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THE BEHAVIOUR OF THE CALIBRATION PARAMETERS IN THE [illegible] CAR OWNERSHIP MODEL, WITH PARTICULAR REFERENCE TO THE EFFECT OF PUBLIC TRANSPORT ACCESSIBILITY

ANTHONY CHARLES FRANSOS

Johannesburg, 1982

DECLARATION

I declare that this dissertation is my own unaided work. It is being submitted for the degree of Master of Science in Engineering in the University of the Witwatersrand,Johannesburg. It has not been submitted before for any degree or examination in any other University.

A. C. Fransos.

ANTHONY CHARLES FRANSOS

25th April 1982

ABSTRACT

The concept of accessibility is investigated,along with various types of accessibility measures. The effect of public transport accessibility on household car ownership is examined,using results of studies in the United States of America and the United Kingdom.

The behaviour of the Jomet car ownership model is studied in detail. Values of calibration parameters are derived for Jomet districts,Jomet zones and for households which were interviewed in home interview surveys. Values of parameters of the land use and transportation system are also found,and statistical tests carried out on the results.

From results of analysis of variance tests and regression tests on the three levels of aggregation,it is concluded that there is a relationship between the calibration parameters of the car ownership model and public transport accessibility in the Jomet study area.

Suggestions are made concerning the meaning of the calibration parameters and their behaviour. Recommendations are made for future use of the car ownership models,as well as for future research.

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I would like to express my sincere gratitude to the following people and organisations :

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CHAPTER ONE : INTRODUCTION

In 1975,a transportation planning study for the Johannesburg metropolitar (Jomet) area in the year 2000,was begun. The Jomet area includes the Johannesburg municipal area,and the surrounding municipal areas,being Germiston,Alberton,Edenvale,Bedfordview,Sandton,Randburg, Roodepoort and Soweto.

Forecasts for the study have been made using a transportation model, at the basa of which is a trip end model of the category analysis type. The trip end model has three parameters - household composition,household income and household car ownership. The car ownership model is, therefore,a sub-model of the trip end model and forms an important technical facet of the study in general.

In addition to the technical importance of car ownership forecasting, political and socio-economic implications of car ownership forecasting have recently become more significant. Issues such as the fuel crisis, provision of highways and parking ,etc., are receiving the increasing attention of politicians and the general public. In order to provide satisfactory facilities in the future,it is important to forecast car ownership reliably.

A model seeks to simulate reality,within the limits of complexity. Thus,it is important to understand the mechanisms of all interactions taking place in the model and in reality. It has been hypothesised, for example,that car ownership rates can be changed by changing the public transport accessibility in a given area. Further,it has been claimed that certain calibration parameters in the Jomet car ownership model reflect the level of public transport accessibility.

It is the purpose of this report to :

- study the performance of the Jomet car ownership in detail,
- study the influence of various household factors,especially public transport accessibility on the calibration parameters of the model.

CHAPTER TWO : THE BETA CAR OWNERSHIP MODEL

The primary purpose of this report is to investigate the behaviour of the parameters "α" and "β", used in the Domet car ownership model. It is, therefore, appropriate to study the development and uses of the "β" car ownership model.

2.1 Development of the model

The "β" car ownership model was first conceived by Wootton and Pick (ref. 1), who assumed that household car ownership is dependent on the income of the household and the parameter, "β". The model is based on the conditional probability of a household owning n cars, given that the household income is x.
Wootton and Pick found that the function was of the form:

$$P(n/x) = a.x^{m}.e^{-\beta x}$$

where $p(n/x)$ is the probability of the household owning n cars, given that the household's income is x, and a, m and β are determined by calibration.

The functions then take the form of the graphs shown in figure 2.1

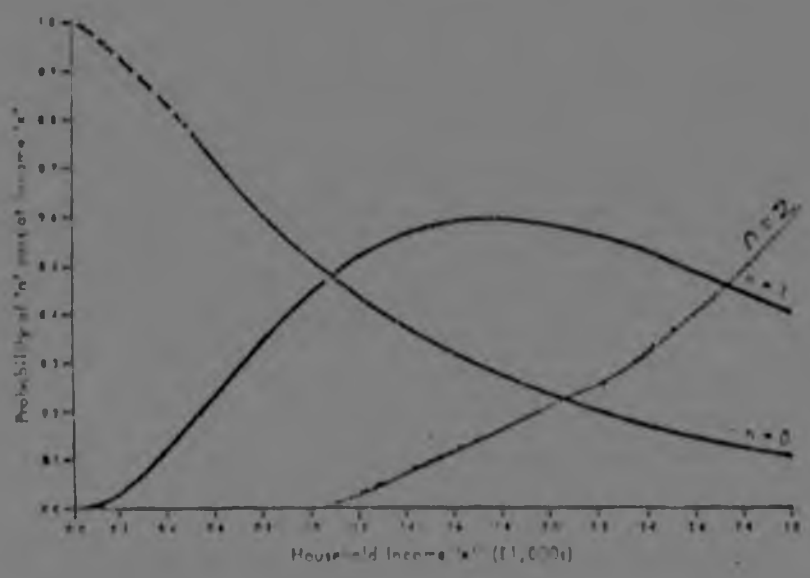


FIG. 2.1. Conditional probabilities of car ownership
Source : reference 1

[illegible]

[illegible] the expressions for the probabilities of a household owning [illegible] found by subtracting the sum of the former prob- [illegible].

$$[illegible]/x = [illegible] x^{m_0} e^{-\beta_0 x}$$

$$[illegible] = [illegible]$$

$$[illegible] = 1-P(0/x)-P(1/x)$$

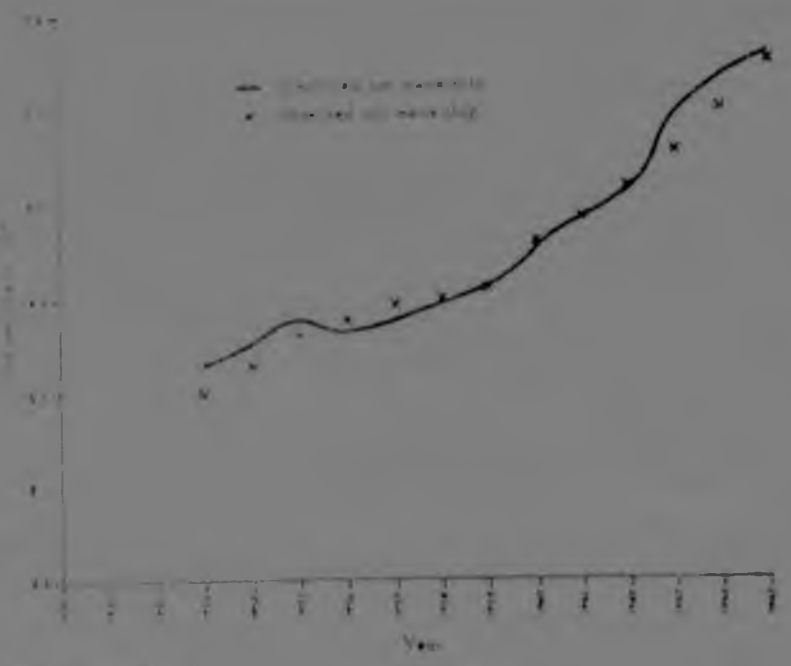
[illegible] the data for West Midlands, Wootton and Pick found the [illegible] expression fitted the data:

$$[illegible] = 1,15e^{-0,8x}$$

$$[illegible] = 1,64x^{2,29}e^{-1,31x}$$

$$[illegible] = 1-P(0/x)-P(1/x)$$

[illegible] and predicted levels of car ownership, [illegible] by the model are acceptable.



[illegible] and predicted car ownership rates-West Midlands

[illegible] : reference 1

A similar model was used for the South Yorkshire County tran[illegible] study(ref.2).However,in this study,the basic relationship was the probability of a household owning 1 car given that it owns at least 1 car and that the income of the household is x.This relationship took the form

$$P(1/1+/x) = \frac{de^{-\beta x}}{1+de^{-\beta x}}$$

where d is a calibration parameter,
and all other terms are as defined previously.

Since $P(1+/x) = 1-P(0/x)$,the following relationships were defined:

$$P(1/x) = P(1/1+/x).(1-P(0/x))$$
$$P(2+/x)= (1-P(1/1+/x)).(1-P(0/x))$$

A negative exponential relationship was fitted to the 0 car owning data,of the form

$$P(0/x) = ae^{-\beta x}-(a-1)e^{-b\beta x}$$

where a and b are calibration constants such that $b = \frac{a}{a-1}$

Thus the final forms of the relationships for this study were:

$$P(0/x) = 1,22e^{-0,512x}-0,22e^{-5,545\beta x}$$

$$P(1/x) = \frac{32,5e^{-0,512x}}{1-32,5e^{-0,512x}} \quad (1-P(0/x))$$

$$P(2+/x)= \frac{1-P(0/x)}{1 + 32,5e^{-0,512x}}$$

$$P(1/1+/x) = \frac{32,5e^{-0,512x}}{1+32,5e^{-0,512x}}$$

ie $\beta = 0,512$

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$$P(1/x) = \frac{32,5e^{-0,512x}}{1-32,5e^{-0,512x}} \quad (1-P(0/x))$$

$$P(2+/x)= \frac{1-P(0/x)}{1+32,5e^{-0,512x}}$$

$$P(1/1+/x) = \frac{32,5e^{-0,512x}}{1+32,5e^{-0,512x}}$$

ie β =0,512

Figure 2.3 shows the theoretical curves with observed values for car ownership in the study area, indicating once again that the model's results appear to be acceptable. Using this model, the effect of β is shown in figure 2.4. In this figure, the curves are shown for a number of values of β. The sensitivity of the model to β values is evident.

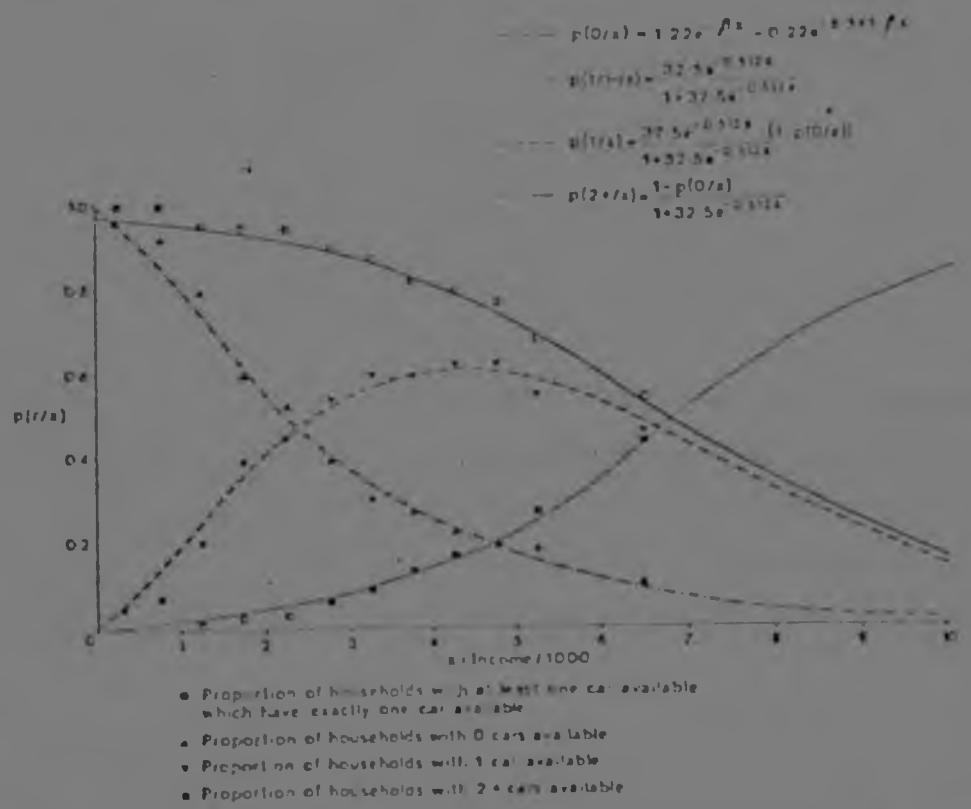

FIG. 2.3. Car ownership curves for South Yorkshire.

Source : reference 2

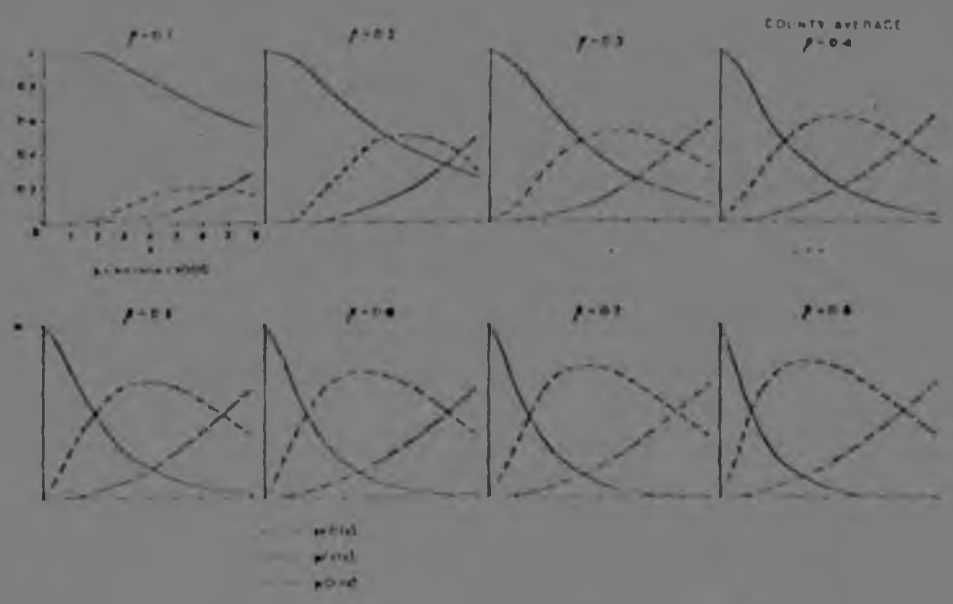

FIG. 2.4 Car ownership curves for a range of β values

2.2 The Jomet Car Ownership Model

The Jomet car ownership model followed a slightly different approach in that the relationships for 0 car and 2+ car ownership were found, and the 1 car owning category was defined as the residual probability.
ie. $P(1/x) = 1-P(0/x)-P(2+/x)$

The form of the relationships for the conditional probabilities were found to be as follows: (ref.3)

$$P(0/x) = a_0 + (b_0-a_0)\, e^{-\beta x}$$

$$P(2+/x) = b_2 e^{ce^{-\alpha x}}$$

where α is a calibration parameter and is an, as yet, undefined function of β,
$c = \ln\left(\frac{a_2}{b_2}\right)$, a_2 is the value of $p(2+/x)$ when $x=0$, and a_0, b_0, and b_2 are parameters defining the asymptotes and intercepts of the curves.

Note: Usually, $a_2=0$.

Car ownership was modelled for four different population groups, viz. Blacks, Coloureds, Asians and Whites. The model for each population group was of the above form, but the parameters varied. The final relationships found for each population group is shown in table 2.1.

