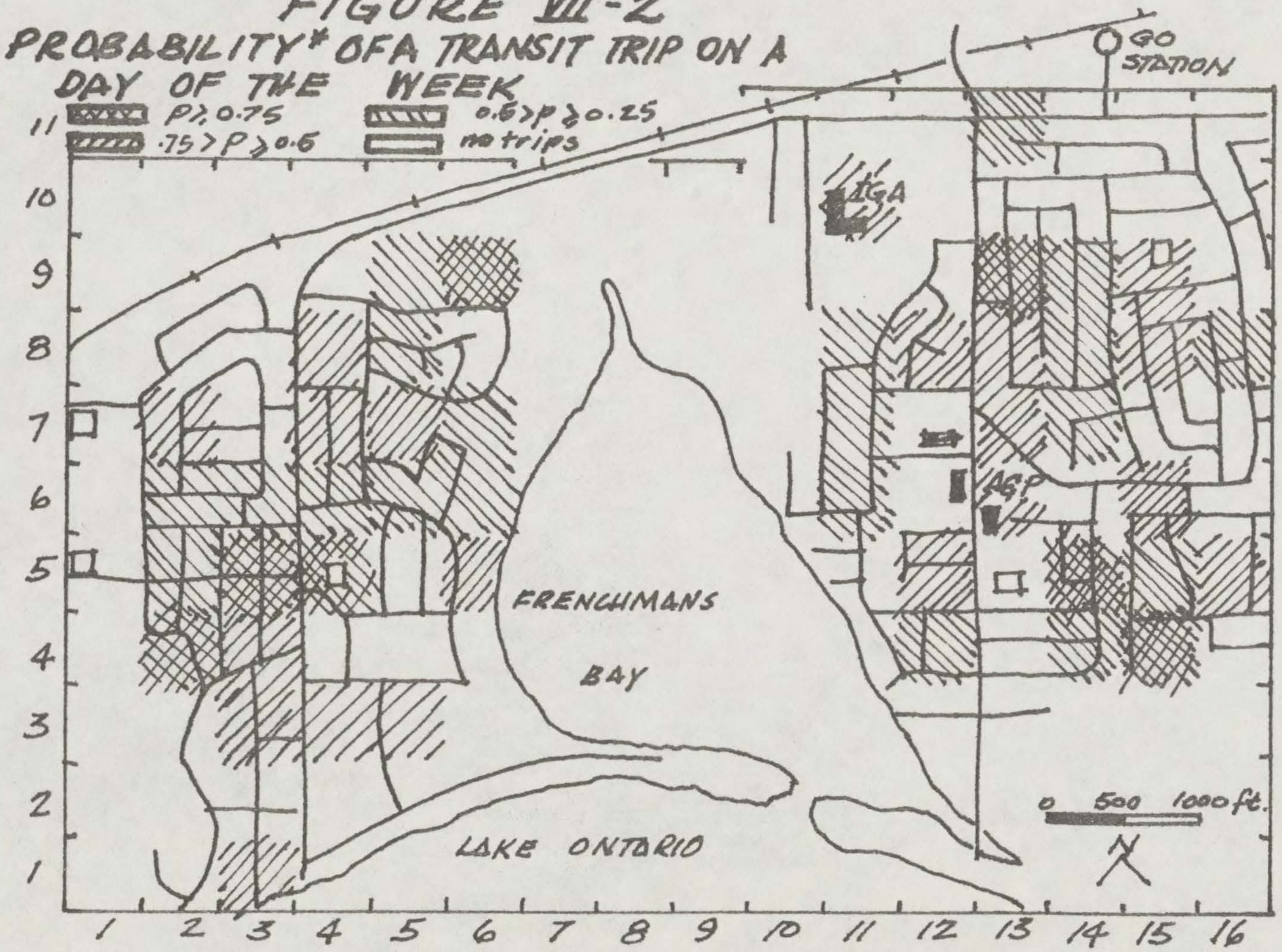


FIGURE VII-2
PROBABILITY* OF A TRANSIT TRIP ON A
DAY OF THE WEEK



probability would be 0.5.

Visually the pattern appears to have a good number of zones with a probability of either equal to or greater than .75 and less than or equal to .25. If this is considered to constitute regularity, then it may be tentatively said that the transit usage pattern is regular. Notice that the lack of transit usage ($p < 0.25$) is more common than frequent transit usage ($p > 0.75$). West of Frenchman's Bay the frequent transit usage is associated with an apartment complex (9,6)* and the old summer cottage areas, coordinates (4,2), (5,3) and (5,4).

Pattern of a Day in Months

To investigate the regularity of a single day throughout successive weeks, a Wednesday morning was selected for ten weeks. A map of the probability of repeated demand in a zone in the same day of successive weeks is shown in Figure VII-3. This pattern appears to be more regular ($0.7 > p < 0.3$) in the demand (or lack of demand) from a particular zone. The lack of adequate numbers of persons wanting to make transit trips, and a wish to keep the analysis areas small enough to give meaningful operational answers, excluded the use of most statistical techniques within each square in Figure VII-3. As an approximation the demand was summed along the edges.

The simplest explanation is by way of a diagram. Figure VII-4 is an idealized set of Dial-A-Bus demands and the demands

*Coordinates (N-S,E-W); the North-South axis is the first number and the East-West axis, the second.

FIGURE VII-3

PROBABILITY* OF A TRANSIT TRIP ON A DAY IN SUCCESSIVE WEEKS

BAY RIDES ONTARIO
*see text for definition

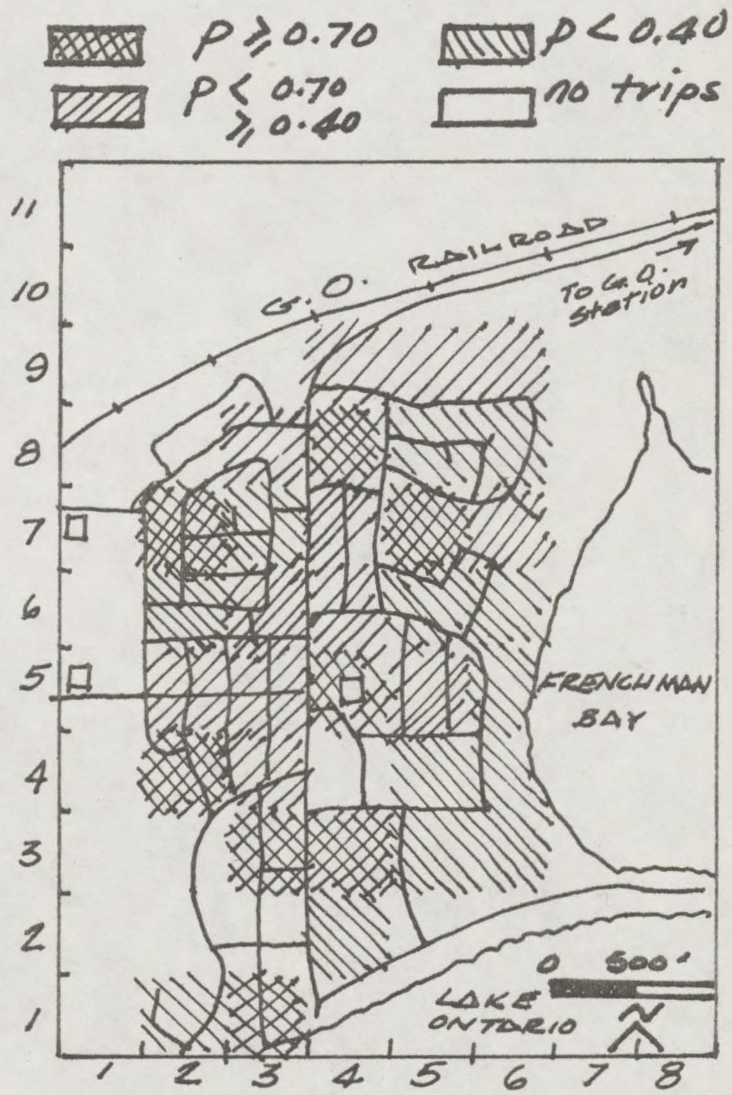
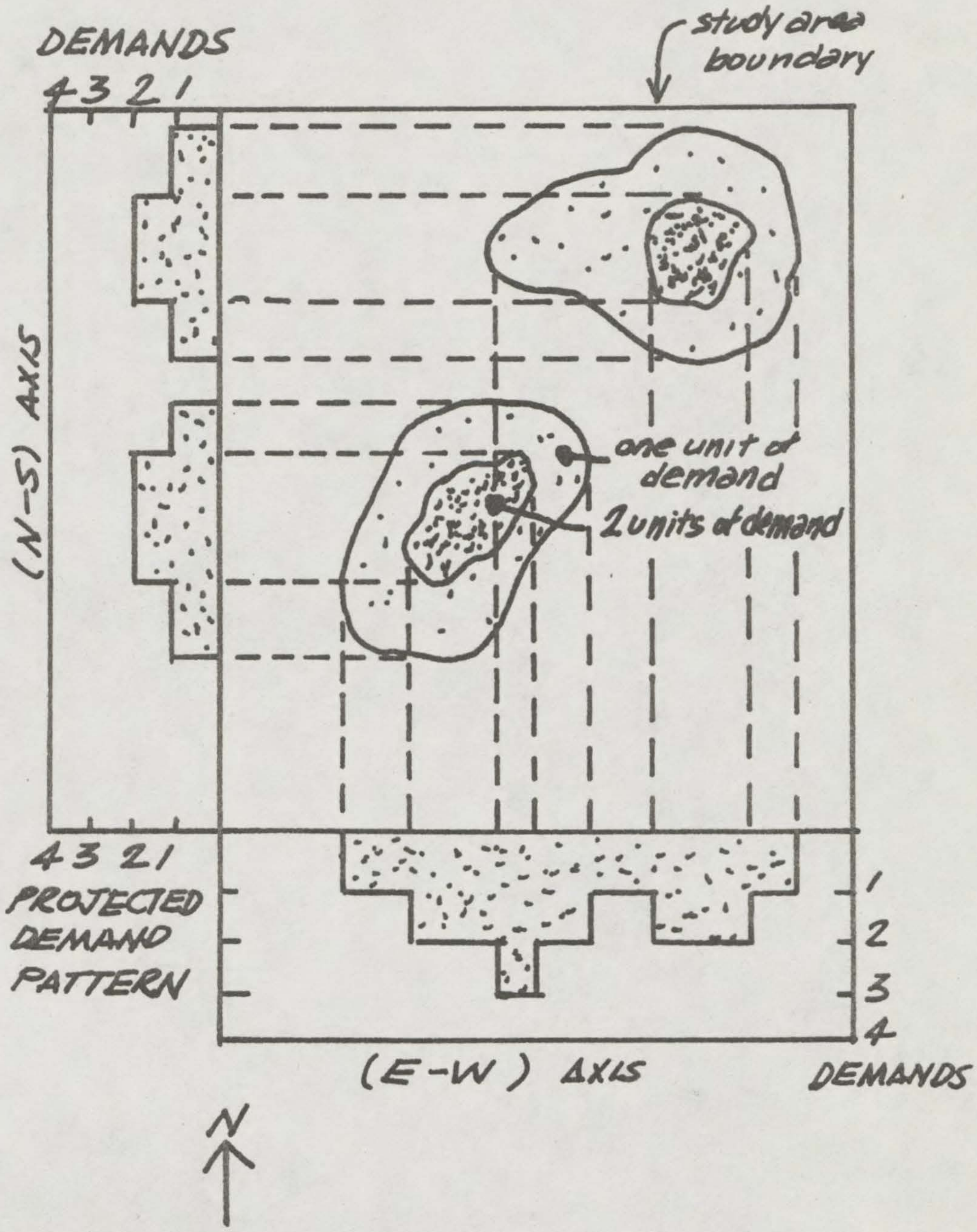


FIGURE VII - 4
HYPOTHETICAL DEMAND SPACE AND PROJECTIONS ON BOUNDARIES



projected along an arbitrary boundary. The size of the analysis grid is such that the majority of areas have less than 5 expected demands per unit of time. This excludes the use of the standard Chi Squared goodness-of-fit test (1). To get a grouping of data that would give 5 expected observations per unit of observation length, a projection of demands on the area boundary was used. The underlying assumption is that a pattern exists and Figure VII-4 has one possible area demand pattern. The projection of this demand pattern on both boundaries produces a unique set of projections. If all the projected patterns can be shown to be similar then the demand over the area is probably similar. Thus if:

$$\text{Pattern }(N,S)_i \equiv \text{Pattern }(N,S)_{i+1} \equiv \ldots\text{Pattern }(N,S)_n$$

and

$$\text{Pattern }(E,W)_i \equiv \text{Pattern }(E,W)_{i+1} \equiv \ldots\text{Pattern }(E,W)_n$$

then

$$\text{Pattern (Area)}_i \equiv \text{Pattern (Area)}_{i+1} \equiv \ldots\text{Pattern (Area)}$$

where i = first observation unit of time
n = last observation
N,S = North-South Axis
E,W = East-West Axis
Area = Space enclosed with boundary

While the arguments presented to support the procedure are not mathematical, they appear to be adequate for the analysis. If the procedure were restricted only to projection, it would fall down under two conditions. First, where the demand is completely random and second, when there is a uniform demand on a diagonal. This latter case requires in the first time unit, a diagonal from (0,0) to (a,b), in the next time unit the diagonal shifts to the right on the E,W axis by "c" units and down the N,S axis by "d" units thus it goes from (o,c) +0 (a-d,b). At the same time a similar uniform diagonal demand appears in the North-West corner going from (a-d,0) to (a,o). Both these situations may be observed with the spatial plotting of the demand. The random case is possible but the uniform demand on the diagonal is highly unlikely in a small area.

The hypothesis for the regularity of the same day during the week is as follows: if a regular spatial demand pattern for the same weekday during successive weeks exists, then the observed demand projected on the North-South and East-West axis will be regular for those days. While testing this hypothesis it becomes apparent that sufficient data was not available to test each day and the data was grouped by pairs of successive days. That is, for the ten Wednesdays for which data were collected the number of analysis periods were reduced to five by combining Wednesdays 1 and 2, 3 and 4 and so on up to 9 and 10. The data are presented in Table VII-1. The resulting Chi Squared analysis* indicated an approximately similar projection pattern at a 90 percent level of confidence. This tends to support the rather tenuous patterns shown in the map of Figure VII-3. The Chi Squared test and

*The analysis was not completely valid since some cells did not have an expected value of 5 and thus decisions are tenuous. Further grouping of the data would have made any analysis meaningless.

TABLE VII - 1

DAY IN MONTH
DIAL-A-BUS DEMANDS IN
BAY RIDGES, ONTARIO

	DAY GROUP				
E - W axis	1	2	3	4	5
1	7	7	3	5	7
2	8	7	13	8	9
3	9	8	12	10	13
4	7	3	11	6	13
5	7	5	6	3	6

Hypothesis: the weekday groups have a similar pattern of trip demands on the east-west axis.

$$\lambda_c^2 = 9.623$$

$$df = 16$$

$$N = 193$$

$$C = \frac{\lambda^2}{\lambda^2 + N} = 0.218$$

$$\lambda^2_{.25,16} = 11.9 > \lambda_c^2$$

$$\lambda^2_{.10,16} = 9.3 \quad \lambda_c^2$$

∴ At somewhat more than 90% significance the weekday groups have a similar pattern of trip demands on the east-west axis.

TABLE VII - 1 CONTINUED

DAY IN MONTH
DIAL-A-BUS DEMANDS IN
BAY RIDGES, ONTARIO

	DAY GROUP				
N - S axis	1	2	3	4	5
1	7	5	4	3	4
2	4	3	5	4	6
3	5	5	10	4	9
4	4	2	4	3	7
5	11	4	7	7	8
6	6	5	9	9	12

Hypothesis: the weekday groups have a similar pattern of trip demands on the north-south axis.

$$\lambda^2_c = 9.966$$

$$df = 20$$

$$N = 176.0$$

$$C = \frac{\lambda^2}{\lambda^2 + N} = 0.232$$

$$\lambda^2_{.10,20} = 12.4 > \lambda^2_c$$

$$\lambda^2_{.05,20} = 10.9 > \lambda^2_c$$

∴ At somewhat less than 95% significance the weekday groups have a similar pattern of trip demands on the north-south axis.

Figure VII-3 can be used to help design a bus routing pattern for a Wednesday morning. The bus must plan to serve the areas where the probability of a trip request equals or exceeds 0.70. Similarly the area with a probability of a trip less than 0.30 should probably be included in any routing by a prior request and not as part of a regular scheduled route. The remaining area should get a regular service as convenient to the operator and the residual area serviced on a prior request basis. If a bus route with route deviation on demand could be arranged through this area to accomplish the service outlined above, then the tour pattern has at best a 90 percent chance of being correct. Since commuter trips tend towards a regular pattern, and transit tends to further encourage regularity, the probability of a correct routing pattern would eventually approach 90 percent.

Generality of Demand Patterns

The next step is to see if the two patterns, days in the week and days in successive weeks, are similar. To do this comparison a Chi-Squared test was conducted with the demand projections on the North-South and East-West axis of the area to the West of the Bay. The tabulated values for the Chi-Squared test are shown in Table VII-2. The patterns are similar at a 90 percent level of significance.

The conclusion that the demand pattern is generally the same each day allows a basic operational policy to be developed for the regular trips. The policy can then be varied to maximize the transit use in areas of low demand.

TABLE VII - 2

DIAL-A-BUS DEMAND FOR

AVERAGE WEEKDAY AND

AVERAGE WEDNESDAY FOR TEN WEEKS

N-S axis	AVERAGE Wednesday**	AVERAGE Weekday*	E-W axis	AVERAGE Wednesday	AVERAGE Weekday
1	5	4	1	6	4
2	4	5	2	9	8
3	6	6	3	10	8
4	3	4	4	8	10
5	9	8	5	6	4
6	5	8			

Hypothesis: the average weekday has a similar pattern of trip demand as that of an average Wednesday.

N-S axis:

$$\lambda_c^2 = 0.984$$

$$df = 5$$

$$N = 67$$

$$C = \frac{\lambda^2}{\lambda^2 + N}$$

$$\lambda^2_{.10,5} = 1.6 > \lambda_c^2$$

$$\lambda^2_{.05,5} = 1.1 > \lambda_c^2$$

E-W axis:

$$\lambda_c^2 = 0.965$$

$$df = 4$$

$$N = 73$$

$$C = \frac{\lambda^2}{\lambda^2 + N}$$

$$\lambda^2_{.10,4} = 1.1 > \lambda_c^2$$

$$\lambda^2_{.05,4} = .71 < \lambda_c^2$$

∴ At somewhat greater than 90% significance the average weekday has a similar pattern of trip demand as that of an average Wednesday.

* Average for 2 days in week i.e. Monday + Tuesday, Tuesday + Wednesday, etc.

** Average for 2 Wednesdays.

Columbia

The Columbia many-to-many Dial-A-Bus operation, and the switch from a two to a three bus fleet, add additional complexity to the Columbia analysis. The sparseness of satisfied transit demands throughout the area also made statistical analysis rather tenuous. The data used in the analysis represents January and February 1970 when Columbia started with a 2 bus fleet. The next set was for a day in May 1970 when they had a 3 bus fleet. The final set was for an evening during September 1970 when only evening Dial-A-Bus operated.

The Time Analysis

To visualize the scheduling of the bus fleet and to look for potential bias in either the amount of work assigned each bus or its operating efficiency, the graphs of Figures VII-5 through 7 are presented. The graphs represent the time commitments of patrons to vehicles. The times plotted for each patron on each bus are: call-time, pick-up time, and drop-off time. The average productivity* of the vehicles is approximately six demands** per hour.

The statistical tests in this section attempt to isolate the similarities or differences which exist in the time service

*Transit productivity is defined as transit trips per hour per vehicle.

**This is in terms of demands, the number of persons may be slightly higher, since one call may represent several riders.

FIGURE VII-5
RIDERSHIP ON BUS NUMBER 1, COLUMBIA. C.A.R.