2.3 The Importance of Beta

The car ownership is a sub-model of the trip end model. Since "β" is contained in the conditional probability expressions of the car ownership model, it lies at the base of the trip end model and it is therefore important to estimate "β" correctly. By knowing the distribution of income, the conditional probabilities may be unconditioned as follows :

$$P(n) = \int_0^{\infty} P(n/x).f(x)\, dx,$$

where $f(x)$ is the distribution function of income, x.

In an exercise carried out by the Jomet study team (ref.5),the Jomet trip end model was used to predict trip ends for different values of "β". The results of this exercise are shown in tables 2.2,2.3 and 2.4.

The total number of trips predicted does not appear to be unduly sensitive to "β". However,modal choice appears to be sensitive to changes in "β",especially at low values of "β". In addition,home based other trips and non home based trips are affected more by a change in "β" than are work trips.

2.4 The Behaviour of Beta

The values of "α" and "β" for the various population groups were found using maximum likelihood methods based on data for the whole study area. Therefore,the values of "α" and "β" used in the model are averages for the whole area.

The primary investigation of this report is the hypothesis that β is a function of public transport accessibility. It is necessary,therefore, to discover a spatial variation in β which reflects the variation of public transport accessibility. The fundamental question is :
Does β vary significantly,spatially and if so,is the variation related to the spatial variation in public transport accessibility?

As will be shown in chapter 3,strong evidence of a relationship between public transport accessibility and car ownership has been found in studies overseas. If a similar relationship exists in the Jomet area, and there seems no reason to assume otherwise,then in areas of high public transport accessibility,car ownership rates should be low. Because of the form of of the "β" model,when car ownership levels are low,β is low. Thus,β should be inversely proportional to public transport accessibility.

Ideally,to study variations in β,values of β from various studies should be compared. However,if one compares,for example,the values

Table 2.1 The Jomet Car Ownership Models

	$P(0/x)$	R^2	$P(2+/x)$	R^2
Blacks	$0,15+0,85e^{-0,1x}$	0,83	$0,4e^{ce^{-0,25x}}$	0,69
Coloureds	$0,052+0,94e^{-0,2x}$	0,75	$0,5e^{ce^{-0,175x}}$	0,73
Asians	$0,04+0,96e^{-0,25x}$	0,88	$0,75e^{ce^{-0,19x}}$	0,88
Whites	$0,97e^{-0,35x}$	0,91	$0,9e^{ce^{-0,225x}}$	0,98

In all cases c is approximately $-4,5$

Table 2.2 β and total trips predicted

	WHITES β			BLACKS β		
	0,15	0,35	0,45	0,05	0,10	0,25
Total trips (x 1000)	1539	1687	1750	1077	1084	1105

Table 2.3 β and % of total trips on public transport

	WHITES			BLACKS		
	β			β		
	0,15	0,35	0,45	0,05	0,10	0,25
% on public transport	18	14	11	54	52	45

Table 2.4 β and purpose splits

	WHITES			BLACKS		
	β			β		
	0,25	0,35	0,45	0,05	0,10	0,25
% Home based Work	34	31	29	55	53	47
% Home based Other	32	35	36	35	33	32
% Non Home Based	13	14	15	6	8	9
% Home based Education	21	20	19	4	6	11

of β found in the SELNEC,West Midlands and South Yorkshire studies,the results of of such a comparison are dubious. The models for the three studies mentioned are of different forms,and therefore the definition of β in each study is likely to be different. Furthermore,extraneous socio-economic influences on β values will differ from one city to another eg. residential and employment densities,average size of households,etc.

In order to minimize the the differences in 'external' factors,statistics for South African cities should be studied. Table 2.5 is presented by Stanway (ref.4) and shows values of β for three cities in South Africa along with some household statistics. It can be seen that household statistics within any population group remain approximately constant. However,there is no great variation in β between the three cities and,further,there is no information on public transport accessibility in the cities. The information shown in table 2.5 does not encourage the hypothesis that β has a spatial variation.

If data is examined for the Jomet area specifically,spatial variation of β is suggested. Table 2.6 shows data gathered from calculations of the Jomet study team (ref 5). The β values for Whites and Blacks are shown for two different areas. For both cases, the values of β change significantly. If Coloureds and Asians are compared,there is once again a significant change in average β values.

There is a complicating factor in the Jomet study,namely the factor, α. Sandrock (ref. 3) states that α is a function of β. The Jomet study team examined the relationship between α and β values and obtained a relationship as shown in figure 5.1. This relationship was obtained by plotting the average α and β values for each population group. Because of the vastly differing socio-economic characteristics of the four population groups,and the unknown effect of these differences on α and β values,the relationship must be considered suspect. The unexpected result obtained for Blacks fuels this doubt.

It is interesting to note that the values of α given in table 2.6 show no variation within a population group. The flat slope of the relationship shown in figure 5.1 also suggests that α is less variable

Table 2.5. Car ownership statistics for some South African cities

Source : reference 4

Variable / Area & Race	'β'	Ave H.H. Income p.a. (R)	Cars/1000 Population	Average per H.H	
				Persons	Workers
JOMET (1975)					
Whites	0,35	9585	420	3,09	1,22
Asians	0,25	6725	161	5,57	1,78
Coloureds	0,20	4454	89	5,71	1,77
Blacks	0,11	2692	34	6,02	1,99
CAPE TOWN (1976)					
Whites	0,32	7600	413	3,03	1,20
Coloureds	0,16	3300	73	5,61	1,88
PRETORIA (1974)					
Whites	0,24	6600	414	3,16	1.35
Blacks	0,05	-	30	5,89	1,91

Table 2.6 α and β values in the Jomet area

Population Group		β-Value	α-Value
Whites	Jomet	0,35	0,225
Whites	Johannesburg	0,30	0,225
Blacks	Soweto	0,11	0,25
Blacks	Dube	0,175	0,25
Coloureds		0,2	0,175
Asians		0,25	0,19

Source : reference 3

than β . The relationship between α and β is investigated in detail in a later section.

2.5 Conclusion

Conceptually,it is likely that there are spatial variations of both car ownership rates and public transport accessibility,within the Jomet study area. The problems which must now be solved are purely analytical. These problems are :

- To calculate car ownership rates for spatially separated units and to express those rates in terms of α and β values.
- To enumerate the public transport accessibility of the above units in terms of a satisfactory measure of accessibility.
- To decide whether there is a relationship between α or β values and public transport accessibility based on results obtained by the exercises described above.

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CHAPTER THREE : THEORETICAL BASIS OF THE INVESTIGATION

The concept of accessibility, its measurement, and its effect on [illegible] ownership are now examined.

3.1 Accessibility

The concept of accessibility is of fundamental importance to [illegible]. It is therefore necessary to examine this concept in detail, along with the means by which it can be measured.

3.1.1 The concept of accessibility

Human activities take place, distributed unevenly in time and space. Individuals are generally separated from these activities temporally, specially or both. Human activity can be represented by a space-time model, in which every action and event which compose an individual's existence, are recognized to have spatial and temporal attributes (ref 1), as shown in figure 3.1. This method of representation reveals the manner in which the activities of an individual are limited by combinations of a variety of constraints.

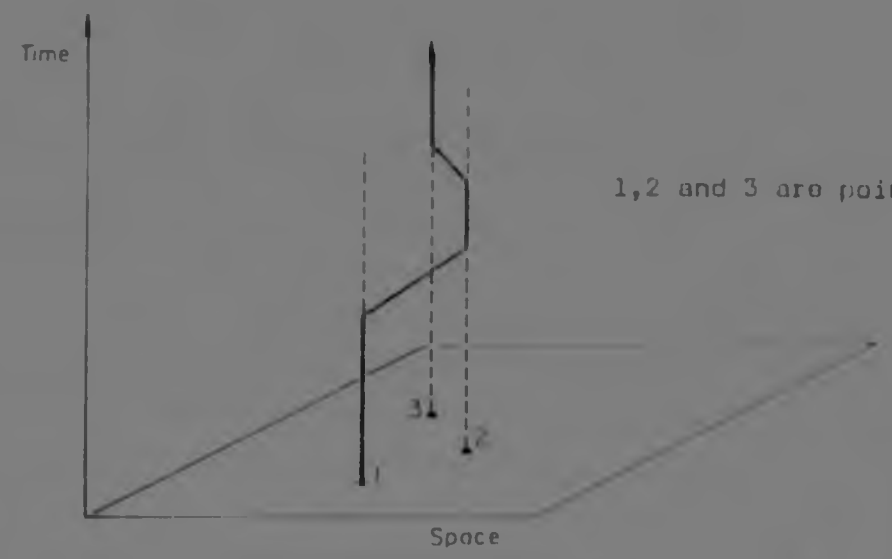

FIG. 3.1. Space-time representation of human activity
Source : reference 1

The constraints include :

- capability constraints - sleeping,eating, system capabilities,etc.
- coupling constraints - places and times where an individual must join others eg. work,entertainment,etc.
- authority constraints - general rules,laws, economic barriers,etc.

Without any constraints,the individual can occupy any point on the space time plane. However,suppose the individual is constrained to being at point r_1 at time t_1,and to being at point r_2 at time t_2. If the maximum speed is v km/h,these constraints can be plotted on the space-time plane as shown in figure 3.2. The individual may then occupy any position within the unshaded portion of the figure. By plotting all such constraints,space-time prisms may be defined,inside which an individual can occupy any point,and outside which it is impossible for him to occupy any point.

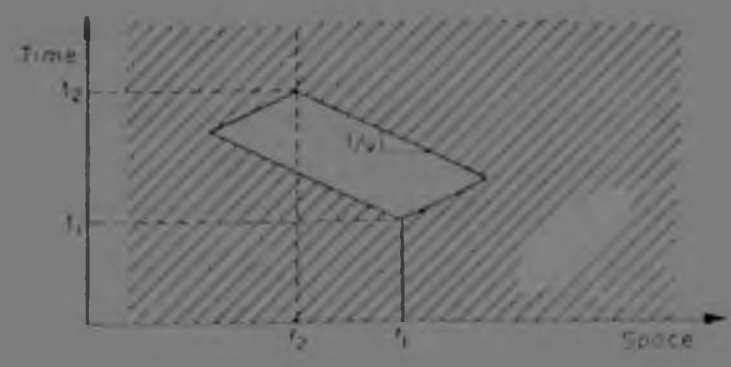

FIG. 3.2. Space-time diagram showing constraints
Source : reference 1

In order for an individual to participate in an activity,it is necessary for the space-time prisms of the individual and the activity to have common area on the space-time plane. Even if this situation is satisfied,it is not sufficient for an individual to participate in that activity. He must also have the ability and authority to participate. Thus,the individual is constrained within his space-time prism by factors such as physical ability,laws,etc.

Disregarding the time and location of activities,it can be assumed that accessibility is related to the size of the prism. This in turn depends on the slopes of lines bordering the prism,and on the locations of the vertices in space and time. Thus it can be deduced that accessibility has two facets :

- the slopes of the prism borders are determined by the velocity with which the individual can move. This is a measure of the performance of the transport and land use systems. If the extent to which the individual is able to use the system is taken into account, the result is a measure of the mobility of the individual.

- the location of the activity in time and space. Not only must the individual be at the place of activity,he must be there at the correct times.

3.1.2 Towards a definition of accessibility

In general,accessibility refers to the ease with which an individual may reach a location to participate in an activity. This definition is,however,rather simplistic and should be more specifically defined.

Mobility is often confused with accessibility. Mobility refers to the ease with which an individual can move to his activities. Accessibility refers to the ease with which an area or activity can be reached by an individual (ref 6).

Detailed definitions of accessibility vary widely,and the final definition may depend on the aims and objectives of the study for which a definition is required. Jones (ref 2) outlines a number of definitions. It can be seen that each definition has a different emphasis eg. spatial seperation,economic seperation,etc. These definitions are repeated here.

a. Accessibility is a measure of spatial seperation between an individual and the location of the activity in which he wishes to take part.

b. Accessibility is a measure of the travel cost of observed or expected trips undertaken by individuals in travelling to the location of the activities in which they wish to take part.

c. Accessibility is a measure of the opportunities which an individual has to take part in an activity.

d. Accessibility of an area is the average accessibility of an individual, weighted according to the importance of the individual to activities in that area.

e. Accessibility is a measure of the net benefit which an individual achieves by using a transport system. This definition is perhaps the most comprehensive,as it takes into consideration,not only the trip and personal characteristics ,but also the importance of the aims and preferences of the individual.

3.1.3 Types of measures

A number of types of measures of accessibility have been used,and these will now briefly be examined.

a. Network measures (ref 2 and 4). These measures are concerned simply with the transport network,usually described in terms of links and nodes, as in a computer model. The accessibility at a node can then be measured in various ways,including the following :

- the distance from any node to the node furthest from it
- the number of nodes which can be reached from a given node within a given time
- the total travel cost from a given node to all other nodes in the network.

This last measure is known as the Shimbel measure and was modified by Ingram (ref 5),who regards the accessibility of a node as a function of the cost of travel between a given node and all other nodes. In addition the accessibility of zones was defined by Ingram in terms of the travel cost between zones :

$$A_i = \sum_j f(c_{ij})$$

where A_i is the accessibility of zone i,c_{ij} is the cost of travel between zones i and j,and f is a function of deterrence of travel cost.

Because the total travel cost from one node to all other nodes decreases with increasing accessibility,the Shimbel measure is one of inaccessibility rather than of accessibility. Ingram's measure appears to emphasize the performance of the transport system rather than the spatial or temporal seperation. As such,it is closer to being a measure of mobility than of accessibility.

b. Measures of travel (ref 2). This type of measure uses the average cost of trips leaving a zone as a measure of the inaccessibility of that zone. This type of measure is simply a travel weighted average of costs from a given zone to all other zones. As such,it is an extension of the Shimbel measure. A problem with this type of measure is that one cannot be sure whether a high inaccessibility is caused by high travel costs or by a low proportion of travel between relevant zones.

c. Disaggregate combined transport and land use measures (ref 2). The first type of measure in this category is the contour measure,in which the accessibility of a zone is measured as the number of relevant opportunities situated within given travel cost or time contours. A second type of accessibility measure is the number of opportunities which occur within an individual's space-time prism. Prisms are determined using principles explained in section 3.1.1.

d. Aggregate combined transport and land use measures (ref 2). The most important aggregate measure of accessibility of this type is known as the Hansen index. The most general form of the Hansen accessibility index may be stated mathematically as follows :

$$A_i = \sum_j B_j \, f(c_{ij})$$

where B_j is the number of opportunities in zone j,
c_{ij} is the cost of travel between zones i and j,
and f is a function of deterrence of travel cost.

There are two common variations of the Hansen measure,which may be stated as follows :

- the normalized Hansen index

$$A_i = \frac{\sum B_j f(c_{ij})}{\sum_j B_j}$$

where all terms are as defined above.

- the population weighted Hansen index

$$A_i = P_i \sum_j B_j f(c_{ij})$$

where P_i is the population of zone i.

It can be shown (ref 2) that the Hansen index is a measure of the consumer surplus.

The revealed value measure of accessibility uses the principle that people seek to maximize the net benefit or consumer surplus obtained by using the transport and land use system.

Accessibility may also be measured with the use of rent and salary differentials between two areas,or the difference in amounts of money that people are willing to pay for houses in the two areas. This measure gives the relative accessibilities of two areas.

Another measure belonging in this category is the index as used in the London Transportation study (ref 5). This measure is intended for public transport and may be stated mathematically as follows :

$$AI_j = \sum \frac{\sqrt{N_{ij}}}{\sqrt{A_j}}$$

where AI_j is the accessibility index of zone j,

where AI_j is the accessibility index of zone j,

N_{ij} is the frequency of the ith service t

A_j is the residential area of zone j.

3.1.4 Relative merits of measures.

The choice of type of measurement of accessibility will be mainly decided upon by the data available. However,a short discussion on

the merits of the types of measures is useful.

a. Network measures. The advantage of network measures is their simplicity. However,they do not take account of the individual or the opportunities for activities. These measures are therefore only suitable for superficial requirements,and are,in fact,measures of mobility.

b. Travel measures. The main advantage of this type of accessibility measure is that the data required for their calculation are often readily available. There is a problem in the fundamental assumption of the measure. In using a travel measure,one assumes that the existing levels of travel are the desired levels of travel,which may not be the case (ref 2).

c. Disaggregate combined measures. These measures take into consideration all aspects of the individual's mobility,as well as the characteristics of the land use and transport system. Time-space geography measures,in particular,also account for the restraints on the individual. Data requirements are,however,excessive,and calculation is complex.

Contour measurements seperate the land use and transport elements of accessibility,and do not attempt to evaluate the combined effect. While this leads to a simple index without hidden assumptions,large numbers of results can be obtained. Data for contours are usually easily obtainable (ref 2).

d. Aggregate combined measures. Revealed value measures are limited to effects which are likely to change property values measurably. The consumer surplus approach can only show a change in accessibilities under two sets of conditions (for example, 'before' and 'after' conitions). This method of measuring accessibility gives little indication of the benefits or costs for those who do not use the system.

All other aggregate measures have a serious flaw,in that the individual effects of the land use system and the transport system are disguised; only the combined effect is known. The London type index is most suited to a city where there is radial and circumferential demand,

since it measures the accessibility of the zone of origin. In cities such as Johannesburg,where there is a poor service and low demand in a large number of zones,the index loses meaning.

3.2 Car Ownership and Public Transport Accessibility

The relationship between car ownership and public transport accessibility has been the subject of much investigation and discussion. It seems logical that car ownership rates are inversely proportional to public transport accessibility because a good transport service should reduce the incentive to buy a car. Conversely,though,areas of high car ownership rates reduce the patronage of services,thus discouraging high public transport accessibility.

The problem which presents itself may be expressed in three questions :
-Is the intuitive assumption that a relationship between car ownership and public transport accessibility exists borne out by fact?
-How sensitive is this relationship?
-Which of the two parameters is more dependent on the other?

This section studies results of investigations into the relationship carried out in the United States of America and in the United Kingdom.

3.2.1 United States of America

In a study of Oregon and Washington metropolitan areas,Shindler and Ferrerri (ref 7) calculated accessibilities of zones based on time for travel by transit and highway. An accessibility ratio for each zone was calculated,denoting the ratio of transit accessibility to highway accessibility. Using a regression analysis for each zone,it was found that better than 40% of the variation in number of cars per household could be explained by the accessibility ratio. Furthermore, the degree of correlation increased from 65% to 70% if the natural logarithm of the accessibility ratio is employed.

The final car ownership model in the study was a regression model including the number ofpersons per dwelling unit,the household income, and the logarithm of the accessibility ratio. The accessibility ratio played a dominant role in this regression model,and if this evidence

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The final car ownership model in the study was a regression model including the number ofpersons per dwelling unit,the household income, and the logarithm of the accessibility ratio. The accessibility ratio played a dominant role in this regression model,and if this evidence

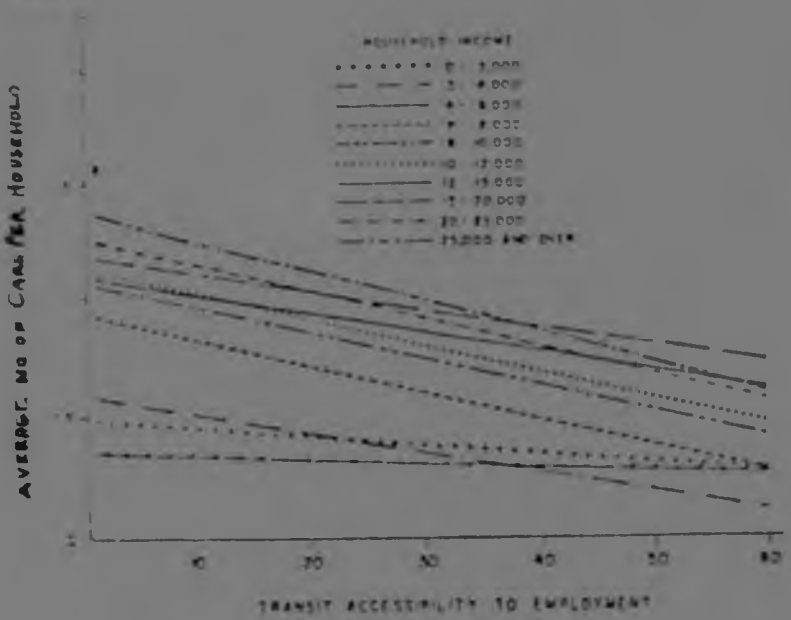
is extrapolated,Ferrerri and Shindler hypothesised that
-after a sufficient period of time has elapsed,an improved transit service will result in lower car ownership rates in that area.
-if a good,high speed transit service is provided at the outset of development of a new area,car ownership rates will be lower than if the transit service was not provided.

The work of Ferrerri and Shindler was criticized because average household characteristics for each traffic zone were used as independent variables. Family size and income are related,not only to each other,but also to transit accessibility. It is,therefore,difficult to determine the precise effect of transit accessibility on car ownership rates while keeping the other factors constant.

Dunphy (ref 8) describes a study undertaken in Washington D.C.,in which data were disaggregated by household size and income. Thus car ownership could be related by linear regression to transit accessibility,for households of the same size and income. Households were divided into 10 income groups and 4 size groups. For each category, the car ownership relationship with transit accessibility was estimated using linear least squares techniques. The transit accessibility measure was estimated by the percentage of jobs reached from an area in 45 minutes by transit. The results of this analysis are shown graphically in figure 3.3.

The only categories which did not show a significant relationship at the 99% level of confidence are :
- one person households with incomes of $4000 to $ 6000
- one person households with incomes of $20000 to $25000
- four or more person households with incomes greater than $25000.

In addition,the regression lines of the relationships for the above categories do not follow the pattern set by the other lines. This suggests that the data for these categories are either insufficient or faulty. In general,though,Dunphy shows that there is a significant relationship between car ownership and public transport accessibility. Furthermore,he shows that the effect of transit accessibility on car ownership is approximately the same at all income levels for a given household size. In addition,the slopes of the regression lines are



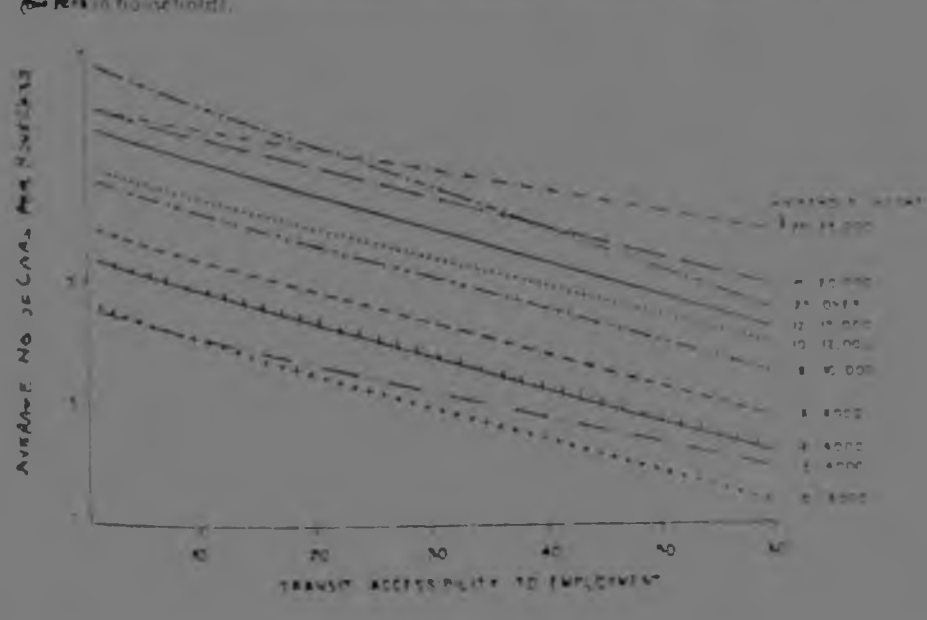


FIG. 3.3 (a) Car ownership and transit accessibility in Washington

Source : reference 8

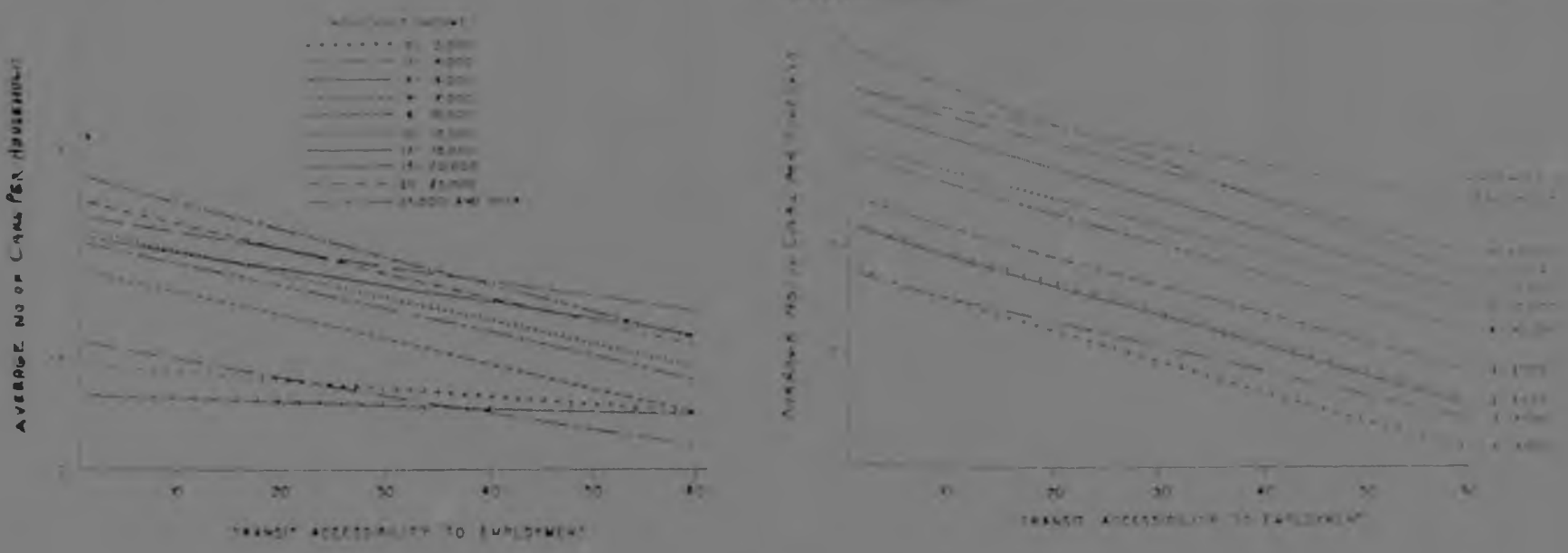
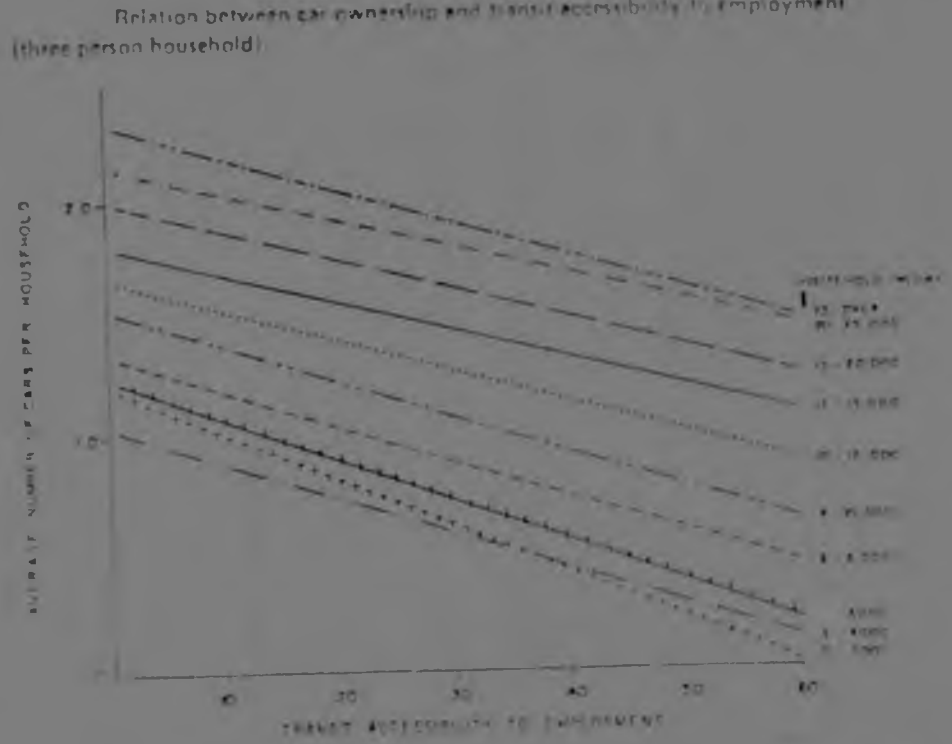


FIG. 3.3 (a) Car ownership and transit accessibility in Washington

Source : reference 6



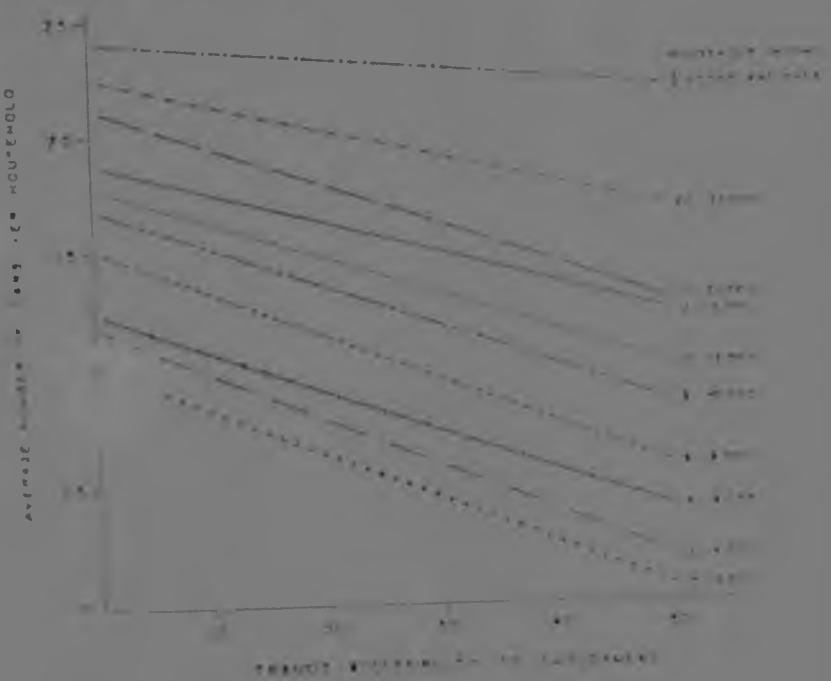


FIG. 3.3 (b) Car ownership and transit accessibility in Washington

Source : reference 8

all approximately the same,suggesting that the car ownership levels change at a constant rate with respect to transit accessibility for all categories of household.