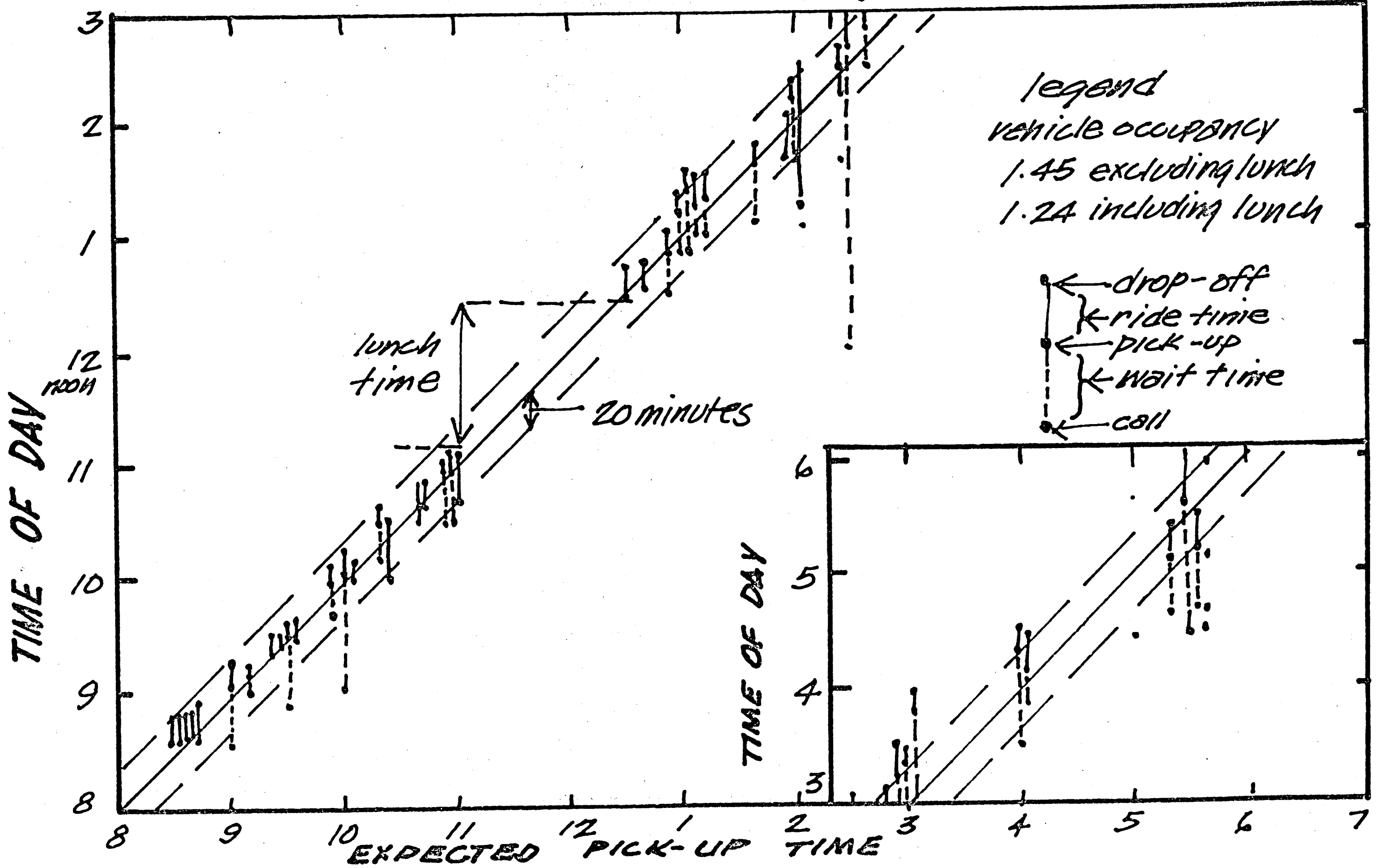


FIGURE VII-6
RIDERSHIP ON BUS NUMBER 2. COLUMBIA C.A.R.

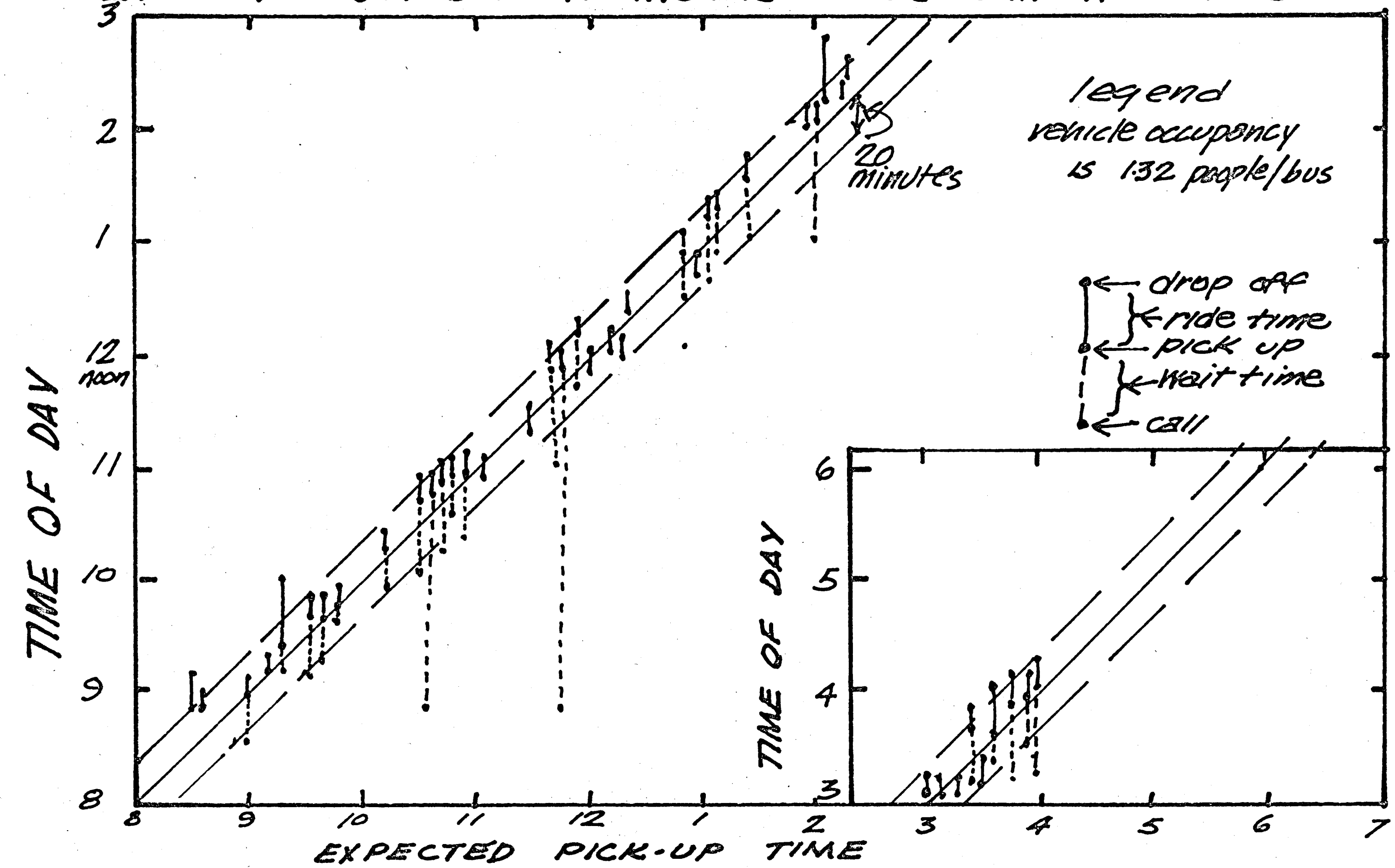
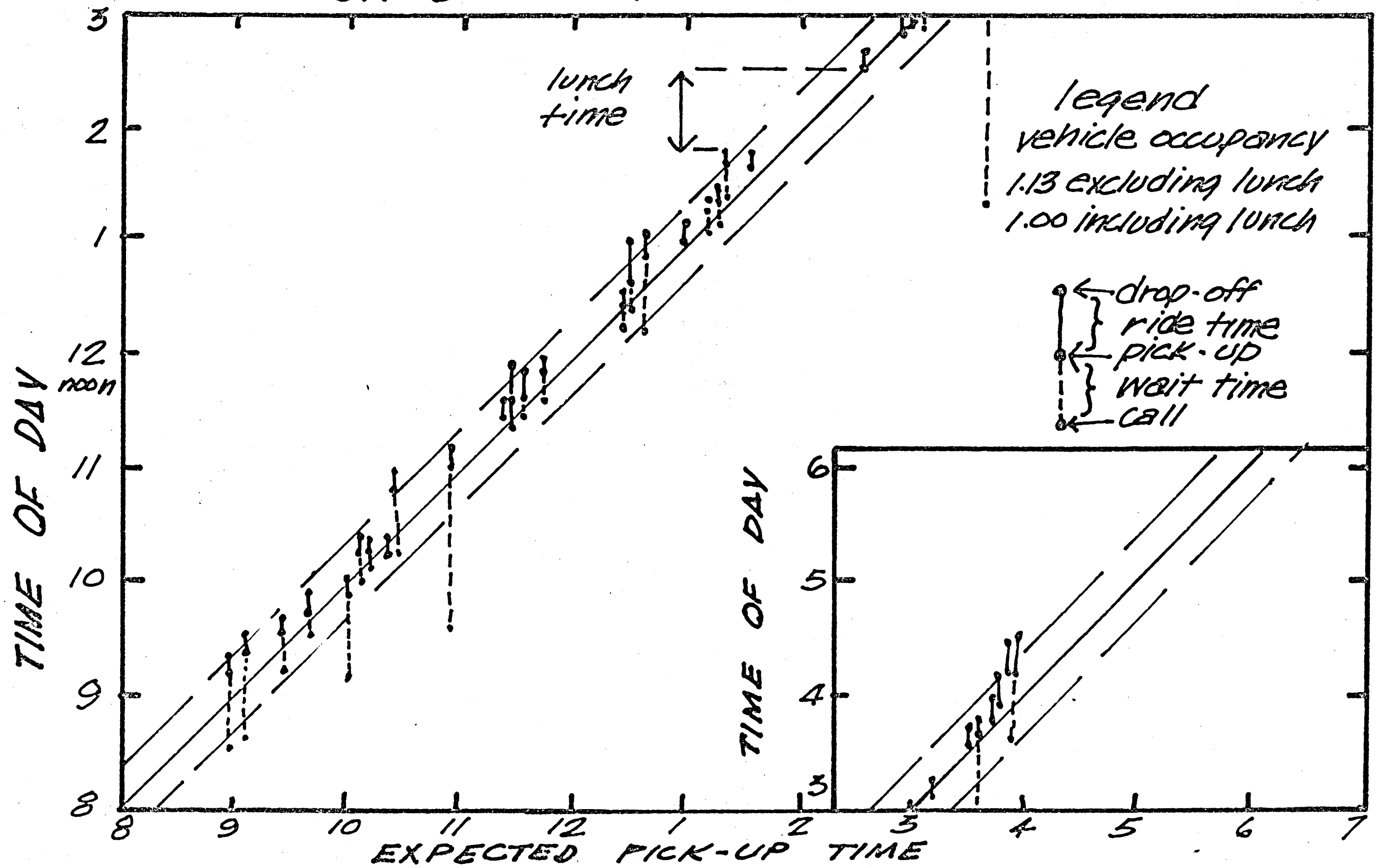


FIGURE VII-7

RIDERSHIP ON BUS NUMBER 3 COLUMBIA C.A.R.



in three time periods. The tests are also used to uncover any potential bias in the assignment of buses to work.

The first set of statistical tests involved the similarity of the four service time indices* of Table VII-3 within each survey period. Considering the "call to drop-off time" within the second survey, the following statistical testing was employed. Assume that the distribution of the data is normal, then "a difference of means for two normal distributions with known variance" is the problem statement.

In this case the mathematical form is:

$$\left| \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{\frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}}} \right| > Z_{\alpha/2}$$

where $\bar{X}_i$ = the mean of observation group

n = number of observations in group

σ_i = standard deviation of group

Z = standard normal

α = level of significance, the probability of a type I error, the rejection of a valid answer when a valid answer is present.

The foregoing equation is interpreted as:

if $\bar{X}_1 - \bar{X}_2$ does satisfy the above equation then $\bar{X}_1$ does differ significantly from $\bar{X}_2$ at 100α percent level of significance.

*The service time indices are:
1. Time request call received until the time the patron is dropped off.
2. Actual time of pick-up until the time the patron is dropped off.
3. Estimated time of pick-up until the time the patron is dropped off.
4. Estimated time of pick-up and the actual time of pick-up.

TABLE VII - 3

CALL-A-RIDE SERVICE CHARACTERISTICS

DATA SOURCE			SERVICE TIME INDICES											
			Call to** Drop-off			Actual Pick-Up to Drop-off			Estimated Pick-Up to Drop-off			-Estimated Pick-Up +Actual Pick-Up		
			n*	$\bar{X}$*	σ*	n	$\bar{X}$	σ	n	$\bar{X}$	σ	n	$\bar{X}$	σ
MAY SURVEY	Bus No.	1	47	76	47.7	63	21	18.7	60	25	33.0	60	-4	29.4
		2	51	62	54.3	71	18	18.7	66	23	23.8	66	-5	17.4
		3	23	71	97.6	32	18	19.5	30	22	26.1	30	-4	17.9
CAR LOG BOOK	Day	1	64	58	71.5	80	17	21.0	80	12	23.6	80	4	16.0
		2	59	75	102.3	72	11	13.5	72	16	20.2	72	-5	21.9
NIGHT	Bus No.	1	7	35	51.9	7	9	14.2	7	13	14.7	7	-3	13.1
		2	8	41	19.1	8	13	13.4	8	28	11.3	8	-14	8.9

* n = total number of observations

$\bar{X}$ = mean time in minutes

σ = standard deviation in minutes

**Includes only those serviced requests which telephoned for service

Using the numerical example for buses 1 and 2 in survey 2 the equation becomes:

$$\left| \frac{76-62}{\sqrt{\frac{47.7^2}{47} + \frac{54.3^2}{51}}} \right| = \frac{14}{\sqrt{48+57}} = 1.36$$

$$Z_{\frac{0.05}{2}} = 1.96 > 1.36$$

$\therefore \overline{X_1}$ and $\overline{X_2}$ are not different at the 95 percent level of significance.

This process was repeated for each pair of buses within each of the four service time indices. The result was that no difference existed between the average service time indices for any buses. Thus no buses appear to be dispatched or handled differently.

Continuing this type of analysis to a comparison of the log book, Day 1 and 2 service gave similar results. There was no difference between the mean service time indices at a 95 percent level of significance on two service days spaced one month apart. This implies a certain stability existed within this dispatching function. A similar set of calculations for the two buses on night service indicated a level of similarity corresponding with that already presented. The dispatching had advanced sufficiently that two days spaced one month apart had essentially similar time service (log book results).

A summary of the statistical tests for similarity within and between groups is shown in Table VII-4. The day time operations, represented by the data from the log book and second survey, are quite similar in the service times. The only difference is in the estimated time of pick-up to actual drop-off time. This represents a time accumulation which includes first a more prevalent delay of the bus (Estimate-Actual pick up is always negative in the second survey) and a slight increase in the actual travel time (Drop-off/Actual pick-up is larger for the second survey).

The night service may be considered substantially different from the two day time services. The night service has an improved level of service as measured by the total time from initiating the service to arriving at the destination. The reliability of pick-up, as measured by the difference of estimated to actual pick-up time, diminished considerably. The high service level probably results from a very low demand such that the service is almost taxi style. The diminished reliability comes about due to inexperienced drivers and a general loss of commitment on the part of the staff after a reorganization of the bus operation during June, 1971.

The bus occupancy* noted on Figures VII-5 through 7 range from a high of 5 to zero. The average occupancy rate for all buses is 1.45 requests per vehicle throughout the day. Figures VII-5 through 7 give an indication of the telephone utilization.

The following is a frequency table of the calls received

*Occupancy is the number of requests assigned to each bus. Actual patron occupancy may run slightly higher.

TABLE VII - 4

SUMMARY OF STATISTICAL ANALYSIS
OF COLUMBIA CALL-A-RIDE
SERVICE TIMES IN THREE TIME PERIODS

		DATA SOURCE		
		LOG BOOK	SECOND SURVEY	NIGHT
LOG BOOK	Call to Drop off	S	*	*
	Actual PU to DO	S	*	*
	Est. PU to DO	S	*	*
	Est. PU to Act. PU	S	*	*
SECOND SURVEY	Call to Drop off	S	S	*
	Act. PU to DO	S	S	*
	Est. PU to DO	D	S	*
	Est. PU to Act. PU	S	S	*
NIGHT	Call to Drop off	D	D	S
	Actual PU to DO	S	S	S
	Est. PU to DO	D	S	S
	Est. PU to Act. PU	D	D	S

S = Similar D = Different

PU = Pick up time of patron

DO = Drop-off time of patron

Call = Time request for service call received from 8.30 a.m. to 3 p.m.

Number of calls per 10 minutes	0	1	2	3	4	5
Observed frequency	11	11	7	7	5	2

These calls include those requesting service which were cancelled after being given the expected pick-up time. These calls require dispatcher decisions on service and thus place demands on the dispatching function. Not included are calls for weekly service or other inquiries which are also handled by the Dial-A-Bus switchboard. The average number of calls per ten minute interval is 1.78 calls ($\bar{X}$) and a standard deviation (σ) of 1.37 calls/ten minutes. If $\bar{X}+2\sigma$ is considered a good level of anticipated telephone calls, then 4.52 calls per ten minutes should be expected. If the 4.52 calls per ten minutes is sustained through one hour there is a total of 27 calls for service. Assuming that all these calls can be serviced then the hourly productivity of each bus would be 9 requests per hour. This is the lower level of productivity suggested by the C.A.R. Project of the Massachusetts Institute of Technology (2). Columbia C.A.R. during the time period of this analysis (8.30 a.m. to 3 p.m.) approached the MIT productivity only 15 percent of the time.

The conclusion of the time analysis in Columbia may be summarized as, first, the time service levels over time and among buses appears to be quite similar. The evening service offered after reorganization of the bus company does differ significantly from the previous observed day time service. The vehicle occupancy averaged only 1.4 patrons per vehicle. It would appear that very quickly any telephone switchboard will become swamped if a system is composed of only demand calls and productivities approach those suggested by MIT. Every effort should be made to pre-register calls at slack times or through a switchboard not directly associated with immediate operations.

Spatial Distribution

The spatial distribution of transit demand in Columbia is related to work and shopping purposes as well as medical trip purposes*. The unique medical insurance services offered in Columbia through the John Hopkins Medical Organization makes the medical clinic a high trip generator (3). The medical center attracts upwards of 7 percent of all the transit trips. The probability** of a serviced demand for Dial-A-Bus for two successive days is shown in Figure VII-8. The locations which stand out as having the probability a demand greater than 0.5 are the shopping-work complex of the village center, downtown, the medical clinic, and the two colleges***.

The low transit use in the remaining area of Running Brook and East of Highway 29 may be explained by their auto orientation and poor service respectively. Running Brook is a medium to high income area, styled for the most part on a typical suburb. The one high use area includes a convenience store and a garden

*See Table V-5 for the proportion of Call-A-Ride trip purposes.

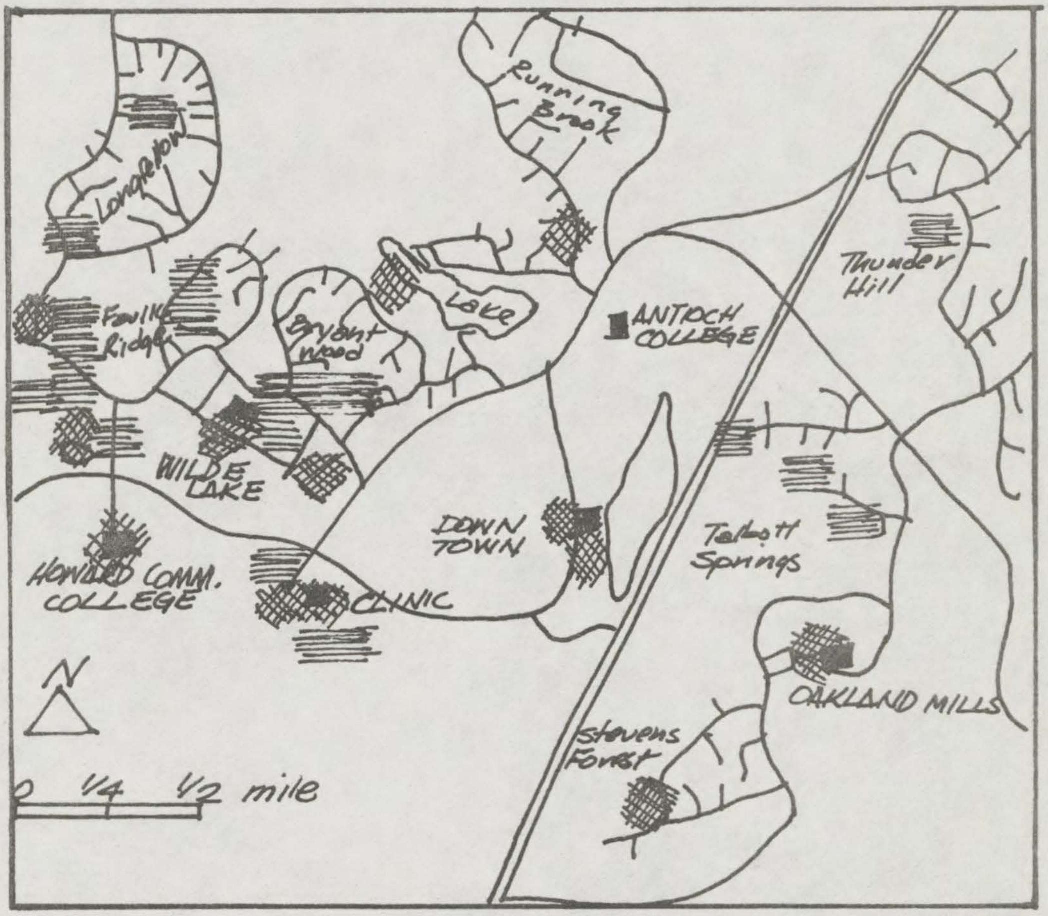
**The probability of a serviced demand is defined as the sum of the one hour periods with at least one request divided by 10 hours and then averaged for the two successive days.

***Howard County Community College and the Columbia Campus of Antioch College.

FIGURE VII-8

PROBABILITY* OF A SERVICED CALL-A-RIDE REQUEST ON TWO SUCCESSIVE DAYS

COLUMBIA MARYLAND SUMMER 1970



* [crosshatched] probability ≥ 0.5 for a serviced request on 2 days at the same hour

[lined] probability < 0.5 but > 0.20

[empty box] no trips sampled over the 2 days apartment complex. The area East of Highway 29 had poor service since all access had to be gained via the road north of Antioch College on the northwest to southeast alignment. This intersection had traffic signals and, since the bus company was licenced with the Maryland Public Services Commission, the operator felt obliged to minimize the possibility of an accident crossing Highway 29 by using the safest crossing at all times. Also the dispatchers would give an expected pick-up time one hour in advance unless a vehicle was already on the east of Highway 29.* The two high use areas east of Highway 29 are a village center and a model home sales area in Steven's Forest.