It should be noted that this approach did not take into account any purpose other than work trips. Thus,the effect of transit accessibility on the need for a second car is not taken fully into consideration. Also,unlike the Ferrerri and Shindler study,no account was taken of highway accessibility.

On the basis of model predictions,Dunphy suggests that in a newly developed area with a special transit proposal,the car ownership rates can be expected to be about 25% lower than similar towns with an average transit service. This suggestion is in agreement with the hypotheses of Ferrerri and Shindler.

3.2.2 United Kingdom

A number of studies in the U.K. have investigated the relationship between car ownership and public transport accessibility,and all have found evidence of correlation between the two parameters.

Fairhurst (ref 5) describes the method used to model car ownership in London. The public transport accessibility measure was evaluated as follows :

$$\text{Public transport accessibility index} = \frac{\sqrt{N_{ij}}}{\sqrt{A_j}}$$

where A_j is the residential area of zone j and N_{ij} is the midday frequency of the ith service to zone j.
The value of the index was plotted against the probability of a household owning 0 cars, as shown in figure 3.4. The final form of the car ownership model was a linear multiple regression type,including household size,income,and bus and train accessibility indices. The accessibility indices were found to have a statistically significant effect on the car ownership rates. In fact, Fairhurst estimates that the accessibility indices were about twice as important as household size in determining car ownership. However,as with the work of Ferrerri and Shindler,there is a high level of correlation between the indepen-

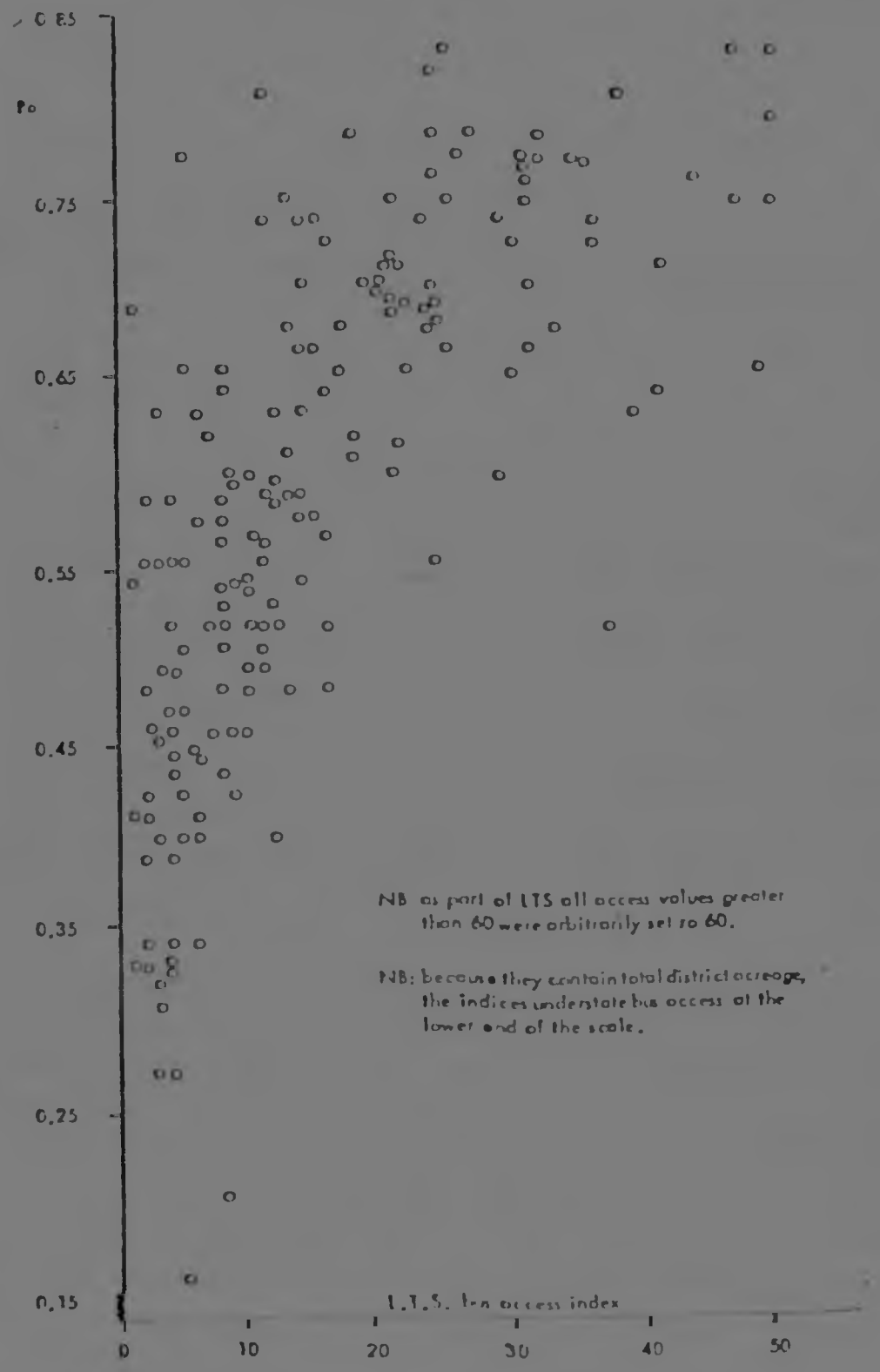


FIG. 3.4. Proportion of non-car owning households and accessibility index in London

Source : reference 5

dent variables,sothat the precise effect of varying one without the others cannot be meaningfully estimated.

Fowkes et al (ref 9) examined the effect on car ownership of three types of measurement of public transport accessibility:
- the household residential density
- an estimate of the journey to work time by public transport
- the mean reduction in generalized cost to households,from having more than 0,6 cars available per driving license to being totally dependent on public transport.

The results were categorized into classes by increasing accessibility, the first measure having 4 categories,the second having 7 categories and the third having 4. The results of this study are shown in table 3.1. It can be seen that density,d, is negatively related to car ownership for all but the lowest income groups. In addition,the car ownership can be seen to be more sensitive to changes in density than to the generalized cost measure. A positive relationship exists between car ownership and journey to work time,although for short times (categories 1,2 and 3) there is little variation in car ownership. The data also suggest that the car ownership for very short journey times increases slightly.

Bates et al (ref 10) found that public transport accessibility was a major factor in determining car ownership levels for the Regional Highway Traffic Model (RHTM). In this study,based on data collected in a Family Expenditure Survey,data were categorized into 6 accessibility bands,band 6 being the most accessible. Car ownership was then predicted as a function of income,for each accessibility band. A form of Hansen accessibility index was used to calculate accessibility. Figure 3.5 shows the proportion of car owning households and the actual proportions against income for each accessibility,and figure 3.6 shows the actual and predicted proportions of multi-car owning households. In both diagrams,the existence of an inverse relationship between car ownership and public transport accessibility is evident.

Further evidence from other studies is documented in TRRL 464 (ref 11), but will not be investigated further in this report.

Table 3.1. Car ownership rates for West Yorkshire and the effect of household accessibility

Source : reference 9

D = household residential density

T = journey to work time

G = generalized cost measure

			% of HOUSEHOLDS WITH NO CAR AVAILABLE, P_0								
			Annual Household Income								
	Accessibility Variable	Value of Accessibility Variable	Under £1041	£1041 – £2080	£2081 – £3120	£3121 – £4160	£4161 – £5200	£5201 – £6240	£6241 – £7800	Over £7800	All Incomes
All	All		93.8	71.1	42.2	29.5	21.7	13.9	9.4	5.9	54.1
D	1		92.3	64.2	37.3	24.0	14.2	5.9	5.8	0.0	46.9
	2		94.9	71.5	33.2	27.3	20.2	5.3	9.3	4.9	49.7
	3		95.1	71.3	46.5	28.1	24.2	16.7	12.8	6.2	55.3
	4		93.0	77.7	52.9	40.9	33.9	38.5	10.3	25.0	65.4
G	1		92.7	71.9	48.7	31.3	26.5	16.9	14.3	13.9	58.0
	2		95.2	72.7	44.8	36.5	21.6	26.6	14.7	3.4	57.9
	3		93.7	72.7	41.7	30.4	21.9	8.5	7.7	6.2	54.1
	4		93.5	66.4	33.8	20.6	17.8	8.0	2.0	1.8	46.4
T	1		91.7	76.4	46.3	36.0	11.8	–	–	–	60.7
	2		75.0	86.1	66.7	47.4	23.8	–	–	–	63.9
	3		100.0	78.7	56.8	43.2	47.9	–	–	–	61.7
	4		82.4	77.8	55.8	37.4	24.3	20.0	7.7	–	53.7
	5		–	72.0	42.1	34.4	8.2	20.0	0.0	–	40.5
	6		–	51.6	28.9	21.9	8.3	18.7	–	–	28.7
	7		–	33.3	28.3	10.3	0.0	4.2	0.0	8.3	14.4

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			Annual Household Income								
	Accessibility Variable	Value of Accessibility Variable	Under £1041	£1041 – £2080	£2081 – £3120	£3121 – £4160	£4161 – £5200	£5201 – £6240	£6241 – £7800	Over £7800	All Incomes
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D		1	92.3	64.2	37.3	24.0	14.2	5.9	5.8	0.0	46.9
		2	94.9	71.5	33 '	27.3	20.2	5.3	9.3	4.9	49.2
		3	95.1	71.3	46.5	28.1	24.2	16.7	12.8	6.2	55.3
		4	93.0	77.7	52.9	40.9	33.9	38.5	10.3	25.0	65.4
G		1	92.7	71.9	48.7	31.3	26.5	16.9	14.3	13.9	58.0
		2	95.2	72.7	44.8	36.5	21.6	26.6	14.7	3.4	57.9
		3	93.7	72.7	41.7	30.4	21.9	8.5	7.7	6.2	54.1
		4	93.5	66.4	33.8	20.6	17.8	8.0	2.0	1.8	46.4
T		1	97.7	76.4	46.3	36.0	11.8	–	–	–	60.2
		2	75.0	86.1	66.7	47.4	23.8	–	–	–	63.9
		3	100.0	78.7	56.8	43.2	42.9	–	–	–	61.7
		4	82.4	77.8	55.8	37.4	24.3	20.0	7.7	–	53.7
		5	–	72.0	42.1	34.4	8.2	20.0	0.0	–	40.5
		6	–	51.6	28.9	21.9	8.3	18.7	–	–	28.7
		7	–	33.3	28.3	10.3	0.0	4.2	0.0	8.3	14.4

= household residential density

T = journey to work time

= generalized cost measure

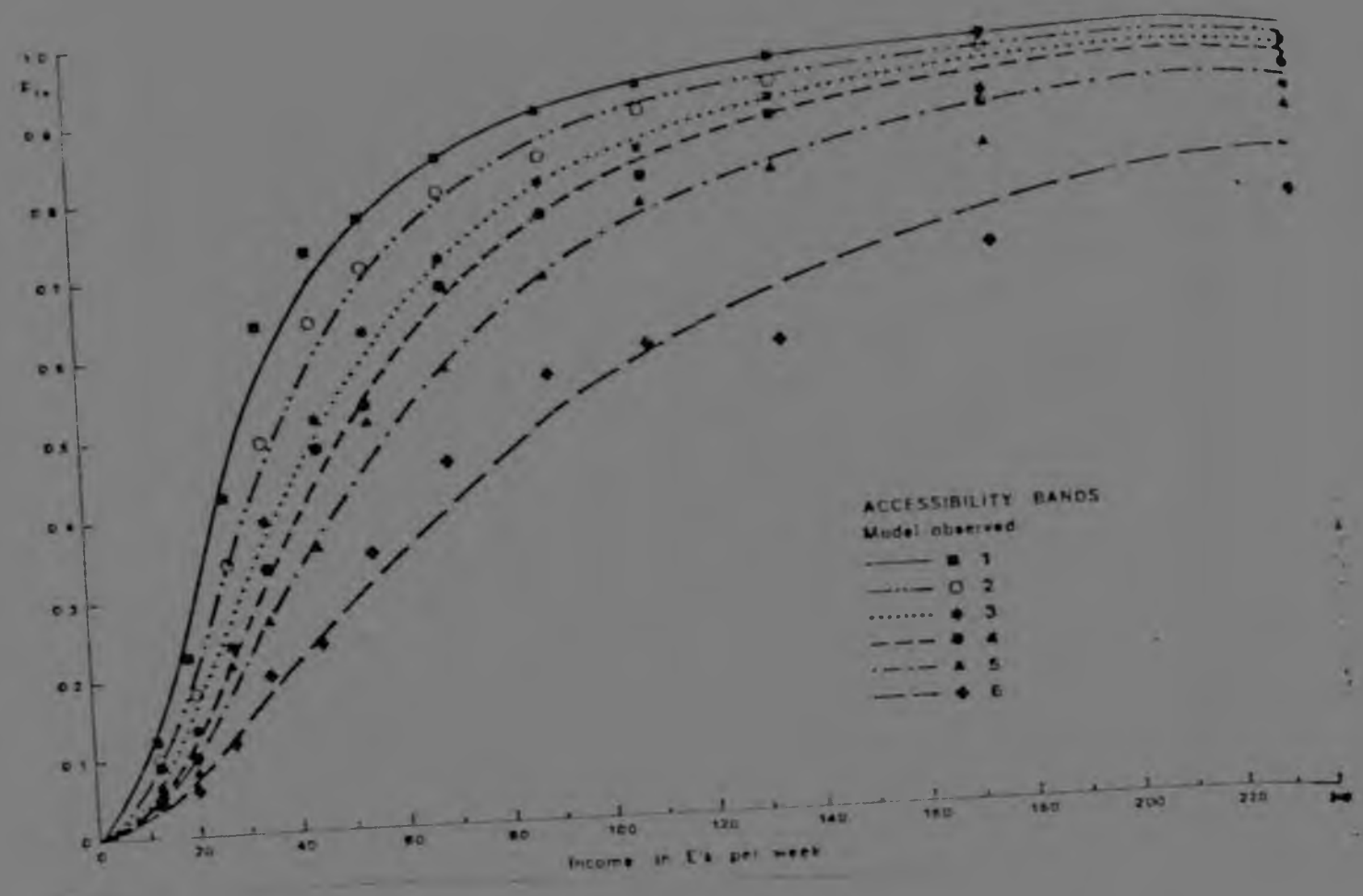


FIG. 3.5. Proportion of car owning households for RHTM

Source : reference 10

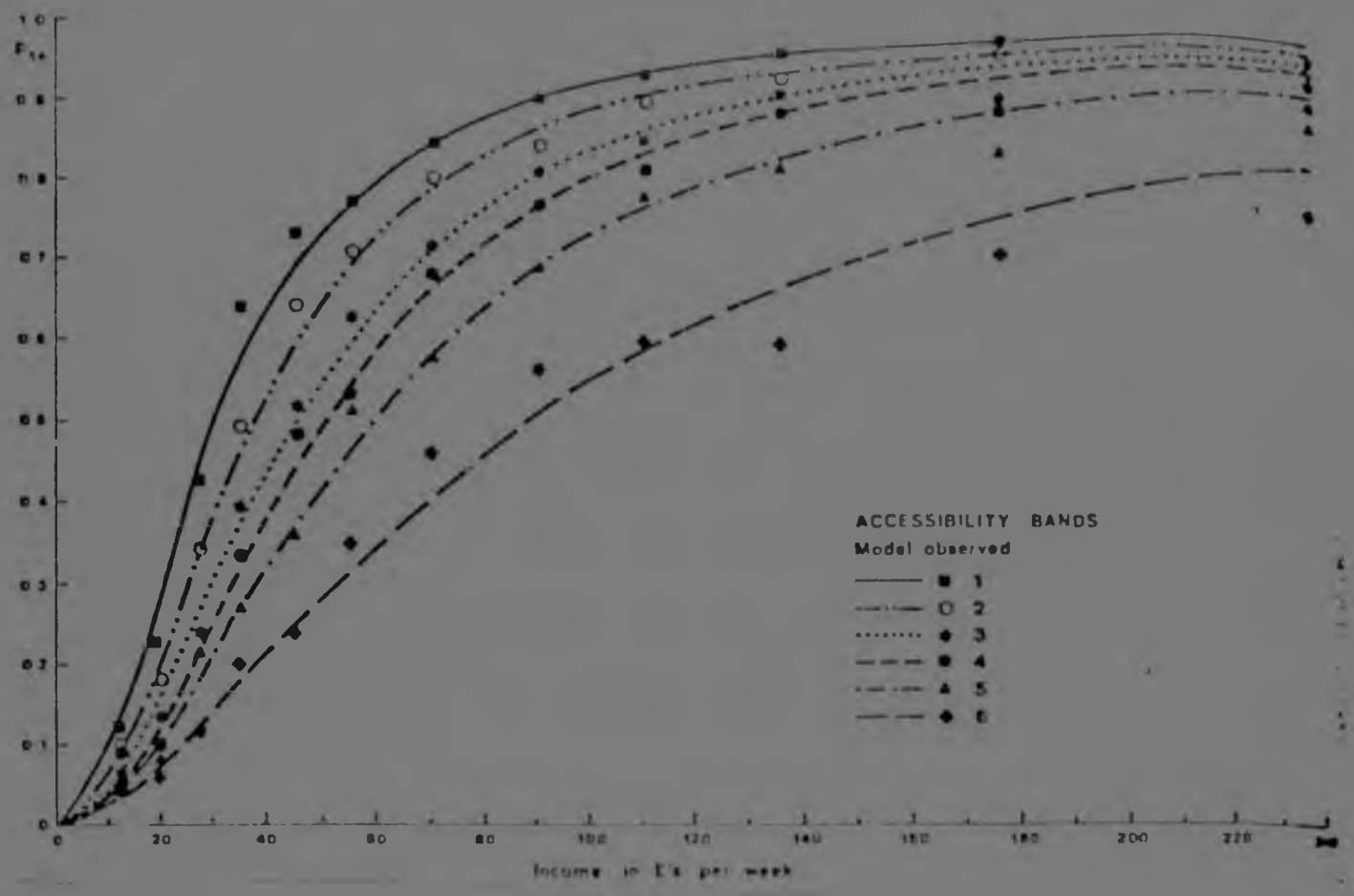


FIG. 3.5. Proportion of car owning households for RHTM

Source : reference 10

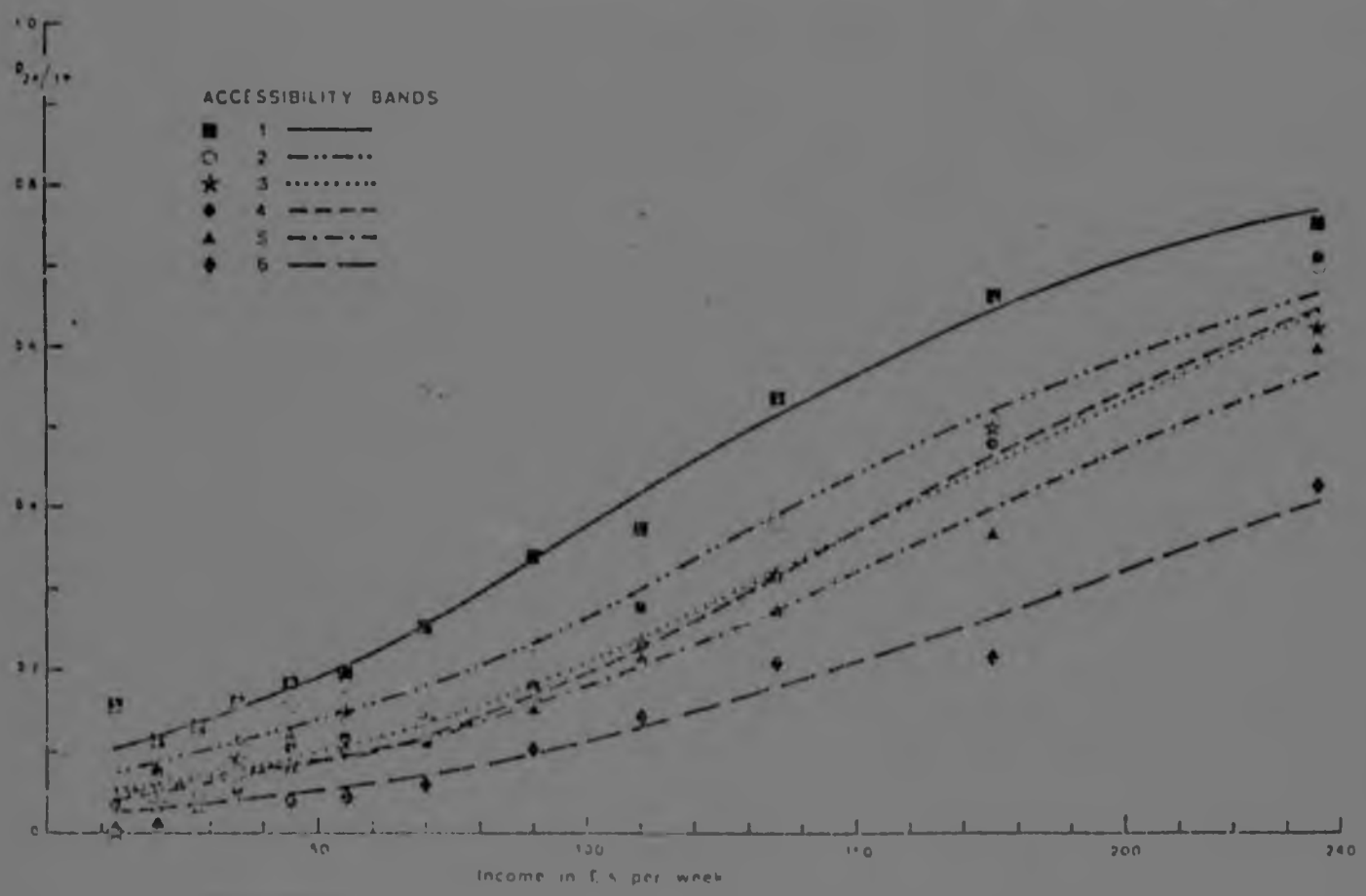


FIG. 3.6. Proportion of multi-car owning households for RHTM

Source : reference 10

3.2.3 The Jomet area

Having examined evidence produced by British and American studies,it is now appropriate to examine local data for similar interaction between car ownership and public transport accessibility. Although no formal reports have been written on this subject,studies have been conducted jointly by the Jomet study team and the University of the Witwatersrand,using data from the Jomet study.

The Jomet study area is divided into 56 districts. Accessibility to place of employment by public transport was calculated using a Hansen type index (ref 12). Accessibility indices for the districts were then divided into 3 accessibility bands - high,medium and low. The proportion of households in each accessibility band owning 0 cars was calculated for each of 12 income groups. The corresponding proportions of households owning 2 or more cars were also calculated. The results of this exercise are shown in table 3.2.

The decrease of the proportion of households owning no cars is well illustrated,as is the increase in the proportion of households owning more than one car,with decreasing public transport accessibility. For the purposes of this study, a further exercise was undertaken using ,as a measure of public transport accessibility,the distance from home to nearest public transport terminal and the corresponding distance from terminal to place of employment. Each distance is divided into 8 categories,category 1 being the shortest distance,and category 8 the longest. The proportion of households owning no cars and that of households owning more than one car were calculated for each accessibility category,and the results plotted as histograms as shown in figure 3.7. Both histograms show results which would agree with results of overseas studies.

Finally,a study was undertaken at University of the Witwatersrand(ref 13) in which the influence of various factors on car ownership was examined using Yates' Algorithm. The study proved to be inconclusive,however, due to the coarse level of aggregation of the data available,and the recommendation was made that the same study be carried out on the more disaggregate zonal level.

Table 3.2 Car Ownership, Income and Public Transport Accessibility for Whites in Jomet Study Area

ANNUAL INCOME	PROPORTION OF HOUSEHOLDS OWNING 0 CARS			PROPORTION OF HOUSEHOLDS OWNING 2+ CARS		
	ACCESSIBILITY			ACCESSIBILITY		
	H	M	L	H	M	L
1. (2400)	0,64	0,14	1,0*	0,05	0,0	0*
2. (2400 - 3600)	0,58	0,21	0,0*	0,02	0,125	0,50
3. (3600 - 4800)	0,47	0,27	0,25	0,08	0,19	0,17
4. (4800 - 6000)	0,12	0,024	0,059	0,12	0,38	0,29
5. (6000 - 7200)	0,16	0,12	0,0	0,21	0,44	0,50
6. (7200 - 8400)	0,08	0,047	0,05	0,25	0,42	0,57
7. (8400 - 9600)	0,07	0,0	0,08	0,37	0,59	0,58
8. (9600 -10800)	0,03	0,0	0,0	0,45	0,68	0,76
9. (10800 -12000)	0,02	0,012	0,04	0,57	0,81	0,68
10. (12000 -13200)	0,03	0,0	0,0	0,70	0,80	0,87
11. (13200 -14400)	0,0	0,0	0,0	0,61	0,88	0,90
12. (14400 +)	0,0	0,0	0,0	0,80	0,92	0,94

* Insufficient Data

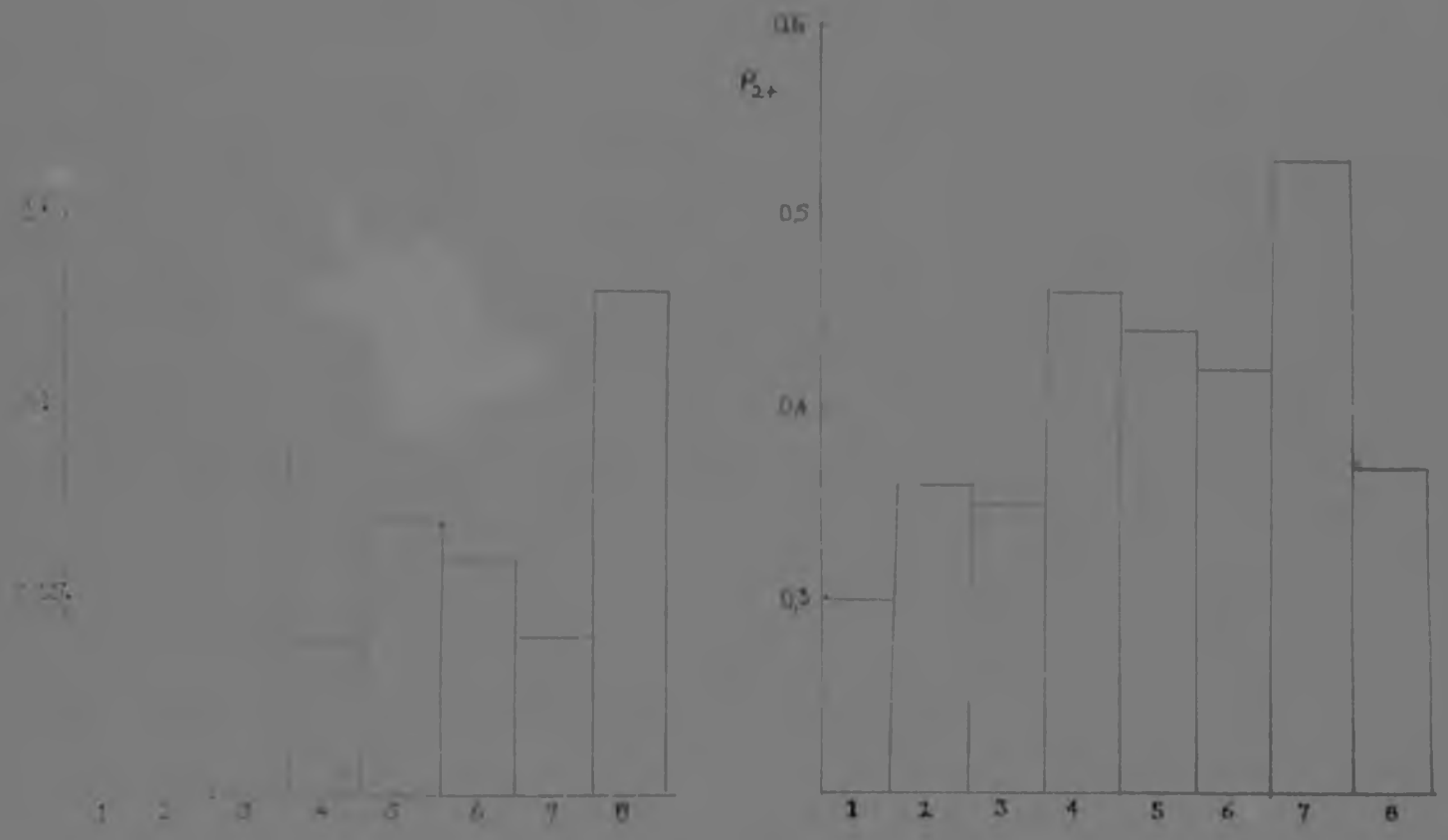
H = High

M = Medium

L = Low

Category 1 is shortest distance (<250 m)

Category 8 is longest distance (>2km)



distances of households from

public transport terminals

Fig. 3.7. Car ownership and distances of households from

public transport terminals.