The destination end of trips appear to concentrate a few selected nodes which are well defined. The home end of many trips appears to be less defined but the majority are within areas of high residential density and often low income rental areas (3).

Travel Patterns of a Three Bus Fleet

The final spatial characteristic analysed is the travel pattern of the three bus fleet on a day in May, 1970. A trace of the travel pattern of one bus for the first seven and a half hours of a twelve and one half hour service day is shown in Figure VII-9. This graph reinforces the focal locations in the Columbia transit system as being the two village centers and the clinic. While many of the trips going to the Wilde Lake Village center are short,

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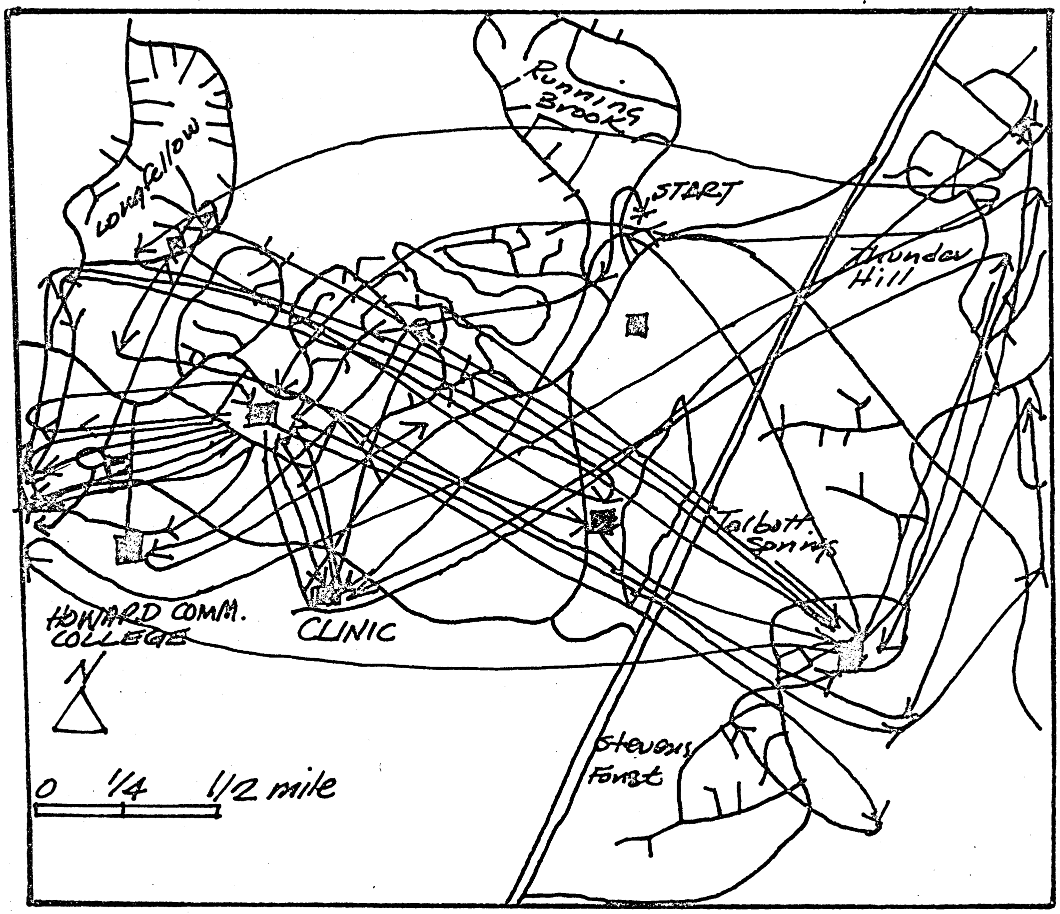
*When questioned about this policy they said it took that long to free a bus and have it in the best position to service the area east of Highway 29. They tried to tie in all these requests with standing calls.

FIGURE VII-9

CALL-A-RIDE PATH FOR A 7 1/2 HOUR TOUR

COLUMBIA MARYLAND
SUMMER 1970



* start point in Running Brook

**44 trips between 0830 and 1800, May 1970 those going to the clinic and the Oakland Mills Center are long. The shortness of the trip may in fact account for the low vehicle occupancy noted earlier in this chapter. The longer the trip length the more probable the vehicle will be shared and thus a higher vehicle occupancy. Another surprising result of the vehicle path shown in Figure VII-9 is the frequency with which this vehicle serviced the area to the east of Highway 29.

The bus made 8 trips across to Oakland Mills and serviced a number of trips originating and terminating within the Oakland Mills area. The use of this figure is too difficult for analysis.

To pursue the travel patterns of the three buses further a traffic analysis zone system was devised for Columbia. The zones were selected such that each major attractor was isolated as well as each of the seven neighbourhoods. The maps showing the zonal boundaries and an identifying number is shown in Figure VII-10.

The objective of this pattern analysis is to see if there is any regularity or similarity within each bus pattern or between the pattern of each bus. To assist in this analysis a graph of the zones of operation and time of day was drawn. The location of each bus over time was plotted as shown in Figure VII-11. The service offered to the area east of Highway 29 is indicated by the points at operation zones: 12, 13, and 14. For the time period presented a bus appears to go to Oakland Mills each half to three quarters of an hour. The majority of activity is in zone 6, the Wilde Lake Village Center. A visual inspection of the three bus travel patterns in Figure VII-11 reveals no striking

FIGURE VII-10

FOURTEEN TRAFFIC ANALYSIS ZONE MAP

COLUMBIA MARYLAND

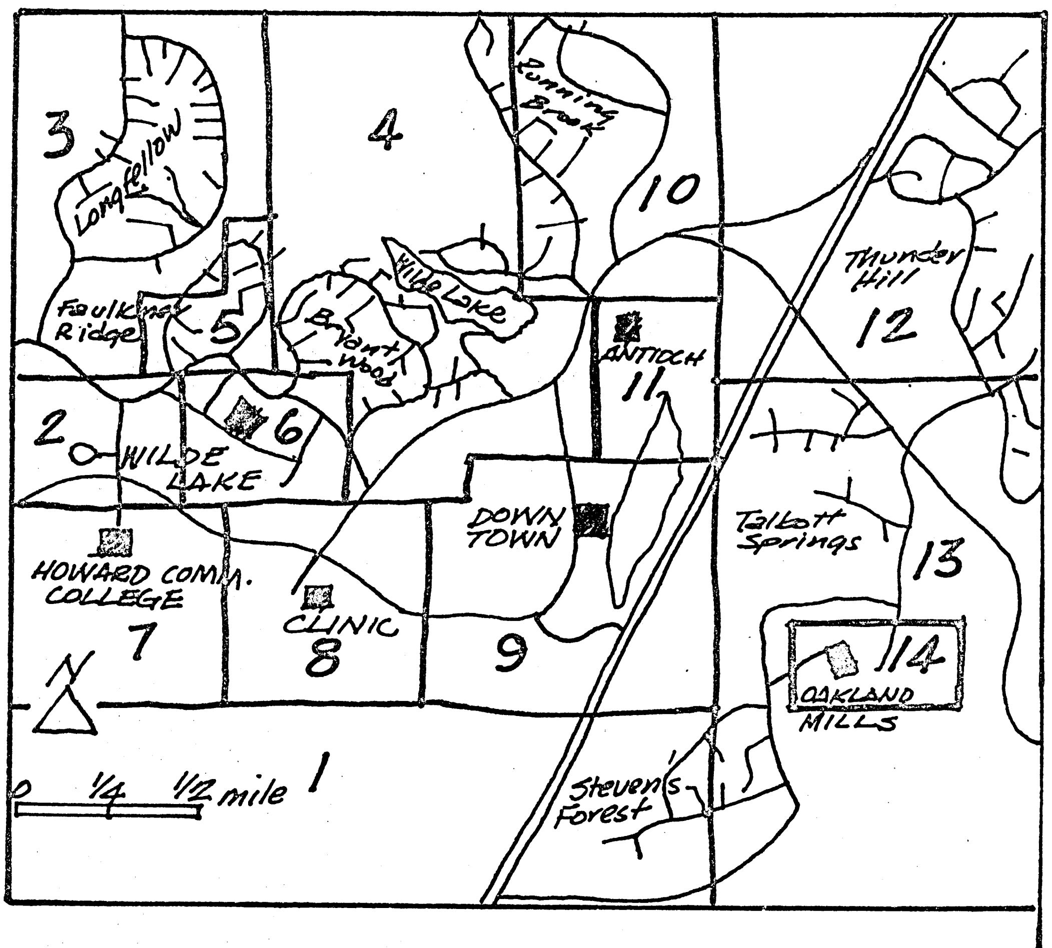
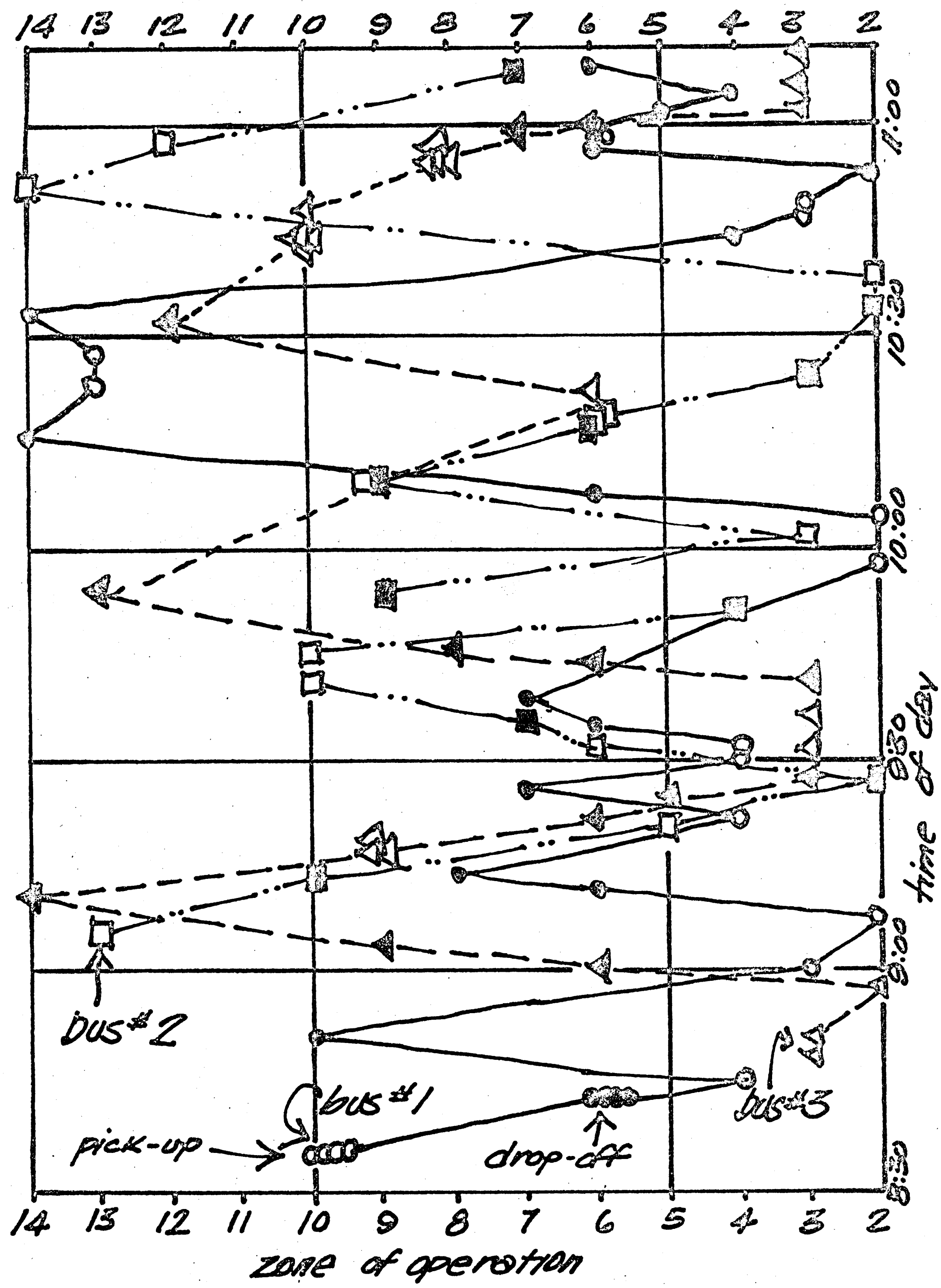


FIGURE VII-11

CALL-A-RIDE TRAVEL PATTERNS IN COLUMBIA



similarity in the deployment of the bus fleet. The operation would appear to be routed as demands occur and that routing does not follow any pattern from one hour to another.

Conclusion

The demand for commuter train oriented Dial-A-Bus Service to Bay Ridges proved to be regular. The regularity was measured in terms of the location of the origin of the trip, similarity between days of the week, and the same day for successive weeks. The limits of the data and the resulting testing methodology do not lend themselves to a direct comparison of each origin for each time period. There was sufficient regularity in the demand pattern to say each day was similar to every other day and that each week was similar to every other week. These findings imply that for commuter oriented trips, a predetermined routing of a demand bus is possible and that the routing will at best be correct 90 percent of the time.

The spatial and temporal analysis of Columbia's many-to-many Call-A-Ride pointed out the importance of a few locations in the city. The locations which focused transit trips in Columbia were the two village centers, the community college and the medical clinic. A temporal analysis of selected service time indicators, such as the time a request was received to drop-off at a destination, and others noted in Table VII-4, showed that the service level for daytime bus service remained fairly constant in Columbia. The night time service was considerably different. The service indicators associated with any particular bus or a succession of days were also similar. A further investigation of the traverse for each bus travelling through the system for a three hour period, indicated that each bus was routed differently.

The Columbia data did show that the number of telephone calls they could expect is in the order of 27 serviced request calls per hour. Assuming that an additional ten percent of calls are information or cancelled requests, then 30 calls per hour can be expected. This was experienced with a three bus fleet, if the fleet were doubled in size then the telephone exchange could become a bottle-neck in the provision of demand bus service. This observation points to the need of arranging a service which will minimize the need to use the telephone exchange. This last need lends itself to a system of more regularity.

REFERENCES

1. Gutterman, I., S. Wilks, Introductory Engineering Statistics, John Wiley, 1965.

2. Altshuler, A., Roos, D., Dial-A-Bus, Advanced Urban Transportation Systems, Transportation Research Institute, Carnegie-Mellon University, May 1970.

3. Bartolo, R., F. Navin, Demand Transit: Columbia's Experience with Call-A-Ride, presented at the American Institute of Planners, San Francisco, October 1971.

Chapter VIII

GENERAL DEMAND RELATIONSHIP

Introduction

This chapter ties together the ideas presented in Chapters IV and VI, Modal Choice Models and Transit Attitudes. The major concern of this chapter is to develop an analytical tool capable of explaining the growth in ridership experienced by various demand transit systems. The first step is the development and presentation of the inter-relationship between the various time components of trip making by public transit. These relationships are then used to develop a more systematic sensitive mode choice model.

The mode choice ridership relationship to be developed has the form:

$$\text{Percent Transit} = f(U_T - U_A)$$

where: $$U_T = a \cdot t_{W1} + b \cdot t_W + c \cdot t_t + d \cdot t_r + e \cdot t_{W2} + f \cdot \text{fare}$$

and $$U_A = A(g \cdot a_{W1} + a_r + h \cdot a_{W2}) + i \cdot \left(\begin{array}{c}\text{out-of} \\ \text{pocket} \\ \text{cost}\end{array}\right)$$

where:

U_T = transit disutility.

U_A = automobile disutility.

a_{W1}, t_{W1} = walk time to mode.
(a for auto time, t for transit)

t_W = wait time for bus.

a_r, t_r = in-vehicle ride time. (a for auto, t for transit)

t_t = transfer time.

a_{w2}, t_{w2} = walk time from mode. (a for auto time, t for transit)

a, b, c, d, e = transformation weights for transit times to put them into in-vehicle travel time.

g, h = transformation weights for auto-excess time to be expressed as in-auto time.

f, i = transformation weights to relate travel costs to in-auto travel time.

A = a factor to transform automobile disutility units into "in-transit time/minutes" disutility units.

This chapter has as an objective the quantification of the transformation a,b,c,d, and e. The values of f and i have been well studied by Thomas et al (8,9) and were explained in Chapter IV. Two distinct steps are involved in the process of quantification. The first step involves relating a,b,c,d and e as equations among themselves. This sets up the disutility proportioning of time as viewed only "within" the transit mode. At this point all the times can be expressed as "in-transit vehicle" travel time and the disutility equation, U_T would have units of "in-transit vehicle minutes".

The next step requires making the travel time by automobile compare to that by bus. Thus the equation to be generated in this chapter relates the individual elements of the travel time within each mode and between the auto-bus mode.

Deficiencies of Existing Mode Choice Models

The utility mode choice models as theorized by Pratt (1), and applied by Shunk (2) and Navin (3), are subject to limitations for small area transit analysis. The limitations concern the base measure of utility and the relative weight to be assigned to the time components of trip making. The models as developed and applied, group all the time spent outside the vehicle together in a single unit of excess time. The original rationale for this procedure was a combination of data limitations and model development costs. In addition, no attempt had been made to investigate the inter-relationship between the various components of the excess time.

The elements of transit tripmaking involve those essentially under the control of the user and others under the control of the transit operator. The user may associate varying degrees of certainty with each event. There is also the amount of comfort or effort required by the user which may influence the weighting of the various time components of a trip.

The user is well aware of the length of time required to walk from the home to a bus stop. The comfort associated with such a walk is associated with the environment and thus has a degree of uncertainty. The time waiting for a bus is uncertain since it depends on the schedule adherence of the drivers, reliability of the equipment and the weather. Similar to walking, the comfort associated with waiting is also variable and uncertain. The ride time in a bus is usually fairly comfortable compared to walking but is generally conceded to be somewhat less comfortable and pleasant than the ride in a private automobile. The amount of time riding is only a little more uncertain than the time driving an automobile since many of the same congestion features affect both modes.

The time spent transferring is probably the most uncertain element of an entire trip since it involves the probability associated with the first bus and the probability associated with the second bus, thus the uncertainties are multiplied. The comfort associated with a transfer may be concerned with the facility provided at the transfer point. Thus a terminal building is more comfortable than a street corner. Finally, the time spent walking from the bus to a destination is usually well known and has essentially no uncertainty, also the comfort is usually similar to the initial walk.

The two events having most uncertainty, waiting for a vehicle and transferring, are associated with public transit travel and do not occur with the automobile.

The next section employs an array of data in an attempt to gain orders of magnitude estimates of the inter-relationship between the trip time elements using auto travel time as the common unit.*

*The units used to represent generalized travel costs have been referred to here as "disutilities" and the difference as "disutility difference". There is some confusion concerning the difference between the travel mode disutilities. Quarmby (10)(4) refers to it as "relative disutility" and Shunk (2) refers to the same procedure as "marginal disutility". I have called the sum of general travel costs "disutility" and the difference simply as the "disutility difference".

Relationship Between Elements of Transit Tripmaking

Methodology

The data used comes from a number of sources and are available only in graphical summaries relating the percentage using transit to some component time of a transit trip. Figure VIII-1 is a hypothetical example of a data source. The dashed lines are hand fitted linear equations assumed to be reasonably accurate representations of the data. The vertical axis is the percentage transit. The horizontal axis is time in units of say, minutes. Let X1 represent total travel time and X2 the first wait time for a transit vehicle. The average handfitted equation for each is given by:

$$PT(X1) = A - B \cdot X1$$
$$PT(X2) = C - D \cdot X2$$

$$A, C =$$
$$X1, X2 =$$
$$PT =$$

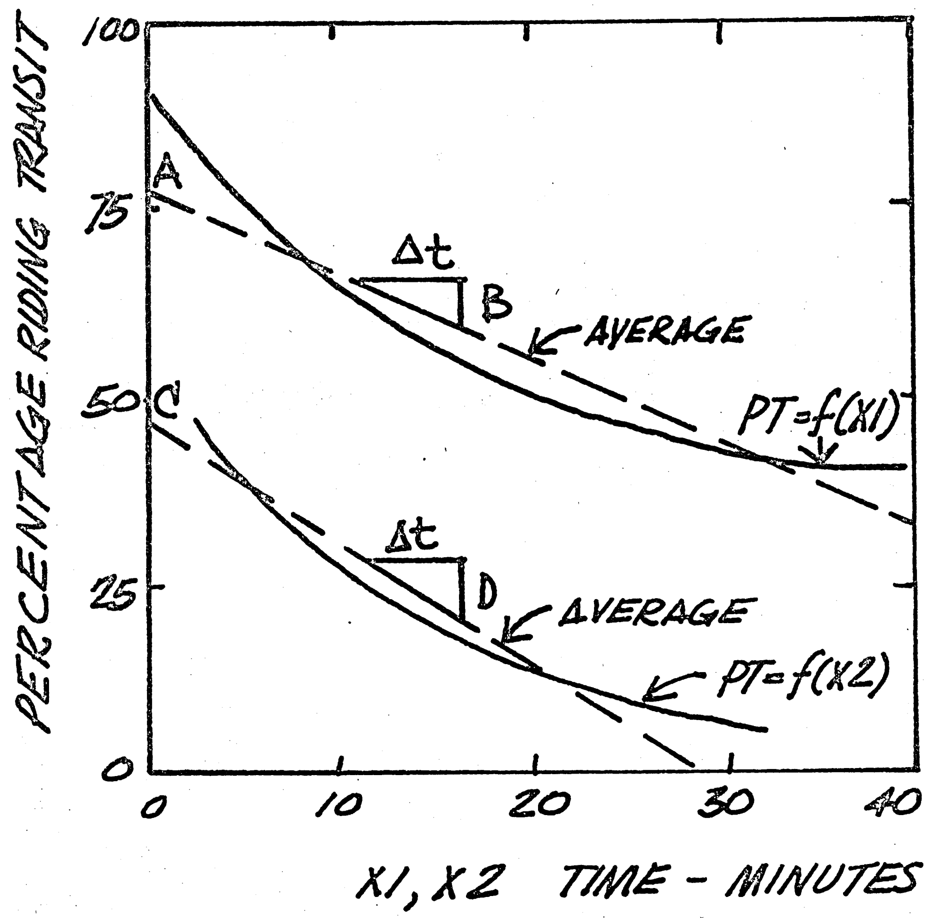
From Figure VIII-1 it may be seen that a small increase in X2 results in a much greater decrease in percentage transit than a similar change in X1. Using a small difference along the time scale gives for X1:

$$PT(X1)_{X1=t} = A - B \cdot X1_{X1=t}$$

$$X1 = t + \Delta t$$
$$PT(X1)_{X1=t+\Delta t} = A - B \cdot X1_{X1=t+\Delta t}$$

FIGURE VIII-1

HYPOTHETICAL INFLUENCE OF TWO TRAVEL TIMES ON THE PERCENT TRANSIT



$$PT(X1) = A + B \cdot X1$$
$$PT(X2) = C + D \cdot X2$$

$$\Delta PT(X1) = -B \cdot (\Delta X1)$$

$$\Delta PT(X1) = PT(X1)_{X1=t} - PT(X1)_{X1=t+\Delta t}$$

$$\Delta X(1) = (X1)_{X1=t} - (X1)_{X1=t+\Delta t}$$

The Δ is small change in X1 and the resulting change in PT(X1).