3.2.4 The form of the relationship

It has been shown that there is strong evidence of a negative relationship between car ownership and public transport accessibility. However,one is faced with a 'chicken or egg' type of problem when trying to decide which of the two factors influences the other.

Instinctively,one feels that a high level of public transport service will not be provided to areas of high car ownership. This implies that car ownership determines the level of public transport accessibility. Also,one can postulate,as did Ferrerri and Shindler,that if an area of low car ownership and high public transport accessibility had its level of public transport service reduced,the car ownership rate in the area would increase.

Thus the relationship is a two-way one,the relative importance of the directions of influence being impossible to calculate,as stated by Jones and Tanner (ref 11).

3.3 Conclusion

The concept of accessibility must be clearly understood before choice of a means of enumerating it. The definition of accessibility used will play a crucial role in determining the type of relationship with public transport accessibility,and in fact ,whether there is a relationship at all.

The evidence of the various studies undertaken support the assumption that there is a relationship between public transport accessibility and car ownership. However,there is little indication of the direction of influence of this relationship or of the sensitivity of the two factors with respect to each other.

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CHAPTER FOUR : METHOD OF APPROACH

Because the concept of accessibility measurement forms an integral part of this study, literature on the concept and measurement of accessibility has been reviewed. In addition, in order to form a foundation for the belief that public transport accessibility may affect car ownership levels, local and overseas literature on the subject has been reviewed. The literature surveyed concerns car ownership rates in general, rather than the behaviour of β in the "β" model.

From available data, the various variables involved in the study were created. This creation of variables takes place on three levels of aggregation :

- Jomet district level (56 districts)
- Jomet zonal level (379 zones)
- Household level (2056 households)

Values of α and β were created for each district, zone and for each household. For Jomet districts, values of public transport accessibility and population density were found. The values of accessibility for this level pertain only to morning peak. For Jomet zones, public transport accessibility was measured for the peak period and for off-peak period. In addition, a measure of peak period and off-peak period mobility was also calculated. Residential and employment population densities were found for each zone.

Factors such as household income, household size, stage in the family life cycle, etc., were found directly from the home interview results.

Having created all the required variables, the effects of each variable on α and β was evaluated using analysis of variance tests for all three levels of aggregation. On the district and zonal levels of aggregation, regression tests were also carried out. Computer programs of the SPSS and SAS statistical packages were used for these tests.

4.1 Data Sets and Sources

Because of the diversity of the nature of the variables involved in this study, there are a number of sources from which data were obtained. The data were required to :

- provide a means of estimating the value of variables accurately.
- provide a range in the values of a variable to enable a satisfactory analysis of variance to be undertaken

As a result of the Group Areas Act, the Non-White population groups are restricted to areas designated for their residence. This fact causes the variation in public transport accessibility for these groups to be very limited. For this reason, this study has been conducted for the White population group only.

4.1.1 Data from home interview survey

The basis of this study is the same home interview survey as used in the Jomet study. The data has three elements :

- household information ,containing a report of the characteristics of each household
- person information, containing details of each person in each household
- trip information, containing a report of each trip made by each member of each household.

The original data files were supplied to the University of the Witwatersrand by the Jomet team, and contained a number of inconsistencies. In the course of his research, Oosthuizen removed these errors (ref 1), and added his own findings to the original data.

4.1.2 Data from other sources

The data from the home interview survey did not include a satisfactory measure of public transport accessibility. Thus, further data had to

be obtained from the Jomet study.

Land use data such as employment,population,or population densities were found in the output of the Jomet trip end model computer program. Information on generalized cost of travel between zones and districts was obtained from the output of the SKIM program (of the TRAMP suite) used to calculate cost matrices in the Jomet model.

4.1.3 Problems encountered with data sets

The home interview survey used in the Jomet study is actually a combination of two surveys used in other studies,being the Greater Johannesburg Area Transportation Study (GJATS, the predecessor of Jomet) and the Pretoria-Witwatersrand-Vereeniging transportation study (PWV). Approximately half the households interviewed were obtained from the GJATS interview and the rest from the PWV interviews. The zone numbers of the households were coded according to the relevant numbering system. This means that half of the data was coded to the GJATS system and the other half according to the PWV system. Consequently,in certain areas there is doubt as to the exact location of households. The fact that the study was undertaken on three levels of aggregation may compensate for this slight doubt.

It should be noted that the generalized costs for Whites used in the Jomet study are actually one sixth of their actual value,a condition which facilitated the running of the Jomet model. Since this study needs only the value of a variable for a zone relative to that of other zones,the application of a general factor will not affect the findings. In fact,all variables were normalized,on the zonal and district levels of aggregation,so that the maximum value of any variable was 100.

A further problem is that the generalized costs used in the study pertain to Non-Blacks as opposed to Whites, but because of the vast majority of Whites over Coloureds and Asians in the Jomet area the influence of this factor is likely to be negligible.

The reader who wishes further information on the sources is referred to references 1 to 5.

4.2 Creation of Variables

In this section, the methods of enumerating all variables used, are explained.

4.2.1 Creation of α and β

In order to estimate α and β for different geographical areas, it is necessary to find the proportion of households in the designated areas owning 0,1 and 2 or more cars. This proportion has to be found for each household income group, of which there are 12. From the data sets (as discussed in the previous section) the households interviewed in each car ownership and income category were counted for each PWV zone and each GJATS zone, resulting in a 3x12 matrix for each zone; the matrix has 36 elements N_{ij}.

	Cars		
	0	1	2+
1	$N_{0,1}$	$N_{1,1}$	$N_{2,1}$
2	$N_{0,2}$	$N_{1,2}$	$N_{2,2}$
.	.	.	.
.	.	.	.
.	.	.	.
12	$N_{0,12}$	$N_{1,12}$	$N_{2,12}$

From these matrices, the values of P(0/x) and P(2+/x) can be estimated for each PWV and GJATS zone i each income group :

$$P(0/x) = \frac{N_{0,j}}{\sum_i N_{i,j}} \qquad \text{where} \qquad i = 0,1,2$$

$$P(2+/x) = \frac{N_{2+,j}}{\sum_i N_{i,j}} \qquad j = 1,2,3,\ldots,12$$

Using Jomet research manual 27, (ref 3), the Jomet zones corresponding to the given PWV or GJATS zones were found. PWV zones are larger than Jomet zones, and all Jomet zones within a given PWV zone were assigned the same values for the probabilities as those for the PWV zone. Many of the GJATS zones coincide exactly with the Jomet zones, and in this case the Jomet zone takes the same values for the probabilities as

the GJATS zone. However,there are a number of cases in which the Jomet zones include several GJATS zones. In these instances,the matrices,$N_{i,j}$, for each GJATS zone within the Jomet zone were accumulated and the values of the probabilities calculated from the accumulated matrices.

A summary up to this stage shows that we have matrices of conditional probabilities of households owning 0 or 1+ cars given that the household income is x. These matrices are on the following levels of aggregation :

- Jomet zones
- Jomet districts
- GJATS zones
- PWV zones

Values of α and β for each district or zone can now be estimated using the Jomet car ownership model's expressions for conditional probability :

$$P(0/x) = 0,97e^{-\beta x} \qquad (4.1)$$

$$P(1+/x) = 0,98^{-4,5\alpha^{-\alpha x}} \qquad (4.2)$$

It is not satisfactory to simply transfer the α or β to the subject of the expressions and solve,because a value for α and β would then be found for each income group in any zone or district. It would then become a problem to decide which of the values is the most satisfactory for the whole zone or district.

To estimate values of α and β for the entire Jomet area in the Jomet study,the technique of 'maximum likelihood' was used (ref 6). It was decided to use this method for each zone and district. A short explanation of the technique follows .

Suppose a value of β gives an estimate of conditional probability using the expression 4.1,of $P(0/x)$ for each income group. This estimate will be called $\beta(0/x)$. The difference between the predicted and actual values of this conditional probability is

$$P(0/x)-\beta(0/x).$$

If this difference is squared ,the error square for a given income

group results. The accumulated total of error squares for all income groups is the ' error sum of squares',and the technique of maximum likelihood seeks to choose a value of β which minimizes the error sum of squares,shown graphically in figure 4,1,.

Error sum of squares =SSQ = $(P(O/x)-\beta(O/x))^2$

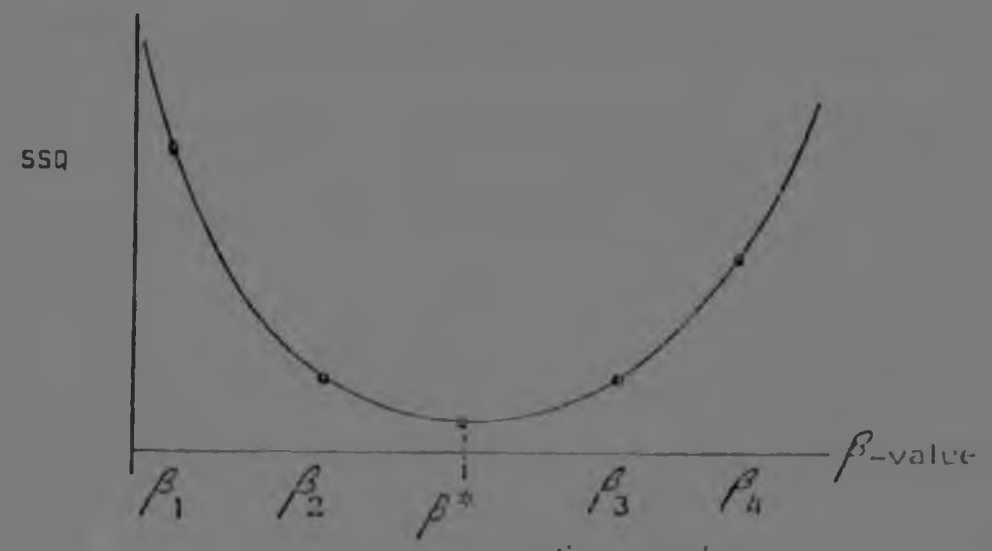


FIG. 4.1 Most likely value of β

In a similar manner the optimum value of α may be found,using the expression 4.2 for each zone or district.

A computar program was written in BASIC to find the optimum value of α and β for Jomet districts and zones,GJATS zones and PWV zones. The program uses a 'hill climbing' process to find the minimum error sum of squares,and thus the most likely values of α and β. The program is listed in Appendix 1. Values of α and β greater than 1 were taken to be 1.

Since the location of households is coded in PWV or GJATS zone numbers, each household was assigned the value of α and β corresponding to the PWV or GJATS zone in which it was located.

4.2.2 Accessibility

In chapter three, the various methods of enumeration of accessibility were discussed. In fact, the vast majority of these measures could not be used in this study because of lack of data. A few elementary measures were within the limits of data available, and these are now discussed.

On the Jomet district and zonal levels, a number of measures were available. The first of these is a Hansen measure, which was used in the evaluation of Jomet strategy and is explained by L.Ferreira (ref 7):

$$(AI)_i = \frac{\sum_j E_j f(c_{ij})}{\sum_j E_j} \qquad (4.3)$$

where $(AI)_i$ is the public transport accessibility index for origin zone i,

E_j is the employment at zone j,

c_{ij} is the generalized cost of travel by public transport from zone i to zone j during the peak period,

f is a function of the generalized cost, assumed in this study to be c_{ij}^{-1},

n is the number of districts or zones.

The indices were normalized so that the highest index was 100.

The above measure involves employment and peak period travel, so the resulting indices pertain only to work trips. To attempt to measure non-work accessibility the following expression was used :

$$(AI)'_i = \frac{\sum_j P_j f(c'_{ij})}{\sum_j P_j} \qquad (4.4)$$

where $(AI)'_i$ is the off-peak public transport accessibility,

P_j is the population in zone j,

c'_{ij} is the generalized cost of off peak travel by public transport.

This measure could only be used on the Jomet zonal level, because the Jomet district study was undertaken for work trips only.

It can be argued that car ownership is more dependent on the mobility of an individual than on the accessibility of a zone. A measure of mobility was devised as follows :

$$(MI)_i = \frac{1}{c_{i,(cbd)}} \qquad (4.5)$$

where $(MI)_i$ is the mobility index for zone i,

and $c_{i,(cbd)}$ the generalized cost of travel by public transport from zone i to the C.B.D.

These measures were calculated for both peak and off-peak periods, and were normalized so that the maximum index was 100.

Accessibility measures of individual households were based purely on the distance of the household from the nearest bus stop or station, and on the distance from place of employment of the head of the household to the nearest bus stop or station. This information was obtained directly from the questionnaires. Distances were given in 8 categories, and the household accessibility was taken as the sum of all distance categories.

$$HHAI = dhb + dhs + dwb + dws$$

where HHAI is the household accessibility index,

dhb is the category number of distance from home to nearest bus stop,

dhs is the category number of distance from home to nearest station,

dwb is the category number of distance of head's place of work from nearest bus stop,

dws is the category number of distance of head's place of work from nearest station.

The values of these indices ranged from 4 to 32, low values indicating good accessibility, high values indicating poor accessibility.

4.2. Other variables.

On the household level of aggregation,a number of variables were tested. These included income,household size,stage in the family life cycle,all of which were obtainable directly from the data set .

On the district and zonal levels of aggregation,average household income,residential population density and employment density were obtained from data supplied by the Jomet study team. Values of all variables were normalized so that the maximum value was 100.

Zonal and district data are listed in Appendix B and Appendix C. All other data data may be obtained from the University of the Witwatersrand,on computer tape BACCED.

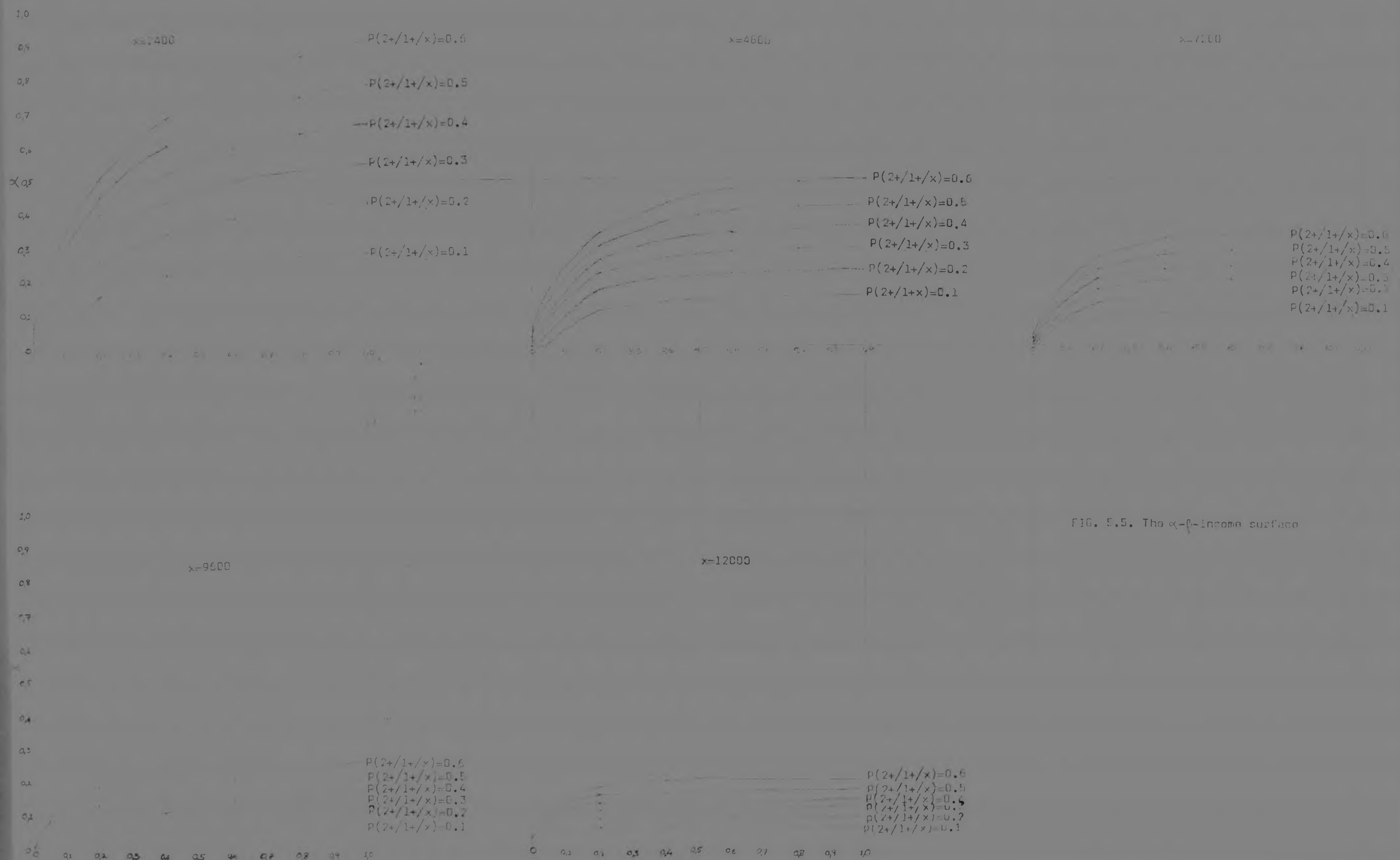


FIG. 5.5. The α-β-income surface

P(2+/1+/x)=0,2



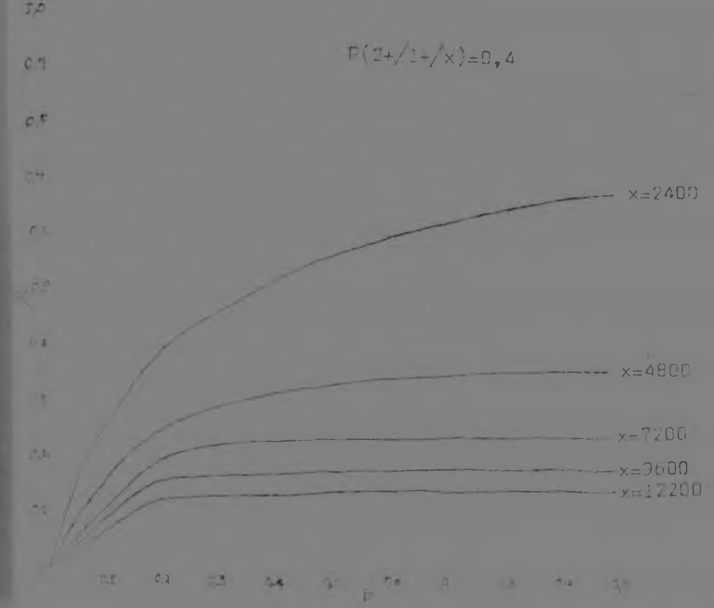
P(2+/1+/x)=0,3



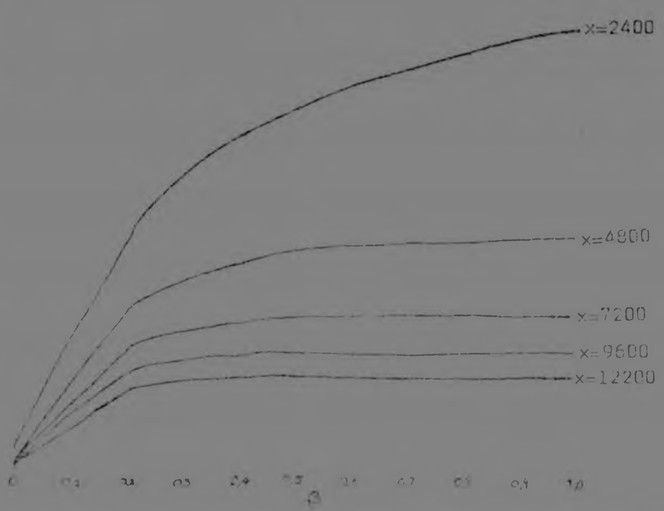
P(2+/1+/x)=0,3



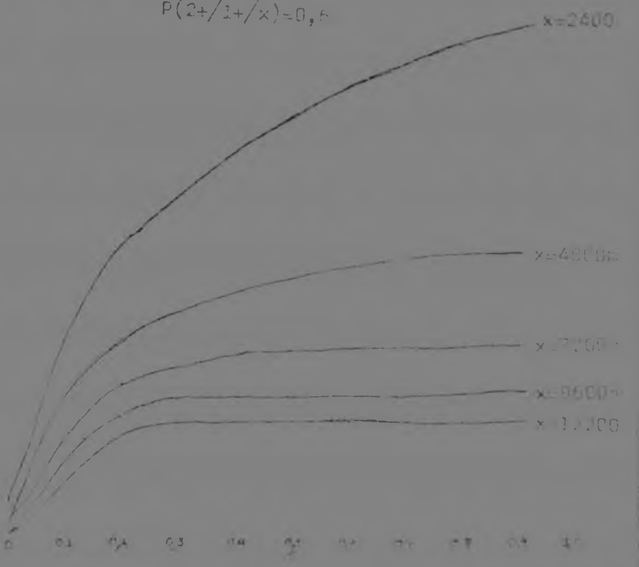
P(2+/1+/x)=0,4



P(2+/1+/x)=0,5



P(2+/1+/x)=0,6



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CHAPTER FIVE : FINDINGS

In this chapter, the results of all exercises, statistical tests and calculations are presented.

5.1 The Relationship Between α and β

Before examining the effects of the various factors on α and β, it was decided to study the relationship between α and β in detail. This relationship could be useful in cases where either α or β cannot be estimated through lack of data.

5.1.1 Jomet suggestion

In an attempt to find the relationship between α and β, the Jomet study team plotted the values of α and β for the four population groups (ref. 1). The results of this exercise are shown in figure 5.1. It was suggested that the line through the non-Black's points forms the graph of the relationship between α and β. The unexpected result obtained for Blacks could not be explained.

It should be pointed out, however, that each population group had car ownership modelled with a different model. Each model has different parameters; the intercepts of the curves, and the asymptotes thereof are all different. In comparing the α and β of the four models, the ceteris paribus conditions were broken, rendering the results obtained rather meaningless.

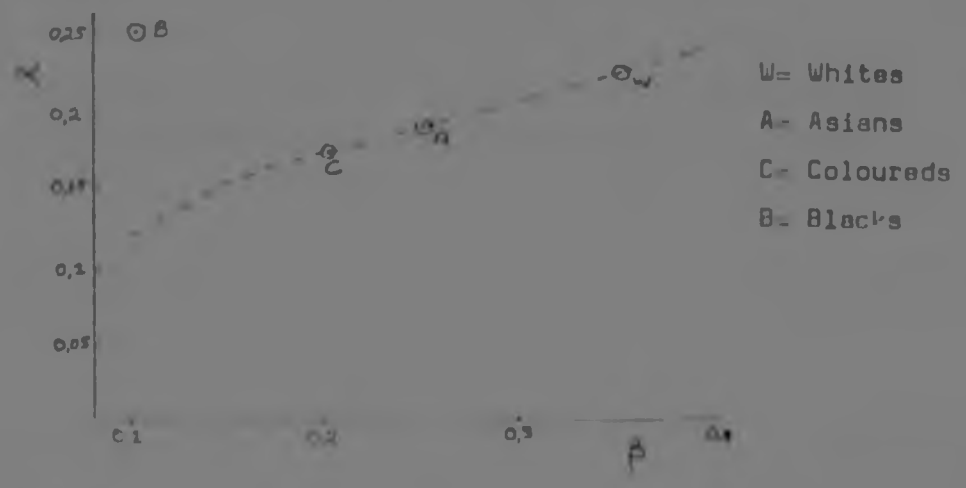

Fig. 5.1 The Jomet suggestion of relationship between α and β

Plots of α against β for Jomet districts and zones are shown in figures 5.2 and 5.3 respectively. These scattergrams do not show evidence of any form of relationship between α and β .

5.1.2 The relationship between α and β : a suggestion

A mathematical expression for the relationship between α and β will now be derived.

The fundamental expressions for the conditional probabilities of the Jomet model (White) are as follows :

$$P(0/x) = ae^{-\beta x} \qquad (5.1)$$

$$P(2+/x) = be^{-\alpha x} \qquad (5.2)$$

Statistically,it can be stated that

$$P(1+/x) = 1 - P(0/x) \qquad (5.3)$$

Now,the probability that a car owning household owns more than 1 car is given by the expression

$$P(2+/1+/x) = \frac{P(2+/x)}{1-P(0/x)} \qquad (5.4)$$

Alternatively,equation 5.4 can be written as follows :

$$P(2+/x) = P(2+/1+/x).(1-P(0/x)) \qquad (5.5)$$

This equation gives a relationship between P(2+/x) and P(0/x),and it can be used to find an expression relating α and β ,by substituting equations 5.1 and 5.2 for the terms P(0/x) and P(2+/x).
The expressions thus obtained are shown in equations 5.6 and 5.7. should be noted that all terms are as previously defined.