The relationship is only valid for small changes within the limits appropriate for the range of the linearized function. A similar set of mathematics may be used to show that

$$\Delta PT(X2) = -D \cdot \Delta X2$$

The constants, A and C, eliminated from the equations represent area specific values. Eliminating the constants implies that "the shape" of the curves is most important. The shape is represented by the slopes -B and -D. Using the ratio of X1 and X2 a relationship between the two variables may be developed as follows:

$$\frac{\Delta PT(X1)}{\Delta PT(X2)} = \frac{B \cdot \Delta X1}{D \cdot \Delta X2}$$

$$\Delta PT(X1) = \Delta PT(X2) = 1$$

$$\frac{1}{1} = \frac{B \cdot \Delta X1}{D \cdot \Delta X2}$$

$$\Delta X2 = \frac{B}{D} \cdot \Delta X1$$

This last equation states:

"An equal change in ridership may be achieved by a change of one unit of X1 or $\left(\frac{B}{D} \cdot 1\right)$ units of X2."

For example, assume that the value of D is 1.4 and B is 0.9, then

$$\Delta X2 = \frac{0.9}{1.4}\Delta X1 = 0.66\Delta X1$$

Thus a change of one minute in X1 has a similar impact on transit ridership as a 0.66 (approximately 2/3 minutes) change in X2.

This may be stated in another way. A potential patron of a transit system views 2/3 minutes of X2 time as being similar to one minute of X1 time. If the travel time components X1 and X2 are to be brought into common units as viewed by the potential rider then he may think of:

One minute of X1 as 1(X1 units)

and One minute of X2 as 1.5(X1 units)*

and 2 minutes of X1 as 2(X1 units)

and 2 minutes of X2 as 1.5(2)(X1 units)

or 3(X1 units)

Thus to get X2 into X1 units the value of X2 must be increased by 1.5 to reflect its influence on transit ridership. This represents a conversion to common time cost units, in this case X1 units, for transit ridership. This simple methodology is used throughout the following analysis and augmented with additional data and judgements.

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*The value of 1.5 comes from 1/0.66 = 1.5 or $\Delta X1 = 1.5\Delta X2$, this equation puts X2 values of time into X1 units.

Within the Transit Mode

A trip by public transit involves time spent riding in a vehicle (t_r) and time spent outside the vehicle, usually referred to as excess time (t_e). The excess time is composed of time spent walking to the bus (t_{w1}) and from the bus (t_{w2}), time spent waiting (t_w), and time spent transferring (t_t).

The following equation is based on work trip information from Chicago (4) and relates the percentage transit to the first wait time, see Figure IV-e*.

$$PT(t_W) = 45 - 1.45\, t_W$$

where $PT(t_W) =$

$t_W =$

The influence of total travel time on the percent transit is given by:

$$PT(t_T) = 75 - 0.95\, t_T \quad (0 < t_T < 40 \text{ minutes})$$

where t_T = total transit travel time in minutes which includes walking, waiting, transferring and in-vehicle travel.

The slopes of the lines represent the rate of ridership loss with each minute of transit waiting or total travel time. Since this study deals with local bus service and small cities, the total transit trip less than 40 minutes is used. The ratio

*The data sources have nothing about the accuracy or precision of the original curves. The equations used by the author are hand fitted approximations. This method of analysis is justified by the multiplicity of data sources and objective of the analysis. The objective of the analysis being to quantify the transformation weights used in the utility type mode choice models.

of the two slopes, as developed in the Methodology Section, gives an approximate relationship between the two times: first wait and total transit travel, thus:

Let $X2 = t_T , \quad X1 = t_W$

and using

$$\Delta X2 = \frac{B}{D} \cdot \Delta X1$$

$$\Delta t_T = \frac{1.45}{0.95} \Delta t_W$$

Using equation 1 yields

$$\Delta t_T = 1.5 \Delta t_W$$

Let $\Delta t_T = \Delta (t_e + t_r)$

For short trips assume the ridership is governed only by the excess time and that the ride times influence approaches zero, thus:

$$\Delta t_T = \Delta (t_e + 0) = 1.5 \Delta t_W$$

$$\Delta t_W = 0.66 \Delta t_e$$

This last equation states that one minute of total excess time is similar to .66 minutes spent waiting for a bus. The total excess time is proportioned between walking, waiting, and transferring. The remaining relationships for walking, transferring and in-vehicle ride time will be expressed in terms of total excess time t_e. The next step is to express the transferring time in terms of total excess time. Unpublished data from the 1956* Toronto (Canada) Transportation Study (5) gave the following percent transit associated with the transit excess times

*Figure IV-6, is the graph of these curves.

$$PT(t_e) = 100 - 3.45\,t_e$$

$$PT(t_{w1}, t_{w}) = 85 - 2.8(t_{w1} + t_w)$$

$$PT(t_t, t_{w2}) = 90 - 4.5(t_t + t_{w2})$$

where: t_e = the total excess time

t_{w1} = the walk time to the bus

t_w = the first wait time

t_t = the transfer time, and

t_{w2} = the walk from the last bus

To reduce the equation 7 into a form which will give a useful result the time spent transferring and walking must be proportioned. Assume that, on the average, for each minute transferring two minutes is spent walking at the destination. Thus the relationship between equations 5 and 7 is:

$$\Delta(t_t + t_{w2}) = \frac{3.45}{4.50}\,\Delta t_e$$

and becomes:

$$\Delta(3t_t) = 0.77\,\Delta t_e$$

$$\Delta t_t = 0.26\,\Delta t_e$$

This may be translated as a one minute change in total excess time is similar to a 0.26 minute change in the transfer time. A one minute transfer change is similar to 3.9 minutes of total excess time change.

To relate walking to excess time these steps were followed. First, a relationship is possible using the Toronto data which gives the percentage transit as a function of the total excess time.

$$\Delta T(t_e) = 100 - 3.45\, t_e$$

$$\Delta(t_{W1} + t_W) = \frac{3.45}{2.8}\, \Delta t_e$$

allowing for a high quality of reliable transit service, one may assume that t_W approaches zero, thus

$$\Delta(t_{W1}) = \frac{3.45}{2.8}\, \Delta t_e$$

$$= 1.23\, \Delta t_e$$

Thus a one minute change in total excess time is similar to a 1.23 minute change in the first walk time.

An additional assumption must be made, that is, the influence of a minute spent walking, be it at the start or end of a transit trip, has the same influence on transit ridership. Therefore

$$\Delta t_{W1} = \Delta t_{W2} = 1.23\, \Delta t_e$$

The relationship between the total excess time and the components must now be placed into an equation such that they all have the same "equivalent minutes". In this case the equivalent minutes unit is total excess time. Thus the equation is:

walking time in "excess time minutes" + waiting time in "excess time minutes" + transferring time in "excess time minutes".

Using equation 14 above

$$\Delta t_e = 0.81\, \Delta t_{W1}$$

The walking time component of total excess time should be multiplied by 0.81 to get it into units of "excess time minutes".

Similarly using equations 4 and 10:

for waiting time is:

$$\Delta t_e = 1.5 \Delta t_W$$

and for transferring time is:

$$\Delta t_e = 3.85 \Delta t_t$$

and the expression for total excess time in "equivalent excess time minutes" is given by:

$$0.81 \Delta t_{W1} + 1.5 \Delta t_W + 3.85 \Delta t_t$$

This expression must now be modified by a constant amount to reflect the relative importance of "excess time" to "in-vehicle ride time". The process requires one additional assumption to develop a useful transit disutility function. Lisco (6) in his study, a Commuter's Value of Time, found that an auto driver perceived walking time as being 3 times more important than driving time. Similarly, Pratt (7), the author and others have successfully calibrated modal choice models with an excess time weight of 2.5. To provide for a conservative result assume that transit patrons view excess time as 2.5 more important than in-vehicle transit travel. Mathematically this becomes:

$$\Delta t_r = 2.5 t_e$$

where Δt_r = a change in transit riding time.

The "within transit" transformation weights for the disutility equation may now be summarized in terms of "in-transit-vehicle" ride time.

To translate equation 15 from "equivalent excess time minutes" to "in-transit-vehicle ride minutes" equation 15 must be multiplied by 2.5 and Δt_r add. Thus the equation "within the transit mode" placing all time components into common units is:

$$2.5(0.81\Delta t_{W1} + 1.5\Delta t_{W} + 3.85\Delta t_{t} + 0.81\Delta t_{W2}) + t_{r}$$

The sign may be dropped if the equation is going to be used to compare changing operating conditions. Also the values generated in this analysis are for short transit trips within the North American urban area as shown in the graphs used to develop the values. The transformation values used to get all the time values into a common unit of "in-vehicle ride time" may now be used in the transit disutility equation presented in the chapter introduction.

$$U_T = 2.05\, t_{W1} + 3.76\, t_{W} + 9.60\, t_{t} + t_{r} + 2.05\, t_{W2} + f.(\text{fare})$$

Equation 17 states that one minute spent walking is similar to 2.05 minutes riding in a bus. Similarly 3.76 minutes riding has the same influence on ridership as one minute waiting. A change of one minute in transferring is valued at approximately 9.60 minutes riding. Table VIII-1 has results for the relative value of travel time. These tabled values correspond with the constants in equation 17. Equation 17 generally places less stress, a smaller coefficient, on walking a higher value on waiting and a much higher value on transferring. The differences between the results is probably indicative of North American attitudes towards the transit travel time components.

The relative value of travel time developed by Lisco (6) for auto travel times are used in the Automobile disutility equation. The equation is:

TABLE VIII - 1

RELATIVE VALUE OF TRAVEL TIME

Time Component	French Transit IAURP[11]	British Transit LGORU[12] LP*	M	LE	LO	Australian Transit Hensher[13]	U.S.A. Pratt[1]	car** Lisco[6]
In-Vehicle	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Walking time	1.75	2.90	2.60	2.50	3.50	1.50	-	3.00
Transfer	2.00	-	-	-	-	-	2.50	-
Waiting time	3.00	1.60	3.60	2.50	3.00	2.00	-	-

*LP = Liverpool

M = Manchester

LE = Leicester

LO = Leeds

**within the automobile Mode only

$$U_A = A\,(3.00\,a_{W1} + a_r + 3.00\,a_{W2}) + f\cdot(\text{out-of-pocket costs})$$

The next step is to obtain a reasonable value of A in equation 18 and thus get the bus and automobile travel time into comparable units of in-transit vehicle minutes.

Transit-Automobile Relationship

Most authors of modal choice models have assumed that the time spent in any vehicle is similar to the time spent in any other vehicle. They have implied that a minute spent in the automobile is considered as equal to a minute in a bus. No direct accounting has been attempted to relate the comfort and privacy differences between the modes.

The attitude studies in both Warren and Columbia gave a relationship between transit and auto riding times that was shown in Figures VI-8 and VI-9. The relative time ratio of transit to auto that should be employed is that ratio which neither favours nor penalizes transit.

The following ratio values of in-vehicle transit time t_r, to in-auto time a_r, comes from Figure VI-9

- o 5 to 10 minute in-auto travel time
  ratio = $t_r/a_r = 2.9$
  or $t_r = 2.9\,a_r$
- o 10 to 20 minutes in-auto travel time
  ratio = $t_r/a_r = 2.1$
  or $t_r = 2.1\,a_r$

o 20 to 30 minutes in-auto travel time

$$\text{ratio} = t_r/a_r = 1.5$$

$$\text{or} \quad t_r = 1.5 a_r$$

At normal suburban travel speeds, or approximately 20 mph, these travel times correspond to 2.3, 4.7 and 8.3 miles of travel. The values of 'a' in equations 20, 21 and 22 form the bridge between the disutility units of "in-transit vehicle minutes" to the disutility units of "in-auto minutes". Thus the value of "A" of the auto disutility equation presented in the introduction can have the values 2.9 through 1.5 depending on the trip length in miles.

The interpretation of equations 20, 21 and 22 is as follows. Assume there is a situation where a ten minute car-ride is anticipated, then a potential Dial-A-Bus user is willing to consider a twenty-one minute ride in a Dial-A-Bus as being similar. In effect he attributes, to the 10 in-auto minutes, a cost similar to twenty-one in-transit minutes. Thus to put both modes into "ride in-transit minutes" requires multiplying the "ride in-auto minutes" by 2.1. The automobile disutility equation becomes for these "medium length trips":

$$U_A = 2.1\left(3.0 a_{W1} + a_r + 3.0 a_{W2}\right) + f\begin{pmatrix}\text{out-of}\\\text{pocket}\\\text{cost}\end{pmatrix}$$

$$= 6.3 a_{W1} + 2.1 a_r + 6.3 a_{W2} + f\begin{pmatrix}\text{out-of}\\\text{pocket}\\\text{cost}\end{pmatrix}$$

Equation 23 preserves the relationship between walking and riding time observed by Lisco. This relationship is that auto drivers are willing to spend up to three times the amount of time driving to save a unit of walking time. The multiple of 2.1 allows for the reaction of potential Dial-A-Bus users to a specified travel time ratio of set trip lengths. Thus equation 23 satisfies both the "within-auto mode" time equivalents and the "dial-a-bus to auto" time equivalents.

Final Transformation Weights

The revised transit disutility and auto to Dial-A-Bus disutility for trip lengths of 5 or more miles may be written as:

$$U_T = 2.05 t_{W1} + 3.76 t_W + 9.60 t_t + t_r + 2.05 t_{W2} + f \cdot \text{fare}$$

$$U_A = 6.30 \partial_{W1} + 2.10 \partial_r + 6.30 \partial_{W2} + f \cdot \text{out-of-pocket cost}$$

(units of: in-transit travel minutes)

Using the other two multiples the transformation values of Table VIII-1 were generated.

The factors developed and presented in Table VIII-2 include in the sampled population all those persons captive to the automobile and transit and thus does not necessarily represent those persons having a true "free choice" of travel mode. The presented values do provide for aggregate analysis of transit systems and can be applied to develop more system sensitive transit service. It may also explain the great increase in ridership experienced by the Dial-A-Ride system in Columbia and Bay Ridges. The next chapter applies the proposed transformation factors to the three demand bus systems presented in Chapter V.

TABLE VIII - 2

TRANSFORMATION VALUES FOR TRIP TIME

Trip Element		TRANSIT	AUTO				
		Within Transit*	Short**	Medium	Long		Within Auto
Walk to mode (a_1, t_{w1})	(a)	2.05	8.70	6.30	4.50	(g)	3.00
Wait for bus (t_w)	(b)	3.76	-	-	-		-
Ride in-vehicle (a_r, t_r)	(d)	1.00	2.90	2.10	1.50		1.00
Bus transfer (t_t)	(c)	9.60	-	-	-		-
Walk from mode (a_{w2}, t_{w2})	(e)	2.05	8.70	6.30	4.50	(h)	3.00
cost***		fare / (1/3 income)					out-of-pocket cost / 1/3 income

* these values may be used when comparing only within the transit mode

** this defines the length of trip in terms of in-auto driving minutes, short = 7 minutes, medium = 15 minutes, long = 20+ minutes.

*** these values come from studies by Thomas(8), Stopher(9) and others.

REFERENCES

1. Pratt, R., "Utilitarian Theory of Travel Mode Choice", Highway Research Record No.322, Highway Research Board, Washington, D.C. 1970.

2. Shunk, G., Bouchard, R., "An Application of Marginal Utility to Travel Mode Choice", Highway Research Record No.322, Highway Research Board, Washington, D.C., 1970.

3. Navin, F., "The Interaction Between Personal Rapid Transit and Demand Activated Bus Transit", Personal Rapid Transit, University of Minnesota, November 1971.

4. Quarmby, D., "Transportation Planning and the Choice of Travel Mode", Report to the Transport Committee of Leeds City Council, Leeds, England, 1966.

5. Unpublished data from the Modal Choice Model developed by D. Hill of Traffic Research Corporation.

6. Lisco, T. "The value of Commuters' Travel Time: A Study in Urban Transportation", Department of Economics, University of Chicago, Ph.D. Thesis, 1967.

7. Pratt, R., Deen, T., "Estimation of Sub-Modal Split within the Transit Mode", Highway Research Record 205, Highway Research Board, Washington, D.C., 1967.

8. Thomas, T., Thompson, G., "The value of Time for Commuting Motorists as a Function of their Income Level and Amount of Time Saved", Highway Research Record No.314, Highway Research Board, Washington, D.C., 1970.

9. Stopher, R., "A Probability Model of Travel Mode Choice for the Work Journey", Highway Research Record No.283. Highway Research Board, Washington, D.C., 1969.

10. Quarmby, D. "The Value of Time Spent in Travelling: Some New Evidence", from The Demand For Travel: Theory and Measurement, Edited by R. Quandt, Heath Lexington Books, 1970.

11. Merlin, P., Barbier, M., "Study of the Modal Split Between Car and Public Transport, Paris", Institute d'Amenagement et d'Urbanisme de la Region Parisienne, 1965.

12. Rogers, K., Townsend, G., Metcalf, A., "Planning for the Work Journey", Reading: Local Government Operational Research Unit, Report No. C67, April 1970.

13. Hensher, D., "The Value of Commuter Travel Time Savings: A Study of Land Modes", Melbourne: Commonwealth Bureau of Roads, May 1971 (unpublished).

Chapter IX

TEST OF THE MODEL

Introduction

The disutility modal choice model developed in Chapter VIII is an interchange mode choice model, that is, individual origin to destination pairs are considered separately. This feature of the model permits preliminary testing of the accuracy of the transformation values. To further verify that the order of magnitude of the transformation factors is correct, some recent work by Quarmby is used.

Comparison with Quarmby's Equation

Quarmby (1) recently published an equation used to develop a modal choice model for a British City. The equation was:

$$\begin{aligned} Z = \; & 0.0787\,(\text{bustime} - 0.327\ \text{car time}) \\ & + 0.0924\,(\text{bus cost} - [\text{car parking cost} + \text{car mileage @ } 3.21d/\text{mile}]) \\ & + 0.579\,(\text{use of car for work}) \\ & + 0.0526\,(\text{bus walking time} + 2.53\ \text{bus waiting time} - 2.23\ \text{car walk time}) \end{aligned} \tag{1}$$

Z = relative disutility of the bus mode compared to the auto mode.

The transit excess time variables, the last elements of equation 1, implies that: 2.53 minutes walking to the bus is similar to one minute waiting for the bus. The value generated from the corresponding values of Table VIII-1 is: three minutes walking is similar to approximately one minute waiting. This is an independent check on the order of magnitude of transit walking to waiting time. The values are sufficiently close, within 17 percent, and therefore may be considered similar particularly in light of the data.

Ridership Increases on Demand-Bus

The ridership experienced on the demand bus systems in Columbia and Bay Ridges was substantial as explained in Chapter V. The ridership went up by a factor of 3.0 to 4.0 in Columbia and by 4.0 to 5.0 in Bay Ridges. The following will test the ability of the proposed model to forecast the change in ridership. To simplify the subsequent arithmetic for this section only the medium length transformation equation will be used. A later section will study the detailed application of the model to Bay Ridges and thus test the sensitivity of the model.

The transit disutility function is: Percent transit $= f(U_T - U_A)$

transit disutility

$$U_T = 2.05 t_{W1} + 6.25 t_W + 1.00 t_r + 9.00 t_t + 2.05 t_{W2} + \frac{\text{fare}}{(1/3 \cdot \text{income})}$$

in-transit vehicle minutes

automobile disutility

$$U_A = 6.30 a_{W1} + 2.10 a_r + 6.30 a_{W2} + \frac{(\text{out-of-pocket cost})}{(1/3 \cdot \text{income})}$$

in-transit vehicle minutes

where

a_{w1}, t_{w1} = walk to mode in minutes

t_w = wait for bus in minutes

a_r, t_r = ride in-vehicle mode, minutes

t_t = transfer time in minutes

fare = transit fare in cents

out-of-pocket = mileage cost in cents of gas and oil plus one half of any parking charges.

income = the annual income expressed in cents per minute, assumed 2000 hours of work equals 120,000 minutes of work.*

Columbia's Experience

To test the sensitivity of the proposed model in a many-to-many dial-a-bus system the Columbia experience and situation may be employed. Under a fixed route and fixed scheduled bus system the ridership was roughly 60 to 80 persons per day. The demand bus system brought the ridership up to 240 persons or an increase of a factor of 4.0 to 3.0.

The unreliable fixed route bus system had the following characteristics.**

t_{w1} = 5 minutes

t_w = 10 minutes

t_r = 15 minutes

t_{w2} = 5 minutes

*As an example, assume a $10,000.00 annual income. This gives a wage of (10,000/2000) $5 per hour or $0.027 per minute. Thus a fare of $0.25 has a disutility value of (0.25/0.0274) 9.2 in-vehicle travel minutes.

**All estimates by the author and the operators of the Columbia bus system.

t_t = 0 minutes

Income = \$10,000 annual income
= 8.3¢/minute

fare = 25¢

The transit disutility is:

$$U_T = 2.05(5+5) + 6.25(10) + 15 + 9.00(0) + \frac{25}{\frac{1}{3}(8.3)}$$

$$= 107.3 \text{ in-transit minutes}$$

and for the new dial-a-ride:

t_{W1} = 1 minute

t_W = 2.5 minutes*

t_r = 18 minutes**

t_{W2} = 1 minute

t_t = 0 minutes

Income = \$10,000 annual income
= 8.3¢/minute

fare = 25¢

$$U_T' = 2.05(1+1) + 6.25(2) + 18 + 9.0(0) + \frac{25}{\frac{1}{3}(8.3)}$$

$$= 50.2 \text{ in-transit minutes}$$

*The relationship between waiting at home or on a street corner is not known. The ratio of 1 to 4 is selected because of the importance expressed in the attitude survey of "protection from weather" and the success experienced in ridership response to the provision of shelters.

**See Table VI-3 for the average ride time during the May 1971 survey of Columbia.

The auto disutility is roughly:

$$\partial_{W1} = 1 \text{ minute}$$

$$\partial_{r} = 4 \text{ minutes}$$

$$\partial_{W2} = 1 \text{ minute}$$

$$C = 15¢ \text{ out-of-pocket}$$

$$U_A = 2.1(3.0(2)+4) + \frac{15}{\frac{1}{3}(8.3)} = 26.5 \text{ in-transit minutes}$$

$$U_d = U_T - U_A = 107.3 - 26.5 = 80.8$$

$$U_d' = U_T' - U_A = 50.2 - 26.5 = 23.7$$

$$\text{RATIO } \frac{U_d}{U_d'} = \frac{80.8}{23.7} = 3.4$$

The ratio of U_d to U_d' is 3.4, approximately the middle of the increase in ridership experienced by Columbia, Maryland. The classical modal choice models as employed by others gave an over-estimate of this ridership ratio. The estimate was 2.7 when 2.5 was used for excess time. This is a low estimate.

Bay Ridges' Experience

Similarly in Bay Ridges the ridership increase with the introduction of dial-a-bus went from 109 to 460 or an average factor increase of 4.2.

The estimated average travel time components for the peak hour in Bay Ridges are:

	Original Transit	Dial-A-Bus	Automobile
Walk to bus (minutes)	3	1	1
Wait for bus (minutes)	5	1.0	0
Ride time (minutes)	8	5	4
Walk from bus (minutes)	1	1	2
Fare	25¢	25¢	13¢
Disutility (in-auto minutes)	$U_T = 56.6$	$U'_T = 25.6$	$U_A = 32.1$

$$U_d = U_T - U_A = 56.6 - 32.1 = 24.5$$

$$U_d' = U_T' - U_A = 25.6 - 32.1 = (-6.5)$$

$$\text{RATIO } \frac{U_d}{U_d'} = \frac{24.5}{|(-6.5)|} = 3.8$$

The ratio of U_d to U'_d is 3.8 which corresponds quite well with the patronage increase multiple of 4.2 experienced by the superior service.

The weighting factors used in the previous mode choice models (excess time weighed at 2.5) were able to explain the relative gains in ridership that are possible by increasing the level of transit service as dramatically as that experienced with dial-a-ride. This model, with the above times and cost, gave an increase ratio of 4.3; close to the 4.2 observed. An explanation for the difference between the proposed model and the old 2.5 model will be explained shortly.

Mansfield, Ohio's Experience

The increase in ridership experienced by Mansfield, Ohio was 25 percent. The following are estimates of the average travel time values of the population affected by the experiment.

Average	Original Service	New Service	Automobile
Walk to bus (minutes)	5	4	1
Wait for bus (minutes)	5	4	0
Ride on bus (minutes)	15	16	5
Transfer (minutes)	2	2	0
Walk from bus (minutes)	5	4	2
Fare (cents)	35	40	35
Disutility (in-auto minutes)	$U_T = 55.7$	$U'_T = 48.3$	$U_A = 41.8$

$U_d = 55.7$ and $U_d' = 48.3$, RATIO $\frac{U_d}{U_d'} = 1.15$

The ratio of the two disutility difference is 55.7/48.3 which equals 1.15 or an expected increase of approximately 15 percent in the ridership. This is similar to the increase in ridership experienced by Mansfield system under the route-deviation dial-a-ride. Using the classical approach with an excess time factor of 2.5 gave an expected ridership increase of 1.49. This is well in excess of the increase experienced along the route.

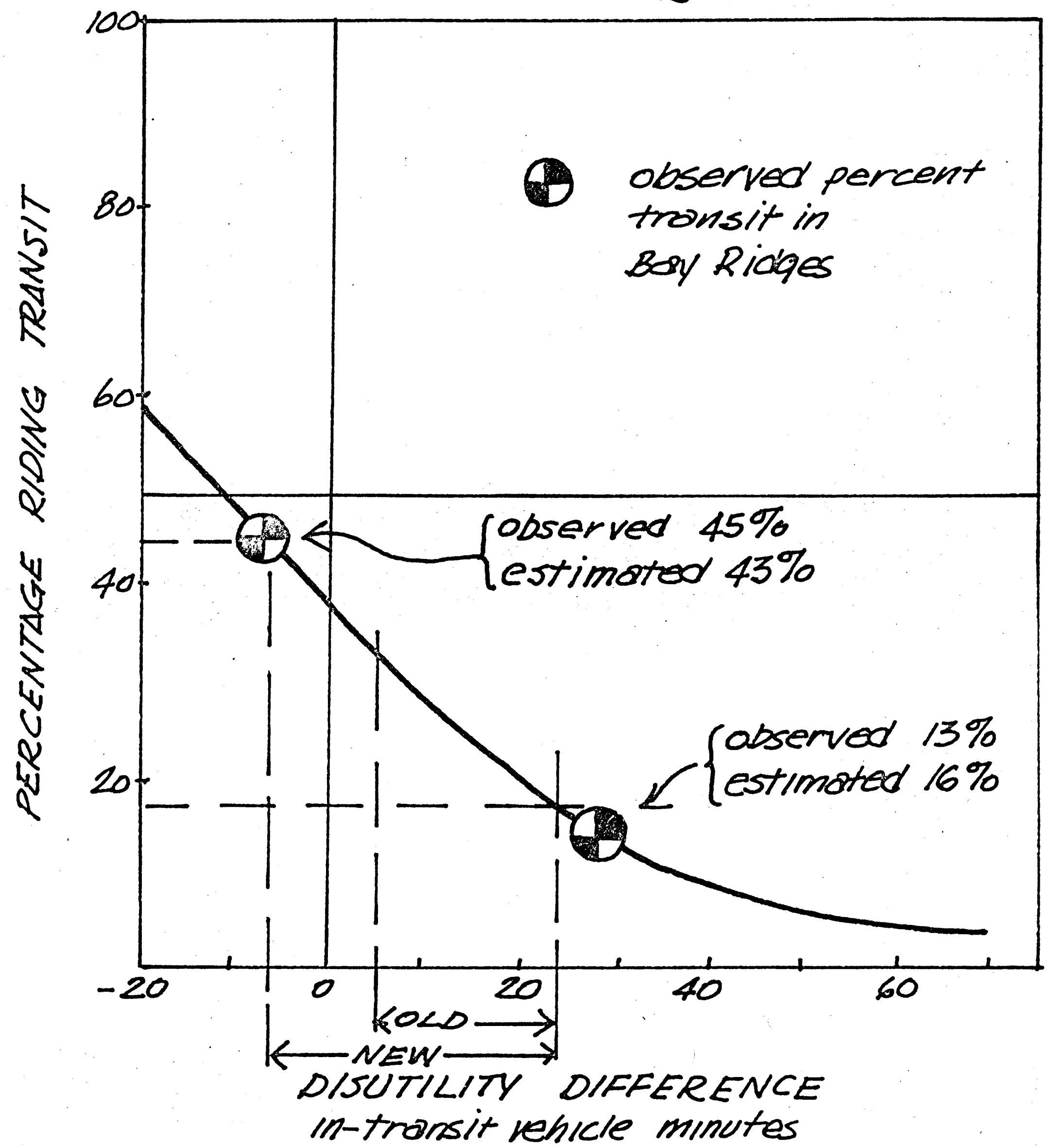
The foregoing are rather crude approximations of the average behavior in the three bus system studies. The fact that the relationship developed can approximate the ridership increases, lends some credibility to the relationship and the time weight generated by a diverse set of data.

Modal Choice Model Experience

To further check on the mode choice model, Figure IX-   is presented. This figure presents a classical mode choice curve developed for "free choice" transit users in Skokie with estimates

FIGURE IX-1

COMPARISON OF OBSERVED AND ESTIMATED PERCENTAGE TRANSIT IN BAY RIDGES



OLD is a shift with a constant 2.5 factor on all excess time

NEW is the proposed model

of the mode choice disutility relationships for Bay Ridges. The increased ridership to be expected using the Skokie curves, are:

Estimated Percent Transit by Routes

	Location	Fixed	Dial-A-Ride
Bay Ridges	Skokie (estimate)	13	42
	Observed	13	45
	2.5 factor	15	35

Increase in ridership estimated by the mode choice curve and the new factors correspond with the results obtained from Bay Ridges.

The results obtained by the constant 2.5 factor on excess time estimated the percent transit for the fixed bus operation but failed to do so for the Dial-A-Bus operation. Therefore the prior test of capability of the new model to estimate ridership was based on its ability to shift the potential disutility difference between the fixed routed transit and Dial-A-Bus. To test this assumption the Columbia data is again used. At a disutility difference of 80.8 the percentage transit is approximately 3 or 4 percent and at a disutility difference of 23.6, the percent transit is 13 to 15 percent. The average of the four possible ratios of percent Dial-A-Bus over percent fixed route is 4.2. This is approximately the high estimate of the resulting ridership increase experienced in Columbia.

This analysis, while not a sufficient proof of the validity of the time weights in the revised mode choice equation, does tend to support the selected weights. Bay Ridges was the only town used in Figure IX-1 since it was the only location with accurate mode choice calibration data.

Conclusions

The first conclusion that comes from the analysis concerns the transformation weights. The time weights for the modal choice model developed in Chapter VIII are indirectly supported by Quarmby's most recent work. The transit weights as represented in the transit disutility (U_T) equation as:

$$U_T = 2.05(t_{W1} + t_{W2}) + 6.25t_W + t_r + 9.00t_t + \frac{fare}{\frac{1}{3}(income)}$$

where

t_{W1} = walk time, origin to bus

t_{W2} = walk time, but to destination

t_W = wait time

t_r = bus run time

t_t = transfer time

income = annual income, cents per minute

fare = transit fare, cents

The automobile disutility (U_A) is given by:

$$U_A = A\,(3.0\,\partial_{W1} + \partial_r + 3.0\,\partial_{W2}) + \frac{C}{\frac{1}{3}(income)}$$

where

∂_{W1} = walk to car

∂_r = walk from car

∂_{W2} = ride time

C = out-of-pocket costs

A = 2.9 for short trips
2.1 for medium trips
1.5 for long trips

The disutility, $U_T - U_A$, was shown to relate well to the Skokie commuter disutility mode choice relationship.

The test use of the equations in the 3 systems are necessary, but not sufficient, to prove the correctness of the weights. The equations do manage to explain the ridership increases experienced by the various dial-a-ride operations presented. Existing mode choice models did not represent the increases in ridership with the same degree of precision.

The relationships developed in Chapter VII and tested here, provide a practical tool for the transit engineer engaged in the detailed analysis of potential demand for local Dial-A-Bus transit.

REFERENCES

1. Quarmby, D., "The Value of Time Spent in Travelling: Some New Evidence", from The Demand for Travel: Theory and Measurement. Edited by R. Quandt, Heath Lexington Books, 1970.

Chapter X

SUMMARY AND CONCLUSIONS

Introduction

This study is a multi-faceted investigation of Demand Responsive Transit. The aim of the study is the development of a theoretical framework and methodology by which suitable demand responsive transit operating policies may be evaluated. To adequately address the many features of this aim, four basic questions have to be answered:

First: What are the important social and economic elements in determining the travel mode?

Second: What are the important transit system characteristics as viewed by the user?

Third: Do transit users and non-users consider the same characteristics equally important?

Fourth: What has been the experience of the transit industry in small urban areas when a demand bus operation has been attempted?

To answer these questions required an extensive review of the literature on modal choice models, transit attitudes, and existing demand bus systems. To augment the data from the literature study, on-site visits to the demand bus operations at Columbia, Maryland and Bay Ridges, Ontario were done during March 1971. The data sources were further expanded by:

1. A summarization and computer coding of selected days of the Columbia Call-A-Ride log books.

2. An on-board Call-A-Ride user survey during May 1971, again during November 1971 and additional bus utilization surveys during 1971 and 1972.

3. An extensive attitude study of Columbia residents towards Call-A-Ride during May 1971.

4. A summarization and computer coding of selected days of the Bay Ridges Dial-A-Bus log books.

The selected observations from the search of the literature, the observed data of surveys and site visits, plus the author's judgement, were combined to produce a modal choice model. This modal choice model is sensitive to minor time changes in the bus operation.

Search of the Literature

The search of the literature on transit attitudes provides the answer to the question concerning model choice determinates. In small communities the use of the existing fixed-routed, fixed-scheduled transit results from the lack of the patron having mobility with an automobile. The search of the literature also indicates that a system sensitive modal choice model is needed for adequate analysis of demand responsive transit. The literature on travel time cost is extensive and well researched. The weakest area of understanding in transit tripmaking is the relative importance of each travel time component. A multiplicity of data sources are used by the author to develop the following transformation weights. The weights change the transit times into equivalent in-vehicle minutes:

o walk time	2.0 to 3.0
o first wait	3.6 to 4.7
o ride time	1.0
o transfer	6.8 to 8.5

Thus a minute spent walking is considered similar to 2.0 - 3.0 minutes riding in a bus.

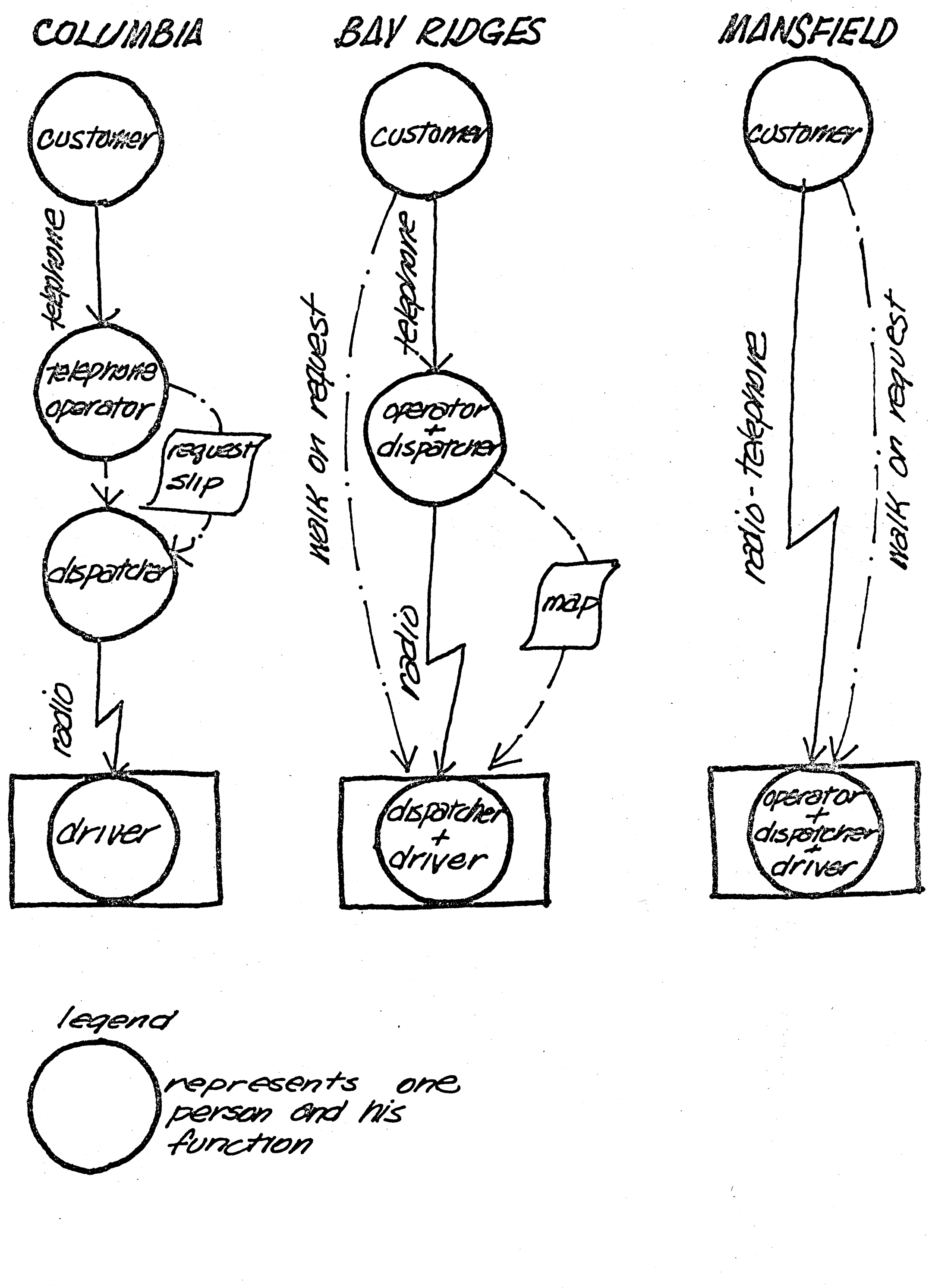
Existing Demand Responsive Transit Systems

Demand Responsive Road Transit, Dial-A-Bus, or Call-A-Ride all operate on the principle of a shared taxi. The patron-vehicle system operates as follows:

1. A patron telephones a system controller stating as minimum information his origin and destination.
2. The transit controller checks the status of the system and gives any conditions associated with the proposed service.
3. The patron accepts or rejects the service, if he accepts, then:
4. A bus is dispatched at the appropriate time to the patron's origin location.
5. The patron boards the bus and then travels in the general direction of his destination while the bus picks up and drops off patrons until it arrives at his destination.

The critical elements of this system are: customers, telephones to the controller, a dispatcher, and a radio link from the dispatcher to the bus. The three demand bus systems investigated are: Columbia, Maryland; Bay Ridges, Ontario; and Mansfield, Ohio. All have these four elements: customer, telephone, bus-radio and dispatcher, but they are arranged in different forms as shown in Figure X-1.

FIGURE X-1
DEMAND BUS COMMUNICATIONS



The dispatching function in Columbia requires 2 persons during the daytime operations, Bay Ridges only one and Mansfield concentrated all functions in the bus driver. The amount of activity required by the dispatchers varied considerably. In Columbia the many-to-many system requires that the majority of requests be handled by the telephone operator and dispatcher. The dispatcher also orders the pick-up and drop-off routine for each bus.

In Bay Ridges the amount of telephone work is reduced by an active policy of prior requests. Also, persons boarding the bus at the commuter train station tell the driver their destination. The dispatcher notes standing calls on a map which he gives to the driver at the start of each run. The driver then arranges his own route according to his knowledge of the area. The only routing constraint is a policy that all drop-offs be completed before any pick-ups could start.

The Mansfield, Ohio system removed the dispatcher and combined all functions in the bus driver. The demand responsive service was offered at a premium over and above the price of the fixed routed service. The driver could accurately state pick-up times because the bus had to maintain a fixed schedule. The number of telephone calls was minimized by having patrons boarding at the city center state that they desired doorstep service to a particular location.

The relative labour efficiencies of the three systems may be seen in the following index: "passengers per total labour hour".

In Mansfield this was 9.8 (this includes 2.0 Dial-A-Bus) Bay Ridges had 7.6 and Columbia had a value of 3.0. The productivity of Dial-A-Bus riders is approximately similar for both Mansfield and Columbia.

The result of the on-site visits and the investigation of each system brought out the fact that the first level of demand transit improvement, route deviation, can often show the best results in labour productivity. It was also the least expensive to implement and caused the minimum institutional difficulties. The next improvement is a "pulsing"* many-to-one system as the one in Bay Ridges, Ontario. Finally, the most complex and least productive per labour hour is the many-to-many, manually dispatched Columbia operation.

Transit Attitudes

The review of the transit attitude studies considers the work of many authors. They all indicate that the ideal type of urban transit system would be one that:

1. arrives at the destination on time,
2. reduces walking at both ends of the trip,
3. keeps one protected from the weather,
4. is reasonably fast and comfortable, and
5. adapts to peak and off-peak transit demands.

The demand bus system as explained in the previous section

*Pulsing means that all buses meet at a central location to allow transfer, then radiate out to deliver and pick-up transit patrons, and return to the center at a fixed time.

can satisfy each of the five points with varying degrees of success.

The results of the paired comparisons and semantic scaled surveys in Columbia indicate that many of the attitudes towards demand transit are shared with the people of Warren, Michigan. They react to waiting time in a similar manner, at either the origin or destination end of a trip. A comparison of results from the attitude survey and the Call-A-Ride log book show that a wait in the home of 15 minutes or less had very little influence on "no-shows" or cancellations. If the wait time is an hour then almost fifty percent of the people reject the service.

A major finding of the Columbia survey is that the two populations, Columbia and Warren, react in a similar manner to the ratio of: in-vehicle transit travel time over in-auto travel time. The ratio ranges from a high of 3 at approximately 5 minutes in-auto time, to a low of 1.5 at in-auto times in excess of 20 minutes. This finding provides a link between time spent travelling in a bus or a car. This also provides a method to transform auto disutility units into transit disutility units. This makes the comparison units for the two modes identical.

The next finding is the reaction to proposed fare increases. These reactions parallel those observed on transit systems which raised fares. The ratio of the percentage of change in fare to the percent change in ridership (or elasticity) which best fits the average "Would you make this trip?" question curve, is a value of 0.4. The elasticity value suggested by the semantic scaling average is somewhat higher at 0.60.

Spatial and Temporal Analysis

The analysis of usage on the Bay Ridge Commuter Dial-A-Bus shows a substantial degree of regularity existed. The regularity of demand locations exists throughout each morning during the week. Employing the Wednesday morning Dial-A-Bus usage as observed over a ten week period, it can be shown that successive Wednesday mornings are similar. Thus, if the location of demand is similar for each day of the week and on a single day of successive weeks, then it may be assumed that demand locations for Dial-A-Bus in Bay Ridges are regular over long periods of time. This observation allows the operator to devise a set of bus routes that could be the correct routing up to 90 percent of the time. The use of route deviation, a combination of fixed route regularity, and demand responsiveness, is suggested by the Bay Ridges usage pattern.

The Columbia, Maryland Call-A-Bus system has a stable level of service for all its daytime operations. The level of service was measured by: first, the length of time from receiving a request for service until delivery at the destination, pick-up time to drop-off time, and the accuracy of the pick-up time. A comparison of a single evening's operation during the fall of 1971 indicated that the service level had changed substantially from May 1971 to the fall of 1971.

An analysis of the daytime bus travel patterns indicates only that the buses are being moved through the area without any degree of similarity in the routing. Another analysis of the regularity of demand locations highlights the major transit trip generators in Columbia. These generators are the two village centers, a community college and a medical clinic.

The temporal distribution of telephone requests indicates that the number of service requests can approach 4.5 calls per ten minutes. This number of calls will lead to congestion on the telephone exchange and potential revenue loss. To get around this a method of automatically queuing calls is necessary. This is particularly true if the productivity rates suggested by the Massachusetts Institute of Technology are being met.

General Demand Relationship

The results which follow depend on: first, the relationship between the various component parts of the transit travel time; second, the relationship between time spent in an automobile or in a transit vehicle; and third, judgements on the part of the author. The final product is a set of transformation weights to change transit travel time into the equivalent in-auto travel time. The following is the modal choice model:

$$U_T = 2.05\,t_{W1} + 6.25\,t_W + 9\,t_t + t_r + 2.05\,t_{W2} + \frac{\text{fare}}{\frac{1}{3}(\text{income})}$$

$$U_A = A\left(3.00\,a_{W1} + a_r + 3.00\,a_{W2}\right) + \frac{\text{out-of-pocket cost}}{1/3\,(\text{income})}$$

where U_T = transit disutility

U_A = automobile disutility

∂_{W1}, t_{W1} = walk time to mode

t_W = wait time for bus

∂_r, t_r = in-vehicle ride time

t_t = transfer time

∂_{W2}, t_{W2} = walk time from mode

A = transformation weight for in-auto time to in-transit vehicle travel time

= 2.9 for in-auto times up to 10 minutes
2.1 for in-auto times 10 to 20 minutes
1.5 for in-auto times greater than 20 minutes

1/3 (income) = transformation weights "t" relate travel costs to in-auto travel time.

The percentage transit can then be shown to be of the following form:

$$\text{Percent transit} = U_T - U_A$$

These results represent an attempt to isolate each element of time consumed in transit tripmaking. Transforming them into common disutility units allows an analysis of the times in detail. The transformation weight allows a more sensitive comparison of the time involved in transit and auto tripmaking in small urban areas. The transformation weights should provide the transit analyst and planner a more powerful analytic tool than now exists.

Test of the Model

The test of acceptability of the transformation weights used in the model involves three indirect procedures. The first compares the transit walk and wait time with recent work by Quarmby.

He estimates that the two times are related as follows: one minute waiting is similar to 2.53 minutes walking. The proposed transformation weights relate the times as: one minute waiting is approximately 3 minutes walking. This is seventeen percent error, which is within any expected error considering the diverse source of information. Another check on the model is a comparison of the expected utility value changes and equating these changes with the known ridership increases of the three demand bus systems. The resulting disutility deficiencies estimated when the system changed from conventional transit to demand bus gave ratio estimates* closely approximating the ridership ratio estimates experienced by the systems. The new transformation weights do a better job than the constant weight of 2.5 for all excess time.

Finally, using the Skokie commuter modal split curve and a set of assumed average travel time data for Bay Ridges, the percentage transit was estimated for the fixed routed and demand bus system.

Conclusion

The summary of many of the key findings of this study are presented in Table X-1. For the remainder of this section assume that the task is to implement Dial-A-Bus into a community which has a fixed route transit system. Columbia's system was inundated on

*The ratios compared are:

$$\frac{\text{conventional transit disutility}}{\text{Dial-A-Bus disutility difference}} \approxeq \frac{\text{Dial-A-Bus ridership}}{\text{conventional bus ridership}}$$

TABLE X - 2

SUMMARY OF DEMAND BUS CHARACTERISTICS

SOURCE	ELEMENT	ROUTE DEVIATION	MANY-TO-FEW	MANY-TO-MANY
MODAL CHOICE MODEL	Walk to bus	choice	minimized	minimized
	Wait for bus	known	known	variable
	Transfer	possible	possible	none
	Ride in bus	moderate	minimized	moderate
	Cost	minimized	moderate	maximized
	Walk from bus	moderate	moderate	minimized
TRANSIT ATTITUDES	Arrive on time	maximized	maximized	minimized
	No transfer	moderate	moderate	minimized
	Shelter	moderate	moderate	maximized
	Short walk	moderate	moderate	minimized
EFFICIENCY*	Work of:			
	Telephone operator	minimized	minimized	maximized
	Dispatcher	minimized	moderate	maximized
	Bus driver	maximized	moderate	minimized
PRODUCTION	Load on:			
	Telephone exchange	minimized	moderate	maximized
	Radio link	moderate	minimized	maximized
MISC.	Ease to implement	maximized	moderate	minimized
	Technological risk	minimized	minimized	moderate

*assumes operations similar to Mansfield, Bay Ridges and Columbia.

the first day of its many-to-many service but later had a reduction in service due to economics. Mansfield, Ohio's Dial-A-Bus had economic success although its parent system failed. Take these two experiences along with the findings of Table X-2 and the plan could be as follows:

Initial Stage

First, orient the bus system so that it meets at one central location. This transfer point should be an active town square, or shopping center. Minimize the other road traffic at the bus entrance and exits. The patrons should wait in comfort (hopefully at someone else's expense) as in a shopping center or store. The cycle for bus meetings should ideally be in multiples of one half hour to minimize the need to remember schedules.

Second, the bus routes on the system should be of such a length that a two to five minute free time exists in the schedule. This free time can be used for route deviation.

Third, communication links between the patron and the driver should be as direct as possible. A shared radio telephone link direct to the bus driver would be one option. If this is not possible then an operator, who also does other office functions, could redirect telephone calls directly through a radio link to the driver.

Fourth, to minimize the use of the direct communication link, a three priced system of fares may be used: fixed route service, standing calls and demand calls. The fare system could be a base of 30¢, plus 10¢ for a standing call, or 20¢ more if taxi-like response is required. At the center transfer point a request for doorstep drop-off would require an extra fare of possibly 10¢.

This first stage of implementation maximizes the use of existing men and materials.

Final Stage

If it is found that the community desires more of the demand service and is willing to pay for such service, then a many-to-one system could be implemented. The only change that would be required would be first, raise the fares to a single level for all and second, use the bus driver to do his own routing as in Bay Ridges.

The advantage of using this incremental approach is that the supply of seats with the bus fleet may more closely approximate the demand for those seats. This incremental approach also insures that the service will not be "over sold".

Chapter XI

RESEARCH RECOMMENDATIONS

Introduction

The research undertaken during this study has encompassed modal choice models, transit attitudes, and Dial-A-Bus operations. The recommendations for further research coming from this study are the following.

Modal Choice Models

An approximate set of transformation weights to relate walking, waiting, transferring and riding time have been generated during this research. These weights need to be refined to reflect the peak hour and off-peak hour response, and possibly, the trip purpose. This type of research is best carried out first with attitude surveys and then confirmed by observation and demonstration. The surveys can give the relative transformation weights of each transit travel time, and field observations can establish the order of magnitude. In addition to further study of the weights considered in this analysis, an investigation of the influence of waiting time should be studied. The weighting of time includes part of "arriving at a destination on time". An attempt should be made to isolate the influence of each of these two variables.

A comfort index as measured by the availability of seats should also be studied. To do this, buses should be run in "trains" or platoons. The time gap between platoons would be held constant thus minimizing any influence of reduced waiting time.

The transferring transformation weight indicated that transfers are very difficult. The weight as developed was for a transfer from one surface vehicle to another. The influence of the comfort and diversion* provided in a well designed transfer facility should be studied. It might even be possible to generate "purposeful transfers" by the provision of shopping facilities. This problem will become more important as major intra-modal transfer facilities are designed and built.

The need to refine these mode choice models is necessary as more advanced untested transit technologies, both vehicle technologies and operating policies, are proposed. A model developed as suggested could attain the necessary level of sensitivity to adequately compare new alternate technology systems.

Attitude Surveys

Research should be undertaken on the more extensive use of attitude surveying within the transit industry. Well worded and sound questionnaire design will give acceptable and usable results. The history of poorly designed and controlled transit surveying is well known within the industry as well as the resulting reluctance of the industries captains to use any suggestions arising from these surveys.

Studies of the transit attitudes of selected groups dependent on transit such as: the poor, the handicapped, and the

*Usually interesting surroundings.

elderly, should be undertaken to uncover their needs compared with those of other transit users. Such a detailing of transit attitudes may allow for the design of bus service to cater to specific transit requirements.

The attitude surveys used in this study indicated that the need to arrive on time and the provision of shelters were considered very important.

How important is arrival time in terms of ridership? It should prove important both in the design of bus schedules and the degree of traffic control considered necessary to maintain schedules. The influence of shelters on ridership could probably be gained from cities such as Toronto where an active shelter building program has been going for some time.

The attitude survey could also be used to confirm the transformation weights developed in this study.

Dial-A-Bus Operations

Small urban areas will probably have to integrate certain taxi operations, limousines, and city bus fleets. The institutional problems will be numerous, and in many cases, impossible. There are still many areas of applied research that should be investigated. Those suggested by this thesis would include the further study of the transit productivity of an area (transit trips per dwelling unit) and the transit operators cost for certain levels of service. A good understanding of the cost productivity relationship would assist in the defining of optimal service boundaries.

Another area of research is the walking mode to a major destination or a feeder bus system. The Bay Ridges data indicated a considerably different relationship between a "primary"* walk or a walk to a feeder bus system.

Finally the usual transit service is designed for the average day. A marginal rate or return analysis could be undertaken to study the cost influence of designing for the peak hour service of the peak day. This type of analysis is particularly critical for Dial-A-Bus type operations.

Spatial Analysis

The limited data available to this study excluded any extensive analysis of time series transit data. It might be possible with the proper data to do studies of demand regularity at the street level, for example each city block.

Such studies would help in setting optimum schedules and also designing service which would maximize the use of a minimum cost bus system such as fixed routed and scheduled buses. This might lead to some way of minimizing the "schedule knowledge"** of the non-peak hour traveller.

Test of the Model

The time transformation weights used in the modal choice model derived by this study should now be subjected to more extensive computer testing. The testing should be in a small urban

*A walk to a major destination.

**Non-work transit users with a multiplicity of transit uses have many schedules which must be learned and amended as changed by the transit authority.

area which has detailed origin and destination data for a regular transit system and Dial-A-Bus system.

Conclusion

There is considerable research to be continued in the social, economic and operational aspects of Dial-A-Bus. The modal choice model presented in this study allows a more detailed analysis than was previously possible. Future refinements, through research, should make the analysis even more advantageous to the transit planner.

APPENDIX A

DEMAND BUS SERVICES

(NORTH AMERICA MAY 1973)

NUMBER	DATE STARTED	FLEET SIZE PEAK HOUR	FLEET SIZE OFF-PEAK HOUR	LOCATION	STATUS
1	6/70	5	3	BAY RIDGES, ONTARIO	OPERATING
2	12/69	3	3	COLUMBIA, MARYLAND.	MANY TO MANY EVENINGS ONLY
3	1/69	1	1	MANSFIELD, OHIO.	ABANDONED
4	9/71	8	4	REGINA, SASKATCHEWAN.	MANY TO ONE
5	2/72	11	5	HADDONFIELD, N.J.	MANY TO FEW
6	10/71	5	3	BATAVIA, N.Y.	MANY TO MANY
7	12/71	3	2	ANN ARBOR, MICHIGAN	CITY WIDE MANY TO FEW
8	10/71	4	3	COLUMBUS, OHIO	MODEL CITIES LOOP
9	2/72	5	5	DETROIT, MICHIGAN	MODEL CITIES

APPENDIX B

SURVEY DESIGN

Introduction

The Columbia Attitude survey was designed to minimize any systematic errors that might arise from the survey procedures. Where economically possible the random processes were used throughout the survey. To insure the validity of the statistical analysis all samples were selected in a random manner.

Selection of Sample

The Columbia attitude survey distinguished between two urban groups: Call-A-Ride users and non-users. Transit usage was very low in Columbia thus it was necessary to assume that each of the two urban groups would have to be isolated. The first group was the non-user. The sample population for this group come from an alphabetic listing of all heads of households in Columbia. A two percent sample was used, this gave approximately 100 interview locations. The sample was a sequential random sample. The population was divided into groups of 50 and the first 50 numbered. A person within the first 50 was drawn by the corresponding random number from a table of random numbers. Assume that this first drawn person was numbered 34. The second person listed for interviewing was 34 + 50 or 84 and so on until all 100 were isolated. The transit users addresses were obtained in the same method. The population list for Call-A-Ride was the prior week C.A.R. log-book and the sampling interval was ten. The C.A.R. log-book had the origin or destination address. The dwelling unit end of the trip was used to locate the sampled address. This gave approximately 100 sampling locations.

All the names and addresses obtained were then placed on a list and on a map. Columbia was then divided in sectors having approximately equal numbers of sampled addresses. The sectors are shown in Figure B-1.

The Survey Design

The remainder of the survey design involved assigning interviews to sectors, days, and sampled addresses. Table B-1 has the codes used to identify the interviewers, days and areas. The assigning of interviewers to days and areas was done by a series of random numbers. Thus, the first random number that was three digits long, placed interviewer 1 to 6 on day 1 to 8 into area 1 to 4. For example if the first random number was 321 then from Table B-1 J. Hess, would survey on Friday, May 7 Sector 1. This procedure was followed until each interviewer had surveyed each area at least once.

Non Responses

The limited budget of this study forced economics that compromised the statistics slightly. If no one was at home the interviewer was instructed to go to the adjacent dwelling until he found one that responded and would fill out the questionnaire. In

TABLE B - 1

COLUMBIA CODES

Surveyors	Name	Code Number
A	S. Flood	1
B	H. Goldworm	2
C	J. Hess	3
D	M. McDonald	4
E	R. Evens	5
F	B. Laupert	6

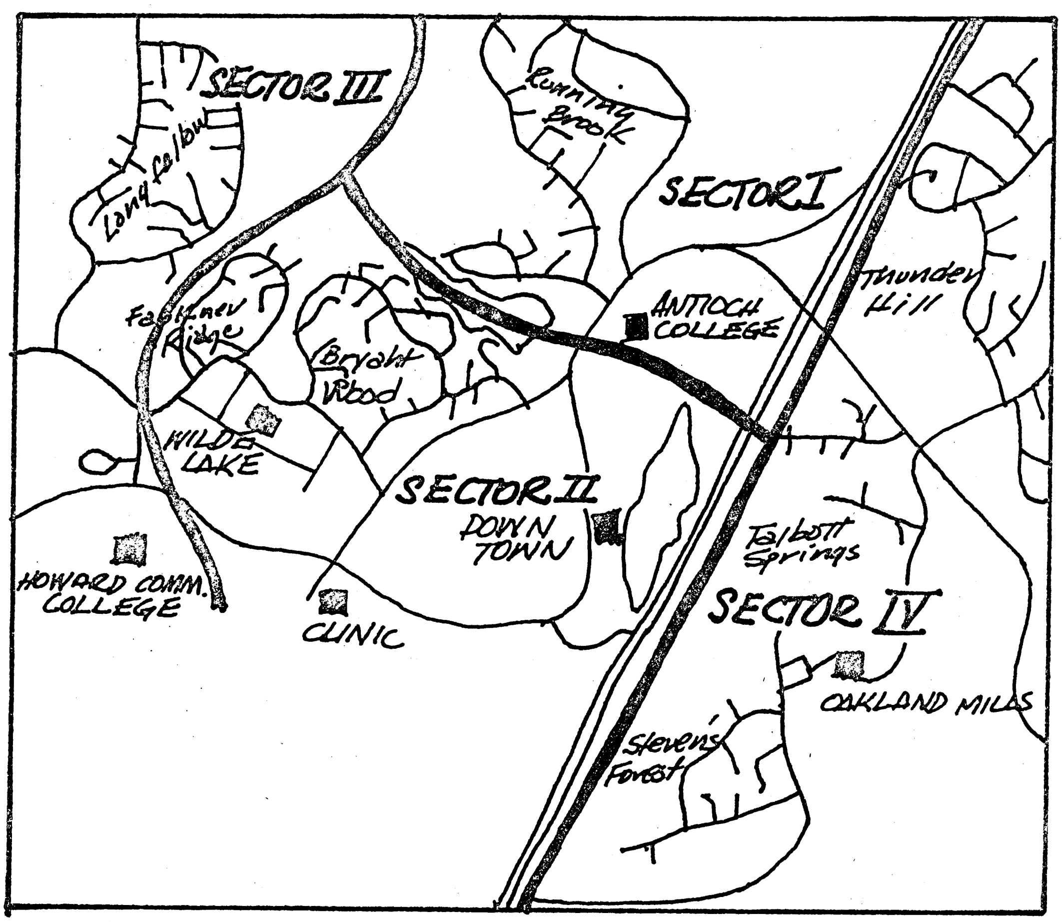
	Day	Code Number
May 6	Thursday	1
7	Friday	2
8	Saturday	3
9	Sunday	4
10	Monday	5
11	Tuesday	6
12	Wednesday	7
13	Thursday	8

Sector	Code Number
I	1
II	2
III	3
IV	4

FIGURE B-1

SAMPLING SECTORS

COLUMBIA MARYLAND



the case of Transit users their name was added to the list of the next interviewer going into that sector. The interviewers were instructed to have anyone over thirteen years of age fill out the questionnaires. Finally there was an attempt to have an equal number of samples collected in each sector by interviewers 1 through 4. Interviewers 5 and 6 were not generally available for the home interview and were used primarily for the on-board bus survey.

Survey Controls

To control the survey the author and one other person tabulated the daily responses, and set up the next day's work for each interviewer. The elements that required control were:

1. equal proportion of paired and semantic scaled questionnaires,
2. equal proportion of paired questionnaire sets 1, 2 and 3.
3. equal proportion of the semantic scaled questionnaire subsets,
4. equal number of collected samples in each sector by each interviewer,
5. follow up telephone calls of a random sample of collected returns to make sure the interviews were carried out.

Survey Results

The resulting number of collected samples in each sector by type of questionnaire is shown in Table B-2. The controls did place approximately equal numbers of returns into each entry of Table B-2. No statistical tests were undertaken to confirm or

TABLE B - 2

SUMMARY OF RETURNED HOME INTERVIEWS

COLUMBIA MARYLAND

INTERVIEWER CODE	SECTOR I		II		III		IV		TOTAL	
	PQ	SS	PQ	SS	PQ	SS	PQ	SS	PQ	SS
1	7	3	10	8	7	3	4	5	28	19
2	7	9	3	3	5	3	7	5	21	20
3	6	4	8	11	9	5	9	7	32	27
4	7	10	5	2	7	5	5	6	25	23
5	0	0	9	6	5	3	0	0	14	9
6	7	2	0	0	0	0	0	0	0	72
TOTAL	34	28	35	30	33	19	25	23	127	100

PQ = Paired Questionnaire

SS = Semantic Scaled Questionnaire

reject the validity of the procedure. It was felt at the time that the samples were representative of Columbia and because of the care taken in the survey design no further testing was necessary.

APPENDIX C

QUESTIONNAIRE DESIGN

Introduction

The design of attitudinal questionnaires includes the following items of concern:

1. questions which ask for the desired information,
2. a minimum number of questions to keep the respondent from getting "fed-up" and not correctly answering questions.
3. no bias resulting from the order of asking the questions.

The accuracy of the information obtained from the questionnaires was assumed to be within acceptable limits. The questions used were those developed by the Research Laboratory of the General Motors Corporation (GM). GM had done extensive pretesting of their questions and had used the questionnaire. To make the Columbia survey comparable with that of GM the questions as developed by GM had to be accepted.

Paired Questions

The wording of the questions used in the paired questionnaire design are listed in Table C-1. If the 15 questions were paired against each other there is a possible $[(15 \times 15 - 15)/_2]$ 105 question pairs that needed to be asked. That is far too many questions to ask a person to answer. The question set was broken into three groups to reflect the attributes of: level of service convenience and vehicle design. The questions within each one of

TABLE C - 1

QUESTIONS USED IN PAIRED QUESTIONNAIRE SURVEY
FOR COLUMBIA MARYLAND

1. Arrive at your destination when you had planned to.
2. Making a trip without changing vehicles.
3. A shorter time spent waiting to be picked up.
4. A lower fare for passengers.
5. Less time spent walking to a pick up point.
6. A shorter time spent travelling in the vehicle.
7. Being able to take a direct route with fewer turns and detours.
8. Small variation in travel time from one day to the next.
9. Assurance of getting a seat.
10. Calling for service without being delayed.
11. More protection from the weather at public pick-up points.
12. Being able to select the time when you will be picked up.
13. Convenient method of paying your fare.
14. More chance to re-arrange the seats inside the vehicle to make talking with others easier.
15. More chance of being able to arrange ahead of time to meet and sit with someone you know.

1 - 8	Level of service attributes
9 - 13	Convenience attribute
14 & 15	Vehicle design attributes

these sets was paired with all other questions of the set. This is shown by the "X" in Table C-2. To tie the matrices together, attributes 4 and 6 ("lower fare" and "shorter travel time") were paired with all other questions as shown by the shaded areas in Table C-2. This tie-in technique allows the comparing of all fifteen attributes. The assumption is the relative ordering of the questions pairs about the attributes 4 and 6 in matrix two and three reflect the ordering that would be obtained if all 105 question pairs had been used. This technique reduced the number of paired questions to 67 from the 105 needed for the entire set.

The next area was to randomly assign a sequence of asking the question pairs. To do this each question pair was assigned a number from 1 to 67. Using a table of random numbers the order of asking each question pair was assigned as shown in Table C-3. The choice of which question went first in the pair was selected using a coin toss. "Heads" put the item in column headed "first in question" first and "tails" put the other part of the pair first.

Ideally the above ordering procedure should be followed for each survey. This is far too expensive a procedure therefore a few simplifications were needed. The question pairs were arranged into six convenient groups, A through F, as shown in Table C-4. The question groups B and F were held constant in their position within the three questionnaire sets. Set 1 had the questions ordered as suggested by the process which generated Table C-3. The question order of set 2 and 3 was obtained by the selection of

TABLE C-2
TIE-IN QUESTIONS TO COMPARE MATRIX I, II, III

	QUESTION NUMBER	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
		LEVEL OF SERVICE*								CONVENIENCE					VEHICLE DESIGN	
I LEVEL OF SERVICE	1															
	2	X														
	3	X	X													
	4	X	X	X												
	5	X	X	X	X											
	6	X	X	X	X	X										
	7	X	X	X	X	X	X									
	8	X	X	X	X	X	X	X								
II CONVENIENCE	9	X	X	X	X	X	X	X	X							
	10		X		X		X	X		X						
	11		X		X		X			X	X					
	12				X		X			X	X	X				
	13		X		X		X			X	X	X	X			
III VEHICLE DESIGN	14				X		X	X		X						
	15		X		X		X				X				X	

MATRIX ONE (questions 1–8 × 1–8); MATRIX TWO (questions 9–13 × 9–13); MATRIX THREE (questions 14–15 × 14–15)

X = question paired, to be asked in survey

* see Table C-1 for code number of the listed attributes

TABLE C - 3

PAIRED QUESTIONS
(COLUMBIA ATTITUDE SURVEY)

ORDER QUESTIONS ASKED
(# in matrix are question numbers)

(FIRST IN QUESTION) (SECOND IN QUESTION)

		#	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
LEVEL OF SERVICE	ARRIVE WHEN PLANNED	1	X	16	22	7		24			49						
	NO TRANSFER	2		X			52	19	15	14	28				66		36
	LESS WAIT TIME	3		20	X	23	50	6		21							
	LOWER FARE	4		13		X	30	63	8	10	33	44		38	40		
	LESS WALK TO PICK UP	5	27				X	53	32	29	31						
	SHORT TRAVEL TIME	6						X			56			43	42		5
	DIRECT ROUTE	7	11		26			12	X			54					
	DEPENDABLE TRAVEL TIMES	8	17					18	25	X							
CONVENIENCE	HAVING A SEAT	9			35				65	67	X				61		
	CALLING WITHOUT DELAY	10		48				37			62	X					
	SHELTERS AT PICK-UP	11		55		51		57			59	58	X	46	60		
	CHOOSE PICK-UP TIME	12									47	39		X	41		
	EASY FARE PAYMENT	13										45			X		
VEH. DESIGN	ADJUSTABLE SEATS	14				1		63	34		4					X	
	ABILITY TO MEET FRIENDS ON VEH.	15				3						64				2	X

TABLE C - 4

PAIRED QUESTIONNAIRE SURVEYS

QUESTION GROUP AND QUESTION NUMBER CODE

GROUP	QUESTION PAIR NUMBER
A	1 - 5
B	6 - 29
C	30 - 36
D	37 - 49
E	50 - 55
F	56 - 61

ARRANGEMENT OF QUESTION GROUPS IN QUESTIONNAIRE SETS

SET 1	SET 2	SET 3
A	D	E
B	B	B
C	A	D
D	C	A
E	E	C
F	F	F

random numbers from a set of random number tables.

The random processes used in the ordering of questions and groups of questions within each of the three survey sets, minimizes the possibility of systematic errors due to survey design. The use of the "tie-in" technique between the three matrices allowed a minimum number (67) of paired questions to be asked thus reducing the time needed to complete the survey.

Semantic Scaling Questionnaire

The semantic scaling asked that 54 items be scaled within ten questions. The question groups were not rearranged to eliminate a possible bias due to the order of asking the ten questions. To minimize the error associated with asking order <u>within</u> each of the ten questions, the order of the attributes was reversed. The following is an example.

5 Indicate on the scales below how acceptable it would be to you to wait for the CALL-A-RIDE for the various amounts of time listed below. Assume that you are waiting at home.

TWENTY MINUTES

FIFTEEN MINUTES

TEN MINUTES

FIVE MINUTES

The next set would have the time questions ordered in the following manner.

FIVE MINUTES

TEN MINUTES

FIFTEEN MINUTES

TWENTY MINUTES

The procedure used minimizes the error within each question but did not assure the minimization of bias for the overall question order. A visual check of the results from Columbia and Warren show considerable agreement. This was taken as sufficient proof that any bias due to the question order was minimal.

Conclusion

The questionnaire designed used for the paired comparison was such that any possible bias due to the survey design was minimal. The procedure used in the semantic scaled questions minimized "within-question" bias and any other bias due to question order was not detected in a comparison of the Warren and Columbia results.

APPENDIX D

EXAMPLE OF PAIRED COMPARISONS AND SEMANTIC SCALING

Introduction

This section discusses briefly the theoretical aspects of paired comparison and semantic scaling. The section also has two simple examples and relates the two questionnaire methods.

Paired Comparisons

Theory

Paired comparisons is a technique of determining the attitude scaled values of particular attributes or stimuli (usually called items by the social scientist). The method was essentially developed by Thurston in 1928 and has been used by various researchers. The essential elements of the technique are: a set of appropriate questions (attributes, stimuli) say A, B, C and D, and a group of judges (persons, etc.) from the population. Each person is asked to select high preference for each possible combination of questions (attributes or stimuli) i.e. A-B, A-C, A-D, B-C, B-D, thus the person must select between five question pairs for the four original attributes. Using the results of these responses it is possible to develop an ordinal interval scale of attributes thus giving an indication of the attitude of those persons sampled.

The attributes (items) to be used in Thurston's paired comparison method must be nonmonotone with a single maxima, that is, the relationship between the attribute (stimuli) and the latent attitude variable is as shown in Figure D-1. It is also assumed that the perceived differences between the stimuli are normally distributed thus:

$$S_i - S_j = X_{ij}\,\sigma_{(i-j)}$$

where

S_i = scaled values of attributes i

S_j = scaled values of attributes j

$\sigma_{(i-j)}$ = standard deviation of the hypothetical distribution of differences

X_{ij} = the unit normal deviate corresponding to p_{ij}, the proportion of times attribute i is selected over attribute j, which is

$$p_{ij} = \int_{-\infty}^{X_{ij}} \frac{1}{\sqrt{2\pi}} \cdot e^{-\frac{t^2}{2}} \cdot dt$$

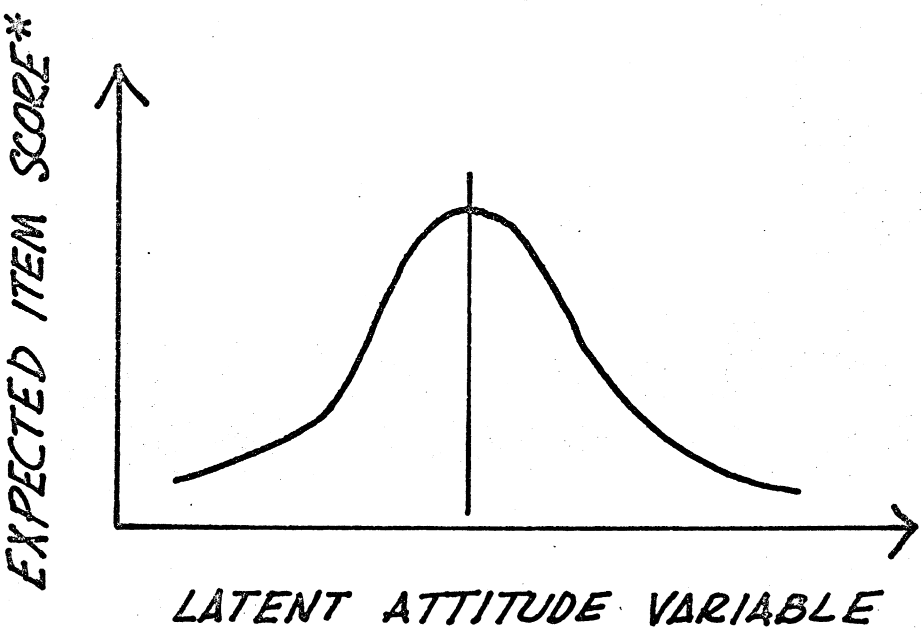
The simplest scaling model is to assume that $\sigma_{(i-j)}$ is unity and the previous difference equation becomes:

$$S_i - S_j = X_{ij}$$

The method developed by Thurston minimizes the sum of squares of the discrepancies between and expected X_{ij} (from the above equation) and the observed X_{ij} resulting in the responses. The discrepancies exist because persons are not one hundred percent consistent in their interpretation of and response to stimuli in the form of written impressions.

FIGURE D-1

NONMONOTONE ITEM OPERATING CHARACTERISTIC



* probability of a positive response to a dichotomous item

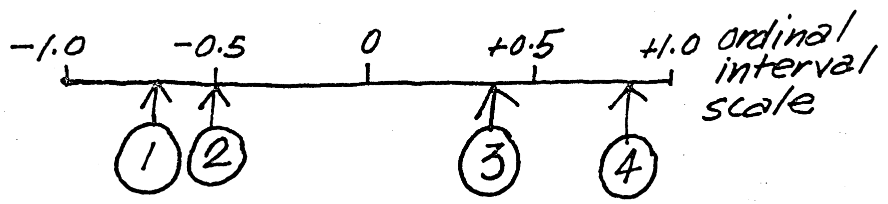
Simple Example

The observed proportions, p_{ij}, must be converted into their unit normal deviate X_{ij}. The X_{ij} are arranged in a Two-way Table as shown in Table D-1. The value of X_{ii} is logically equal to zero, and any X_{ij} beyond the range of ±2.00 should be rejected as unstable.

The scale value of attribute i is the average of all entries in the i^{th} column of the transformed observation, matrix B.

The scale is a relatively arbitrary device and in this example the scale factor ($\sigma_{(i-j)}$) was set to one by the assumption that $\sigma_{(i-j)}$ was one. Implicit in the mathematics of the complete matrix is that the "zero point" of the scale was set by letting the average scale value (for all observations) equal zero.

The graphical interpretation of the results of the paired comparison are:



This is an ordinal interval scale, ordinal in that the order of attributes is given, interval in that the amount of difference separating the attributes 1 through 4.

This has been a very simple example that in many ways only touches the surface. There are details that require special consideration such as: non response by the judge to selected question pairs, incomplete entries in question pair matrix because that question pair was not asked as part of the survey design.

TABLE D - 1

PAIRED COMPARISONS COMPUTATIONS

COMPLETE MATRIX

p_{ij}

A. OBSERVED PROPORTIONS OF FAVOURABLE RESPONSES

		attribute j 1	2	3	4
attribute i	1	-	.58	.83	.95
	2	.42	-	.80	.92
	3	.17	.20	-	.65
	4	.05	.08	.35	-

X_{ij}

B. p_{ij} TRANSFORMED TO UNIT NORMAL DEVIATE

		attribute j 1	2	3	4
attribute i	1	0	.20	.95	1.65
	2	-.20	0	.84	1.41
	3	-.95	-.84	0	.39
	4	-1.65	-1.41	-.39	0
Column Sum		-2.80	-2.05	1.40	3.45
Scale values*		-.70	-.51	.35	.86

*Scale values = column sum/4

Semantic Scaling

Semantic Scaling is a technique to determine the unanimity of attitude towards a particular attribute. The essential elements of the technique are: a set of appropriate questions and a group of judges. The questions have two extreme ratings, for example "very desirable", "very undesirable". Between these two extremes there may be three to five additional ratings, the central location being neutral. The "semantic values" are scheduled by letting very desirable equal 1 and very undesirable equal 7, see Figure D-2 for an example. The judges are required to complete the questionnaire.

Employing standard statistical procedures the mean and standard deviation are:

$$\bar{A}_i = \frac{\sum_{j=1}^{n} A_{i,j}}{n}$$

where $\bar{A}_i$ = mean semantic scaled response to attribute i

$A_{i,j}$ = semantic scaled response to attribute i by person j,

n = total number of people in sample.

The standard deviation is given by:

$$\sigma_{A_i}^2 = \frac{\sum_{j=1}^{n} (A_i - A_{i,j})^2}{n-1}$$

The mean, $\bar{A}_i$, indicates the attitude the sampled persons have towards a certain attribute. The standard deviation, σ_{A_i}, measures the degree of unanimity in attitude of the sampled

FIGURE D-2

EXAMPLE OF A SEMANTIC SCALED QUESTION

7 Some of your trips on the CALL-A-RIDE would require that you get to your destination at a particular time. It might be desirable sometimes to arrive early. Show on the scales below how you would feel about arriving at the times listed. Assume that you have a medical appointment.

THIRTY MINUTES EARLY

	1	2	3	4	5	6	7	
Unacceptable	I	I	I	I	I	I	I	Very Acceptable

TWENTY MINUTES EARLY

	1	2	3	4	5	6	7	
Unacceptable	I	I	I	I	I	I	I	Very Acceptable

TEN MINUTES EARLY

	1	2	3	4	5	6	7	
Unacceptable	I	I	I	I	I	I	I	Very Acceptable

FIVE MINUTES EARLY

	1	2	3	4	5	6	7	
Unacceptable	I	I	I	I	I	I	I	Very Acceptable

population towards any attribute.

The Relationship Between Paired Questions and Semantic Scaling

The two techniques are complementary in their use in any survey to uncover the attitudes of persons towards a selected set of attributes (stimuli). The paired question technique ranks a set of attributes in order of importance. Thus in the example presented in Figure D-3 the order of importance of the seven attributes sampled is, starting with the most important:

WAIT TIME

TRAVEL TIME

SHELTER

HAVE A SEAT

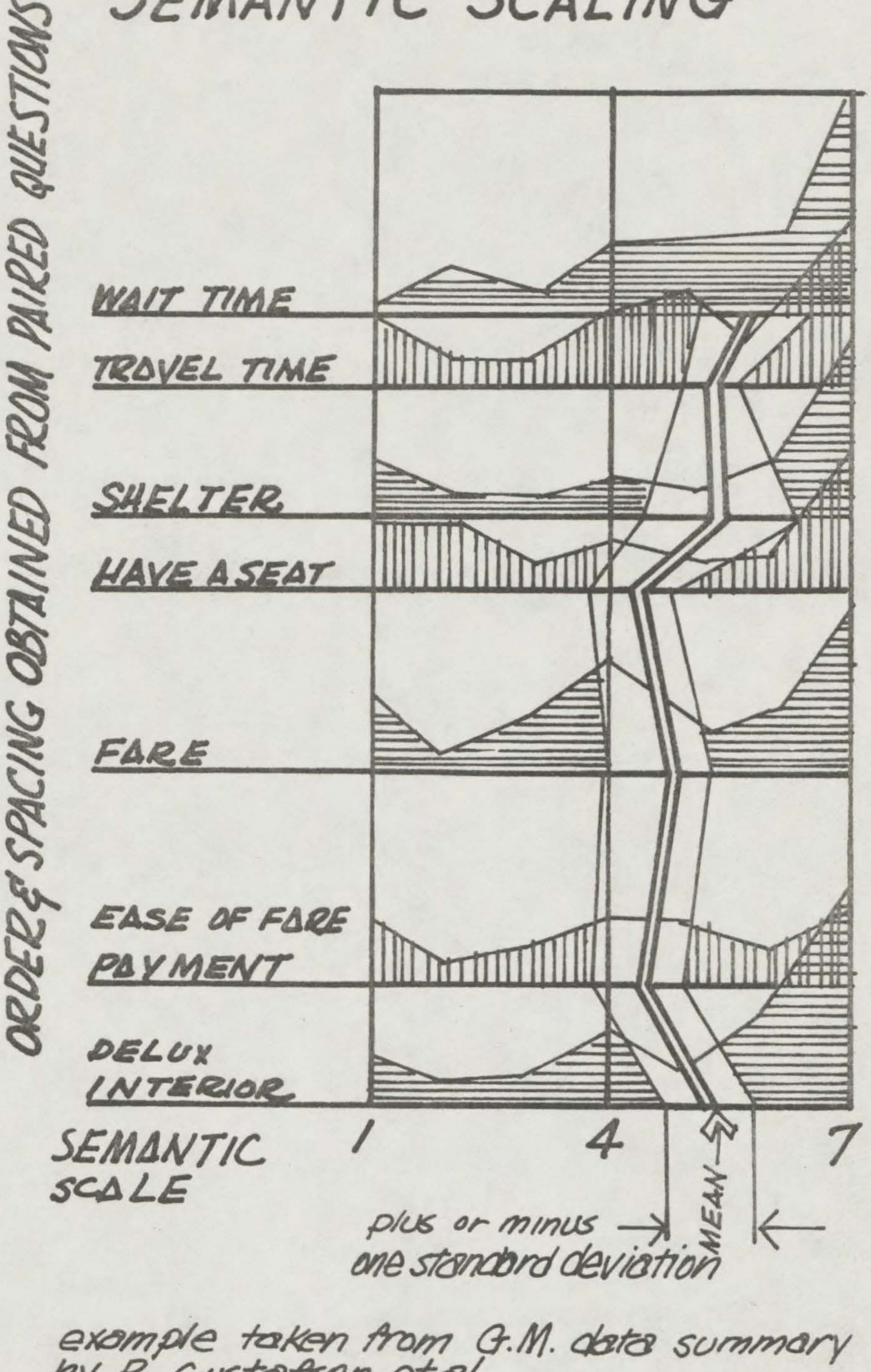
FARE

EASE OF FARE PAYMENT

DELUX INTERIOR

The technique of paired comparisons also permits an interval to be established between the seven variables. The "amount" of importance in the ranking scale may be estimated. Again from Figure D-3, the first two attributes are grouped close together as are the next two, SHELTER and HAVE A SEAT. Thus the paired questionnaires give an ordinal (attribute ordering) interval (importance separation between attributes) scale as represented by the vertical arrangement of transit system attributes in Figure D-1.

FIGURE D-3
THE RELATIONSHIP BETWEEN PAIRED QUESTIONS & SEMANTIC SCALING



example taken from G.M. data summary by R. Gustafson et.al.

The profile of the semantic scale responses are shown by the hatched lines in Figure D-1. A good example of the interaction of the semantic scales is shown in the first three attributes. The two time attributes are relatively close in their mean values. The response to the TRAVEL TIME attribute is sometimes more unanimous than the response to WAIT TIME. The standard deviation of the responses to the SHELTER attributes are much less unanimous than that of TRAVEL TIME even though the mean values are similar. The technique of semantic scale provides a measure of the attitude towards an attribute and degree of unanimity held by the sampled population towards the selected attribute.

A combination of the two techniques indicates to the analyst the relative importance of selected attributes and the degree of unanimity in the response to those attributes.

APPENDIX E

SEMANTIC SCALED RESULTS

The following is a summary of Semantic Scaled questionnaire survey results obtained in Columbia, Maryland. The first table has the detailed results for the total Columbia population and the mean values obtained by General Motors in Warren, Michigan. The second table gives the semantic scale mean and standard deviation for the following sub-groups in Columbia:

1. No drivers license, drivers license
2. Never use Call-A-Ride, frequently use Call-A-Ride.

COLUMBIA MARYLAND MAY 1971

SEMANTIC SCALE QUESTIONNAIRE RESULTS TOTAL POPULATION

	1 Very Poor	2	3	4	5	6	7 Very Good	MEAN	# MISS	GM MEAN
1 IMPORTANCE OF FARE	13	1	7	25	12	15	27	4.75	0	5.7
2 TRAVEL TIME IMPORTANCE	9	2	5	17	18	13	36	5.16	0	5.5
3 ASSURANCE OF A SEAT	13	11	6	17	9	9	35	4.65	0	5.2
4 WAITING TIME AT PICKUP	4	3	1	14	12	18	48	5.73	0	5.9
5 PICKUP AT PLACE OF CALL	0	1	1	11	4	5	77	6.38	1	6.1
6 PICKUP AT NEAREST CORNER	7	1	4	10	10	25	36	5.13	7	5.5
7 PICKUP IN NEIGHBOURHOOD	18	5	11	21	12	14	18	4.15	1	4.9
8 PICKUP AT NEAREST MAJOR ST.	19	4	5	20	12	13	24	4.28	3	4.1
9 NO FACILITIES AT PICKUP	16	8	9	23	14	5	24	4.19	1	4.0
10 CURBSIDE C-A-R STOP	8	4	6	25	10	10	36	4.96	1	4.6
11 ENCLOSED SHELTER AT PICKUP	6	0	3	15	8	16	51	5.68	1	5.5
12 OVERHEAD SHELTER AT PICKUP	5	1	2	9	18	11	52	5.69	2	5.4
13 CASE 1, EARLIEST ARRIVAL	13	1	6	20	14	7	39	4.98	0	5.7
14 CASE 1, LATEST ARRIVAL	4	0	2	4	7	4	79	6.38	0	6.3
15 CASE 1, EARLIEST PICKUP	9	1	7	16	11	9	47	5.34	0	5.8
16 CASE 1, LATEST PICKUP	1	1	2	9	9	8	70	6.28	0	6.1
17 CASE 2, EARLIEST ARRIVAL	15	2	2	16	17	10	33	4.65	5	5.6

SEMANTIC SCALE QUESTIONNAIRE RESULTS CONTINUED

18 CASE 2, LATEST ARRIVAL	7	2	3	12	11	9	51	5.34	5	5.6
19 CASE 2, EARLIEST PICKUP	8	1	4	15	18	6	45	5.23	3	5.8
20 CASE 2, LATEST PICKUP	5	3	2	12	16	9	49	5.42	4	5.6
21 CASE 3, EARLIEST ARRIVAL	15	3	2	19	17	9	31	4.59	4	5.6
22 CASE 3, LATEST ARRIVAL	6	2	1	10	6	11	61	5.76	3	6.0
23 CASE 3, EARLIEST PICKUP	7	0	1	23	12	9	45	5.31	3	5.8
24 CASE 3, LATEST PICKUP	2	0	1	14	5	8	67	6.03	3	6.1
25 TWENTY MINUTE WAIT	23	11	4	22	10	8	21	3.90	1	3.8
26 FIFTEEN MINUTE WAIT	3	4	9	18	19	16	28	4.97	3	4.9
27 TEN MINUTE WAIT	0	0	4	3	12	24	55	6.13	2	5.8
28 FIVE MINUTE WAIT	3	1	0	3	3	5	32	6.36	3	6.1
29 TRAVEL 20 MIN/CAR 15	3	0	2	1	9	17	66	6.22	2	NA
30 TRAVEL 15 MIN/CAR 5	6	1	12	18	28	16	17	4.71	2	4.6
31 TRAVEL 20 MIN/CAR 5	23	11	21	16	17	6	3	3.14	3	NA
32 TRAVEL 10 MIN/CAR 5	1	0	2	4	10	23	58	6.17	2	6.0
33 TRAVEL 30 MIN/CAR 10	29	16	22	15	9	2	5	2.79	2	NA
34 TRAVEL 15 MIN/CAR 10	4	1	1	6	5	15	66	6.10	2	6.3
35 ARRIVE 30 MINUTES EARLY	37	15	11	22	7	2	3	2.56	3	2.7
36 ARRIVE 20 MINUTES EARLY	9	8	14	35	16	6	11	4.00	1	4.2
37 ARRIVE 10 MINUTES EARLY	1	1	3	4	8	26	56	6.16	1	6.1

SEMANTIC SCALE QUESTIONNAIRE RESULTS CONTINUED

38 ARRIVE 5 MINUTES EARLY	4	0	2	3	4	8	78	6.36	1	6.1
39 STANDARD INTERIOR	3	3	4	14	12	16	47	5.62	1	5.1
40 INTERIOR WITH GROUPED SEATS	26	8	8	19	11	3	23	3.76	2	3.0
41 DELUXE INTERIOR	9	2	2	18	7	12	49	5.41	1	5.2
42 ONE-WAY FARE OF $.50	32	7	14	12	15	10	9	3.34	1	6.0
43 ONE-WAY FARE OF $.90	76	14	3	1	2	1	2	1.47	1	3.0
44 ONE-WAY FARE OF $.75	68	8	11	5	4	1	2	1.77	1	4.4 (70¢)
45 ONE-WAY FARE OF $1.00	84	4	4	3	2	0	2	1.40	1	1.7
46 ONE-WAY FARE OF $.40	22	9	7	16	12	9	24	4.07	1	5.7
47 ONE-WAY FARE OF $.80	72	10	8	3	3	1	2	1.63	1	2.9
48 ONE-WAY FARE OF $.60	57	10	12	5	9	3	4	2.24	0	4.5
49 TWENTY TRIP TICKET	19	1	7	21	15	12	23	4.34	2	4.2
50 CREDIT CARD	43	10	9	15	3	1	17	2.90	2	3.3
51 MONTHLY PASS	29	3	5	16	9	16	20	3.95	2	3.7
52 TOKENS	13	5	11	19	14	15	20	4.32	3	4.1
53 EXECT FARE ONLY	9	6	9	18	22	12	22	4.56	2	4.2
54 CASH RECEIVING CHANGE	3	2	2	12	5	18	57	5.93	1	5.3

100 TOTAL OBSERVATIONS

SEMANTIC SCALE RESULTS
COLUMBIA, MARYLAND

	SAMPLED POPULATION	NO LICENCE		LICENCE		NEVER USE		FREQUENT USE		
	CHARACTERISTIC	$\overline{m}$	σ	$\overline{m}$	σ	$\overline{m}$	σ	$\overline{m}$	σ	
1	Fare	3.41	.49	5.00	.79	4.59	.43	3.96	.47	1
2	Travel	5.24	.77	5.17	.87	5.10	.54	5.48	.81	2
3	Seat	4.82	.73	4.56	.84	4.41	.45	4.61	.59	3
4	Wait pick-up	5.94	.95	5.73	1.34	5.83	.62	5.91	.92	4
5	Pick-up place of call	6.41	1.04	6.48	3.20	6.31	1.34	6.39	1.25	5
6	Pick-up nearest corner	5.29	.99	5.54	1.07	5.79	.78	5.05	.65	6
7	Pick-up neighbourhood	4.24	.59	4.22	.61	4.90	.48	4.00	.45	7
8	Pick-up major street	4.35	.57	4.47	.60	5.07	.63	4.04	.43	8
9	No fac. at pick-up	5.06	.74	4.10	.64	4.14	.40	3.96	.44	9
10	Curb 'car' stop	5.65	.88	4.85	.95	4.69	.50	5.13	.65	10
11	Shelter enclosed	5.24	.81	5.83	1.57	5.52	.61	6.00	1.01	11
12	Shelter overhead	5.06	.78	5.95	1.78	6.00	.91	5.30	.64	12
13	I Earliest arrival	5.65	.84	4.85	1.06	5.14	.58	5.52	.84	13
14	I Latest arrival	6.06	.98	6.43	3.28	6.45	1.67	6.00	1.10	14
15	I Earliest pick-up	5.59	.88	5.32	1.28	5.45	.65	5.61	.82	15
16	I Latest pick-up	6.41	1.09	6.23	2.51	6.38	1.23	5.91	1.01	16
17	II Earliest Arrival	5.29	.82	4.82	.86	5.04	.49	5.04	.63	17
18	II Latest Arrival	5.88	.93	5.58	1.59	5.39	.86	5.64	.78	18
19	II Earliest pick-up	4.82	.72	5.53	1.44	5.68	.72	4.96	.64	19
20	II Latest pick-up	5.65	.90	5.65	1.50	5.82	.87	5.26	.70	20
21	III Earliest Arrival	4.94	.79	4.76	.80	4.75	.47	5.13	.60	21
22	III Latest Arrival	6.00	.91	5.91	2.29	5.96	1.20	5.91	.91	22
23	III Earliest pick-up	5.35	.80	5.52	1.52	5.50	.63	5.30	.75	23
24	III Latest pick-up	6.00	.94	6.25	2.57	6.46	1.26	5.91	.91	24
25	20 min. wait	3.59	.48	4.09	.70	3.48	.36	4.91	.59	25

	SAMPLED POPULATION CHARACTERISTIC	NO LICENCE		LICENCE		NEVER USE		FREQUENT USE		
		m̄	σ	m̄	σ	m̄	σ	m̄	σ	
26	15 min. wait	5.00	.83	5.16	.75	4.76	.50	5.70	.76	26
27	10 min. wait	6.00	.93	6.29	1.85	6.28	.87	6.29	.86	27
28	5 min. wait	6.31	1.16	6.60	3.48	6.31	1.45	6.38	1.37	28
29	20/15	6.13	1.02	6.40	2.46	6.66	1.29	5.77	.91	29
30	15/5	4.06	.60	4.90	.79	4.38	.42	4.41	.52	30
31	20/5	2.50	.50	3.39	.72	2.83	.44	3.19	.34	31
32	10/5	5.75	.91	6.39	2.10	6.38	1.02	5.86	.86	32
33	30/10	2.88	.41	2.87	.88	2.76	.60	3.00	.37	33
34	15/10	6.06	1.02	6.24	2.34	6.17	1.05	5.41	.77	34
35	Arrive +30 mins.	1.88	.98	2.75	1.05	2.52	.52	2.10	.86	35
36	Arrive +20 mins.	3.69	.55	4.10	.94	4.17	.55	3.82	.61	36
37	Arrive +10 mins.	6.19	.97	6.21	1.85	6.10	.97	6.00	.81	37
38	Arrive +5 mins.	6.19	.99	6.49	3.36	6.34	1.44	6.36	1.33	38
39	Standard inside	6.06	.94	5.59	1.36	5.59	.60	6.09	.99	39
40	Grouped seats	4.13	.59	3.85	.78	3.79	.41	3.81	.43	40
41	Deluxe	5.25	.84	5.54	1.48	5.66	.83	4.95	.62	41
42	Fare 50¢	2.69	.62	3.56	.74	3.28	.44	3.27	.40	42
43	Fare 90¢	1.69	1.37	1.46	3.46	1.34	2.45	1.86	1.25	43
44	Fare 75¢	1.56	1.39	1.85	2.76	1.45	2.14	1.95	1.08	44
45	Fare $1.00	1.44	1.61	1.42	4.05	1.48	2.58	1.55	1.92	45
46	Fare 40¢	3.75	.55	4.20	.70	4.00	.38	3.77	.42	46
47	Fare 80¢	1.88	1.34	1.62	3.10	1.48	2.28	1.91	1.38	47
48	Fare 60¢	2.71	.69	2.17	2.15	1.79	1.54	2.83	.82	48
49	20 Tickets	4.31	.68	4.54	.71	4.14	.39	5.10	.65	49
50	Credit Card	2.56	.61	3.09	1.30	3.31	.72	3.24	.55	50
51	Monthly basis	4.25	.65	4.06	.84	3.93	.47	4.38	.52	51

SEMANTIC SCALE RESULTS
COLUMBIA, MARYLAND

	SAMPLED POPULATION	NO LICENCE		LICENCE		NEVER USE		FREQUENT USE		
	CHARACTERISTIC	$\bar{m}$	σ	$\bar{m}$	σ	$\bar{m}$	σ	$\bar{m}$	σ	
52	Tokens	4.12	.62	4.51	.56	4.00	.38	4.43	.56	52
53	Exact fare	4.50	.72	4.66	.61	4.62	.46	4.57	.59	53
54	Cash/Change	6.47	1.00	5.86	1.72	5.62	.78	5.91	.85	54
	OBSERVATIONS	17		81		29		69		

Semantic Scale	1	2	3	4	5	6	7
	Very Poor			Neutral			Very Good

APPENDIX F

A MATHEMATICAL FORMULATION OF DIAL-A-BUS REQUIREMENTS

Introduction

During the course of this research the following question was formulated. "What are the number of vehicles required in a Dial-A-Bus fleet under varying transit demand conditions?" The question was later expanded to control the type of variables employed in the resulting equation. The variables had to directly include at least one from the following categories:

a variable reflecting area demand for transit,

a variable reflecting the efficiency of the street system,

a variable reflecting the "responsiveness" of the patron, i.e. the time to load on to a vehicle,

a variable reflecting the operators utilization of the vehicle fleet.

After considerable work the following solution statement was formulated:

"The number of buses needed to provide adequate service in an area is dependent on factors which reflect the efficiency of the roadway network, the density of demand, the response rate of patrons and the number of riders per bus."

A Mathematical Statement

The variables used in the analysis are defined in Table F-1. The tie in between the variables and their purpose is also listed in Table F-1.

As a first order approximation to actual operation assume that the loading and unloading of passengers requires no time. This means that the dwell time, or time waiting at a stop, is zero. If the bus travels at a constant speed S mph and patrons (who spirit on and off the vehicle) travel an average L miles then the following is the mathematical formula for the number of bus hours needed to service one demand.

$$h = \frac{L}{S} \qquad (1)$$

h = bus hours of operation to service one demand

L = trip length, miles

S = bus speed, miles/hour.

If the demand is D trips then the total number of bus hours of operation required is D times the time for a single trip. Thus Equation 1 becomes:

$$H = h \cdot D = \frac{L}{S} \cdot D \qquad (2)$$

where

H = total bus hours required to service D demands per hour per unit area.

This transit operating agency's view of the dial-a-bus

TABLE F - 1

VARIABLES USED IN DIAL-A-BUS REQUIREMENT EQUATION

VARIABLE	SYMBOL	PURPOSE
Dwell time minutes/person	d	Represents the degree of promptness of patrons and lost bus production time
Trip length miles	L	Probability of multiple riders Possible processing efficiency Unit operational costs per rider Street system efficiency
Bus speed mph	S	Bus processing efficiency Peak hour to off-peak hour policy variable
Riders per bus people	R	Income potential per bus Operators policy variable
Demand trips	D	Residential (user) density

needs may be gained through the bus utilization in riders per hour. Assume the average riders on a bus is R then, Equation 2 may be rewritten to reflect the number of bus hours needed as:

$$N' = \frac{L}{S} \cdot \frac{D}{R} = \frac{H}{R} \qquad (3)$$

where

N' = number of buses

So far we have considered a phantom population which may get on and off a bus in zero time. If the load time (dwell time) is expected to be considerably different from zero then it must be considered in a revised bus requirement equation. Now all that need be developed is an equation to represent the bus driving time available as a function of loading times. The time to make a trip is L/S and, assuming a bus occupancy of R, the persons carried (P) by a bus in one unit of time is:

$$P = \text{average bus occupancy} \cdot \text{trips per unit of time}$$

$$P = R \cdot \frac{S}{L} \qquad (4)$$

where

P = persons carried by a bus in one unit of time.

The total dwell time (loading and off loading) used in one unit of time for a bus is:

$$d \cdot P = d \cdot R \cdot \frac{S}{L} \qquad (5)$$

where

d = the average dwell time for one person.

The driving time left in one unit of time for a bus is:

$$DT = 1 - \text{total dwell time} \qquad (6)$$

Equation 6 may be rewritten as:

$$DT = 1 - d \cdot R \cdot \frac{S}{L} \qquad (7)$$

The ratio of equation 3 and equation 7 gives the number of vehicles required when the dwell time is greater than zero. Considering the unit of time to be one hour then verbally the equation is:

Number of Buses	=	Hours of operation needed to satisfy a demand D with zero dwell time	Hours of driving time available with non zero dwell time.

Mathematically this becomes:

$$N = \frac{N'}{1 - d \cdot R \cdot \frac{S}{L}} \qquad (8)$$

and substituting in equation 3 for N', N becomes:

$$N = \frac{\frac{L}{S} \cdot \frac{D}{R}}{1 - d \cdot R \cdot \frac{S}{L}} \qquad (9)$$

Equation 9 states that the number of vehicles needed in a bus fleet is directly proportional to the demand and inversely proportional to the loading and off loading time. The relationship between trip length, speed and riders per bus is somewhat more complex. The requirement is now to map the relationship between N and the other variable in equation 9 and find any resulting optimum answer.

Optimum Number of Buses

The number of buses needed, for the given set of criteria, is represented by Equation 9. Assume that the operator's view is the most important and that the only variable under his policy direction is the riders per bus. Equation 9 may be rewritten to:

$$N = \frac{X/R}{1 - YR} \qquad (9)$$

where

$$Y = \frac{S}{L} \cdot d$$

$$X = \frac{L}{S} \cdot D \qquad (10)$$

Taking the first derivative of equation 10 after rewriting is:

$$\frac{\partial}{\partial R}(N) = \frac{\partial}{\partial R}\left(\frac{X}{R - YR^2}\right) = 0$$

$$= \frac{(R - YR^2)\frac{\partial X}{\partial R} - X\frac{\partial}{\partial R}(R - YR^2)}{(R - YR^2)^2}$$

$$= -X\frac{(1 - 2YR)}{(R - YR^2)^2}$$

since $R - YR^2 \neq 0$ then

$$R = \frac{1}{2Y} = \frac{L}{2 \cdot S \cdot d} \qquad (11)$$

Substituting this bus occupancy into equation 9 gives the minimum number of buses required as:

$$N_m = 4\, D \cdot d \qquad (12)$$

where

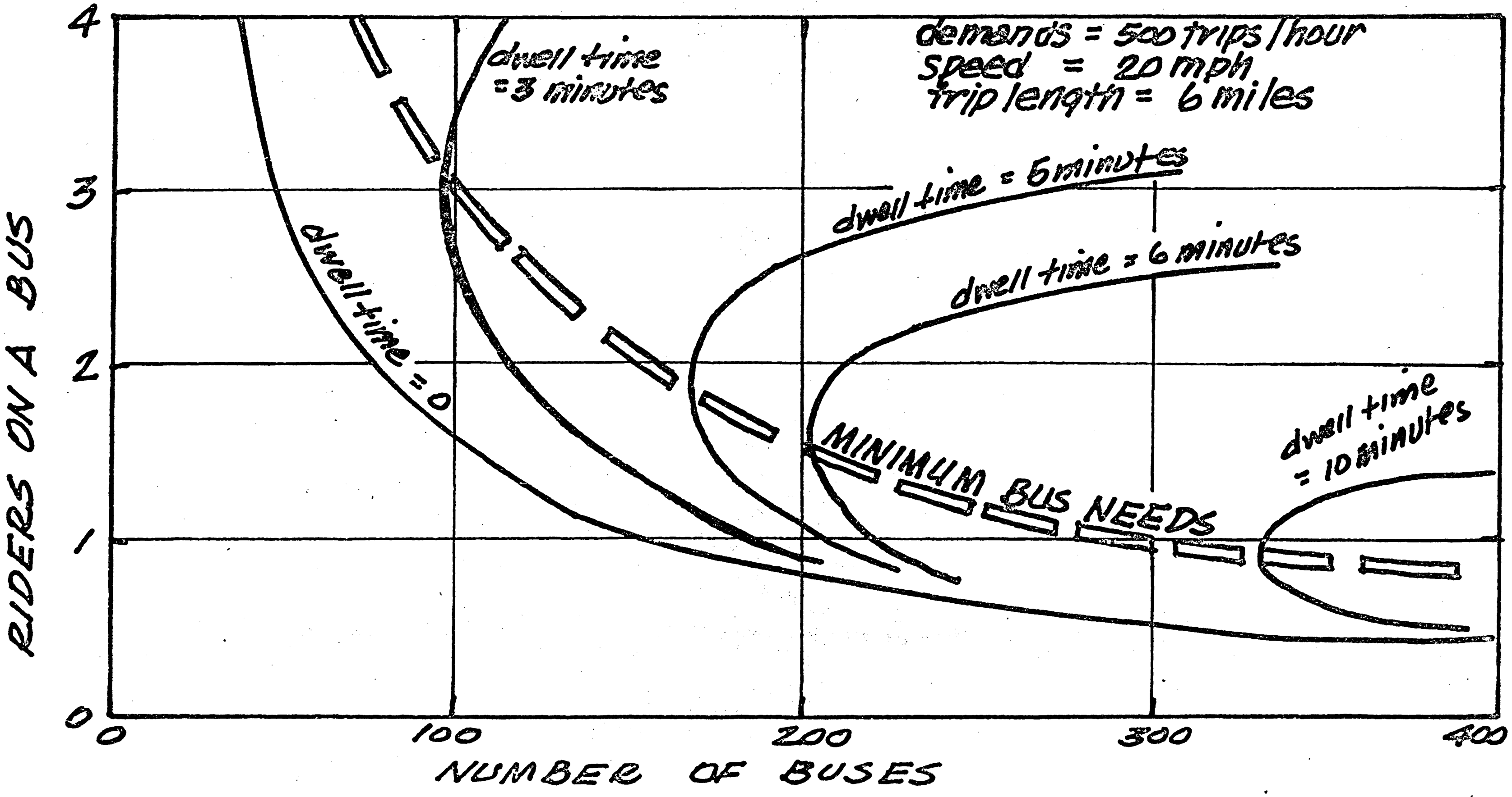
N_m = minimum buses needed when $R = \frac{L}{2 \cdot S \cdot d}$ riders per vehicle

D = transit demands per hour per mile square

d = dwell time to load and off load patrons

The graph of Equation 9 is shown in Figure F-1 for a unique D, S and L. The sensitivity of the vehicle fleet size to dwell time is easily seen in the graph and further reinforced by Equation 12. More revealing is the relationship between the number of vehicles and the ridership per vehicle. There is an optimum number of riders per vehicle.

FIGURE F-1
BUS REQUIREMENTS
BY AVERAGE BUS OCCUPANCY AND LOADING/OFF-LOADING TIME



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