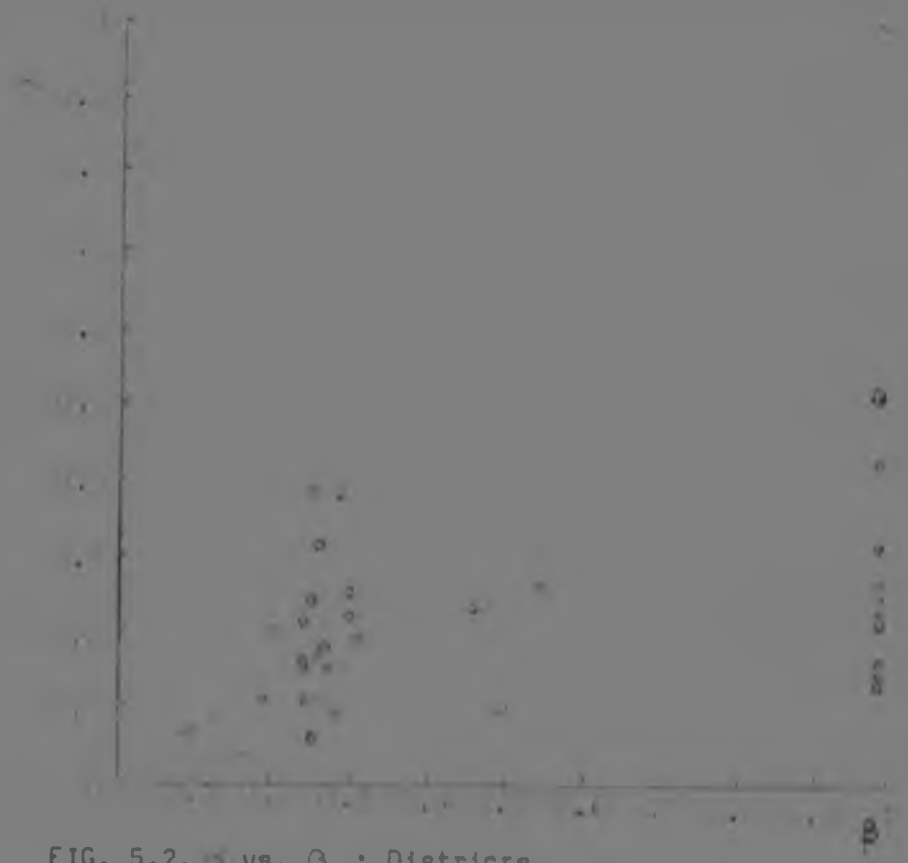

FIG. 5.2. vs. β : Districts

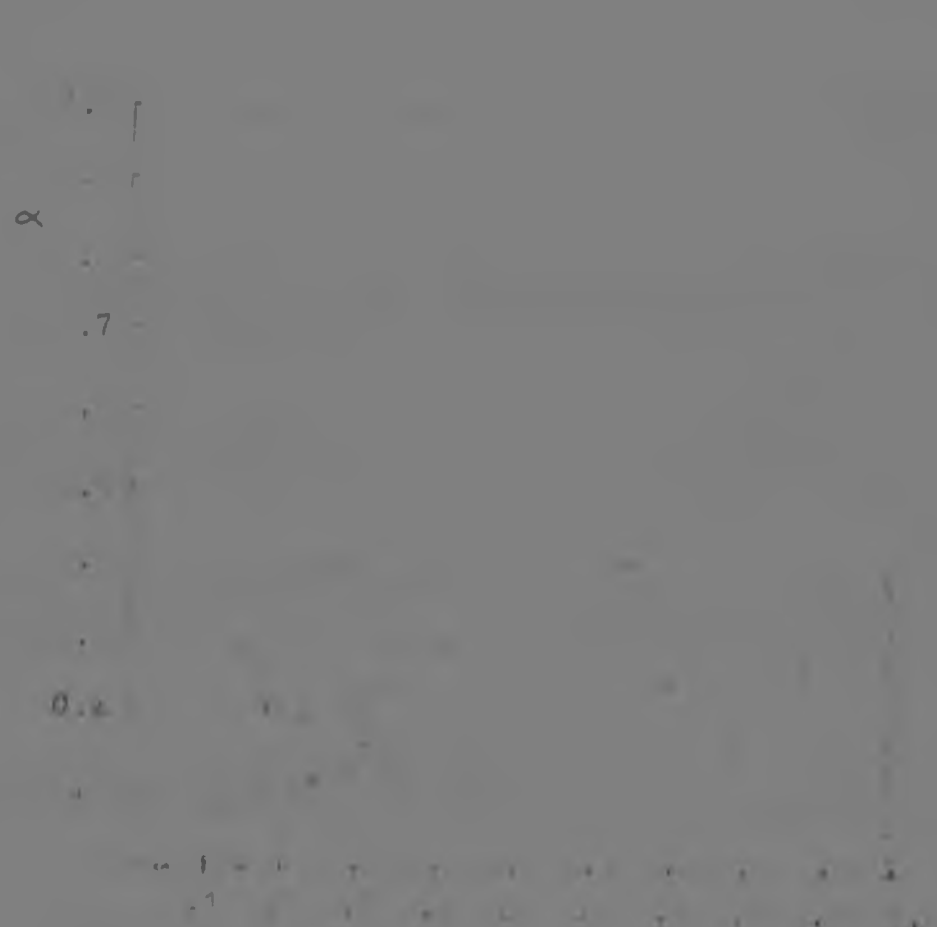

FIG.5.3. ∝ vs. : Zones



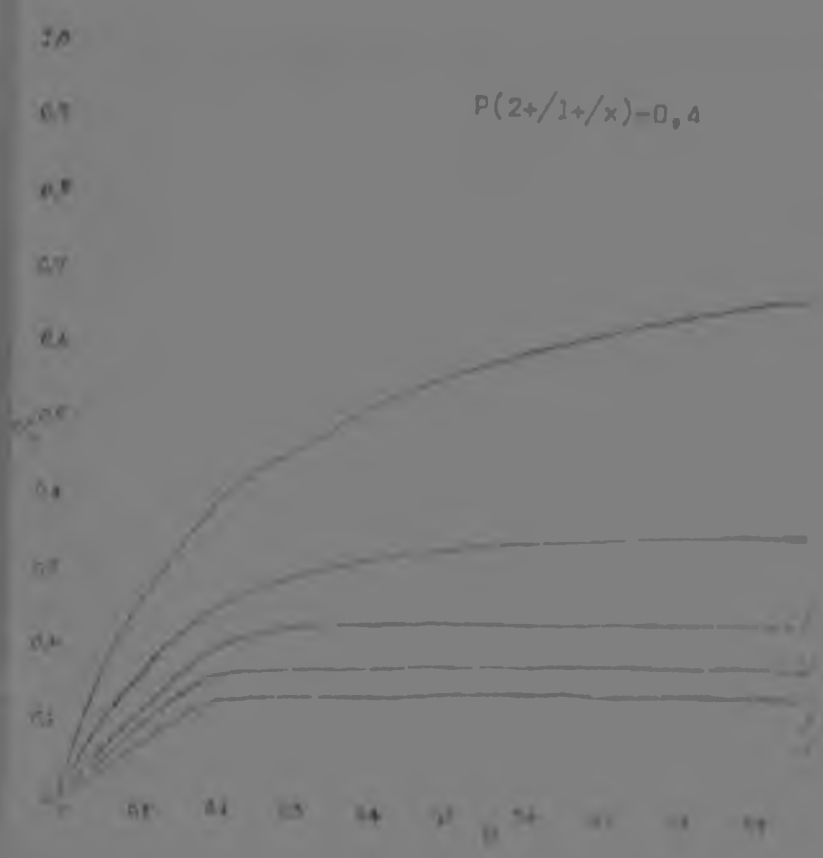

FIG. 5.3. The α-β-income surface

$$\alpha = \frac{1}{x}.\log\left[\frac{c}{\log\left[\frac{P(2+/1+/x)}{b}.(1-ae^{-\beta x})\right]}\right] \qquad (5.6)$$

$$\beta = \frac{1}{x}.\log\left[\frac{a\,(2+/1+/x)}{P(2+/1+/x)-be^{ce^{-\alpha x}}}\right] \qquad (5.7)$$

These expressions were then used, for various values of x and P(2+/1+/x), to draw diagrams showing the form of the relationship. These diagrams are shown in figures 5.4 and 5.5. Represented in these diagrams are the α-β-x-P(2+/1+/x) surfaces, illustrated, in this case by the Jomet White car ownership model, with a=0,97; b=1,9; c=-4,5.

Using the average income, x, and the average value for P(2+/1+/x) for each population group, α values were calculated using Jomet β values, and vice versa. The results are shown in table 5.1.

As a further test of the above expressions, they were used to calculate α values for Jomet districts, knowing the β values, and then to calculate β values for the districts, knowing the α values. Scattergrams of the actual values against the predicted values were plotted and are shown in figures 5.6 and 5.7.

As can be seen from the diagrams, most of the points do not lie close to the line of unit slope, as would be expected. The diagrams indicate that the expressions tend to underestimate values of α and β. A regression of predicted values on actual values yielded, in each case, lines with non-zero intercepts and slopes not equal to unity.

The single most influential factor in the expressions is the income x. In addition, income appears to be the most sensitive issue in a home interview survey, and if the true income of a household is not revealed, the estimate for average income becomes unreliable. It is felt by the author, that this is a major reason for the underestimates of α and β values. Consequently, it becomes of prime importance either

Table 5.1 : Jomet and predicted values of α and β

	Mean Income ('000 per year)	P(2+/1+/x)	α predicted	Jomet α	β predicted	Jomet β
Whites	9,6	0,53	0,221	0,225	0,354	0,35
Blacks	2,7	0,21	0,27	0,25	0,091	0,10
Coloureds	4,5	0,12	0,114	0,175	0,175	0,20
Asians	6,7	0,28	0,16	0,19	0.220	0,25

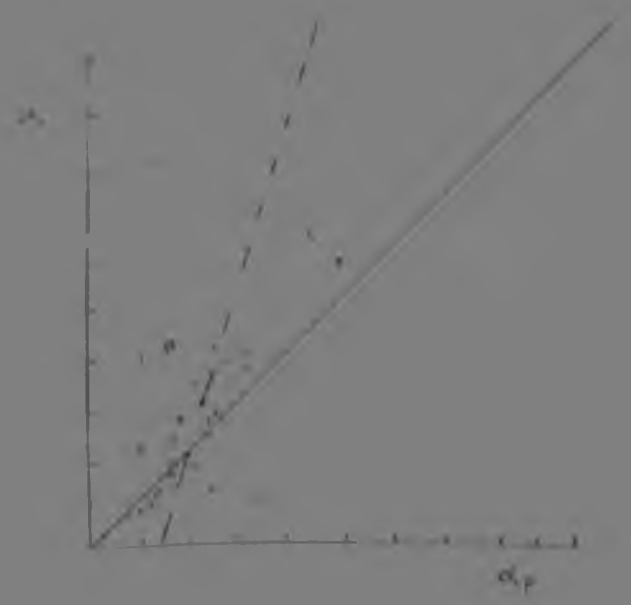

FIG. 5.6. Actual and predicted values of α

— — — Regression lines

——— 45^{0} lines

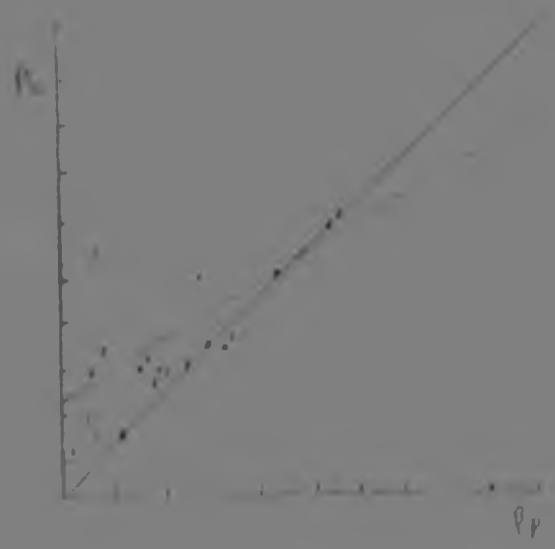

FIG. 5.7. Actual and predicted values of β

to establish accurate estimates of household income,or to adopt a model in which income does not play as prominent a role.

5.1.3 Conclusions

The relationship between α and β is complex,but a theoretical expression may be derived linking the two parameters. The expressions derived in this section underestimate the values of the parameters,probably because of unreliable income information.

In spite of the shortcomings of these expressions,they are more satisfactory than the suggestion of the Jomet study team,because an attempt is made to introduce local socio-economic conditions into the relationship between the two parameters. Furthermore,the Jomet suggestion violates 'ceteris paribus' conditions and is therefore unacceptable.

5.2 Results

The results of statistical studies undertaken are presented in this section.

5.2.1 District level of aggregation

Figure 5.8 shows a scattergram o α values against Hansen public transport accessibility indices for the Jomet districts. Figure 5.9 is the corresponding scattergram for β. Figures 5.10 and 5.11 are the scattergrams of α and β against district population density,respectively.

Accessibility indices were then divided into 11 categories,category 11 being the most accessible and category 1 the least accessible. Population densities were classified in 7 categories,category 7 being the most dense and category 1 being the least dense. An analysis of variance was carried out on this data,and the results are shown in table 5.2. Results of a regression of α and β on other variables are shown in table 5.3.

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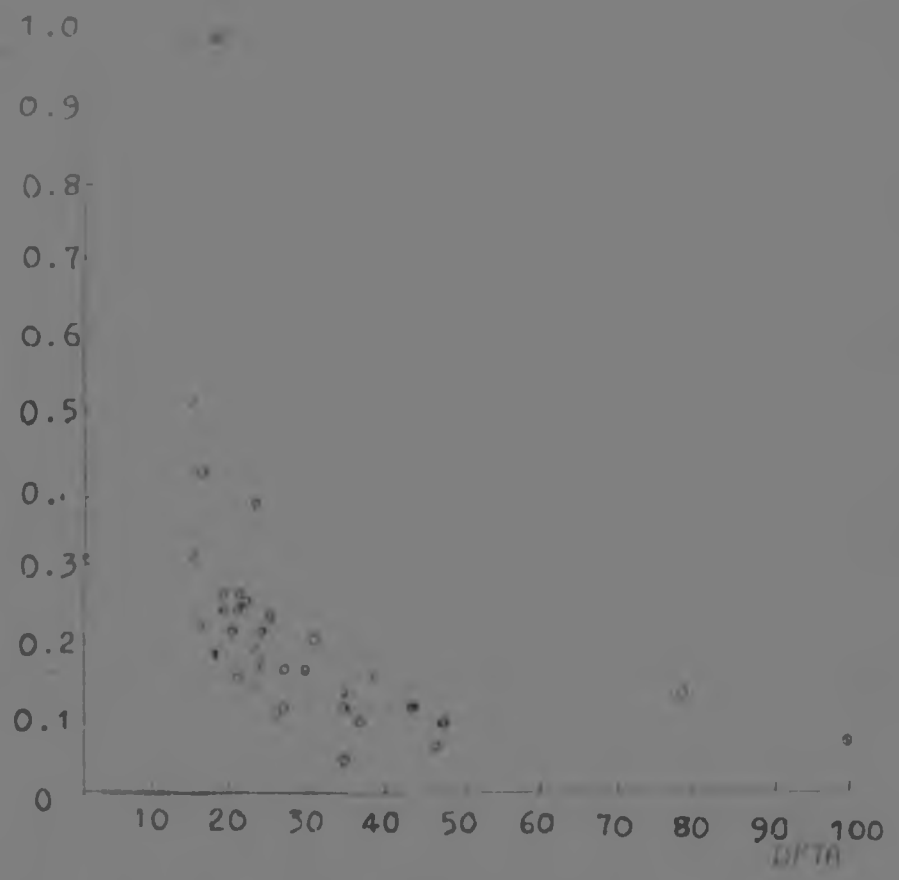

FIG. 5.8. α vs. District public transport accessibility.

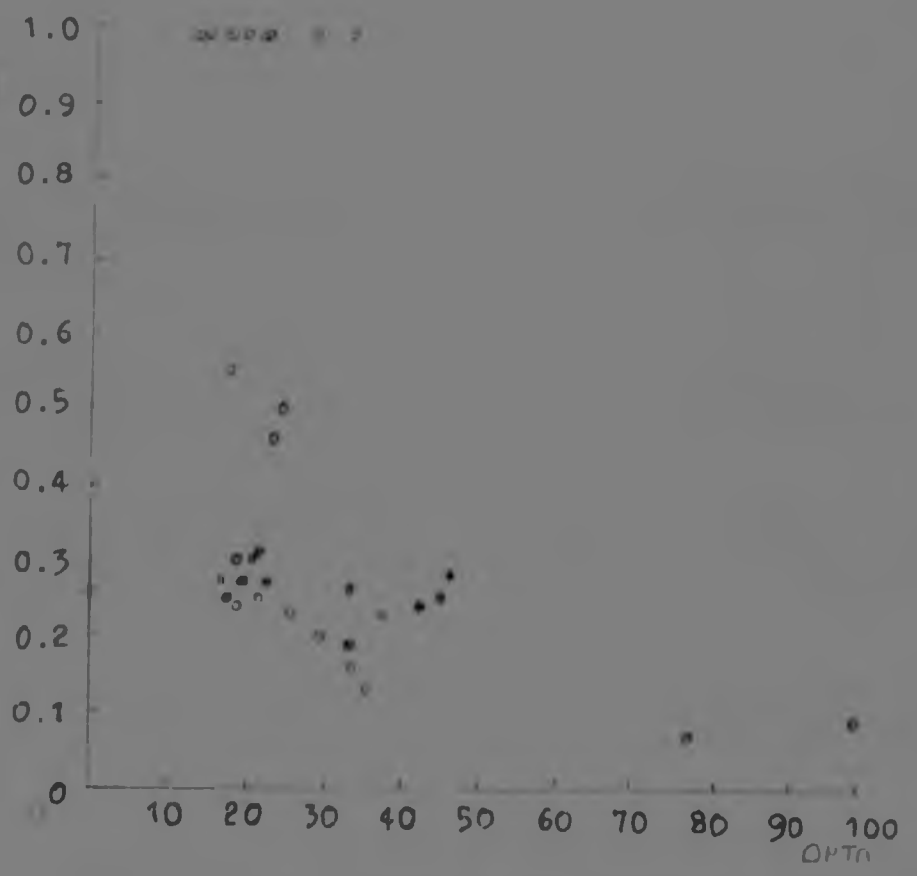

FIG. 5.9. β vs. District public transport accessibility.

Fig. 5.10. α vs. District population density.

Fig. 5.11. β vs. District population density.

Table 5.2 : % variation explained by parameters

	% variation explained α	% variation explained β
Accessibility	38,1	39,8
Population Density	21,1	25,1
Accessibility and Population Density	41,3	45,5

Table 5.3 : Regression correlation coefficients for district α and β

		% variation explained in α	% variation explained in β
Accessibility	1.	38,97	45,20
	2.	56,53	60,67
	3.	43,77	29,64
	4.	28,42	21,07
Population Density	1.	28,33	38,54
	2.	37,80	48,14
	3.	48,11	43,57
	4.	37,16	36,65
Population Density and Public Transport Accessibility	1.	43,21	47,30
	2.	45,60	62,11
	3.	51,12	51,84
	4.	39,30	32,49

1. Linear
2. Semi Log (α or β)
3. Full Log
4. Semi Log (accessibility or density)

5.2.2 Zonal level of aggregation

Factors whose influence on α and β were investigated for Jomet zones are :

- Peak period public transport accessibility
- Off-peak period public transport accessibility
- Peak period mobility by public transport
- Off-peak period mobility by public transport
- Residential population density
- Employment density

Scattergrams of α and β against the above factors are shown in figures 5.12 to 5.23.

Results of analysis of variance tests are shown in table 5.4,and results of regression of α and β on the various factors are shown in table 5.5.

5.2.3. Household level of aggregation

Results of analysis of variance tests for car ownership and various factors are shown in table 5.6. Results of analysis of variance tests for α and β against the same factors are shown in table 5.7.

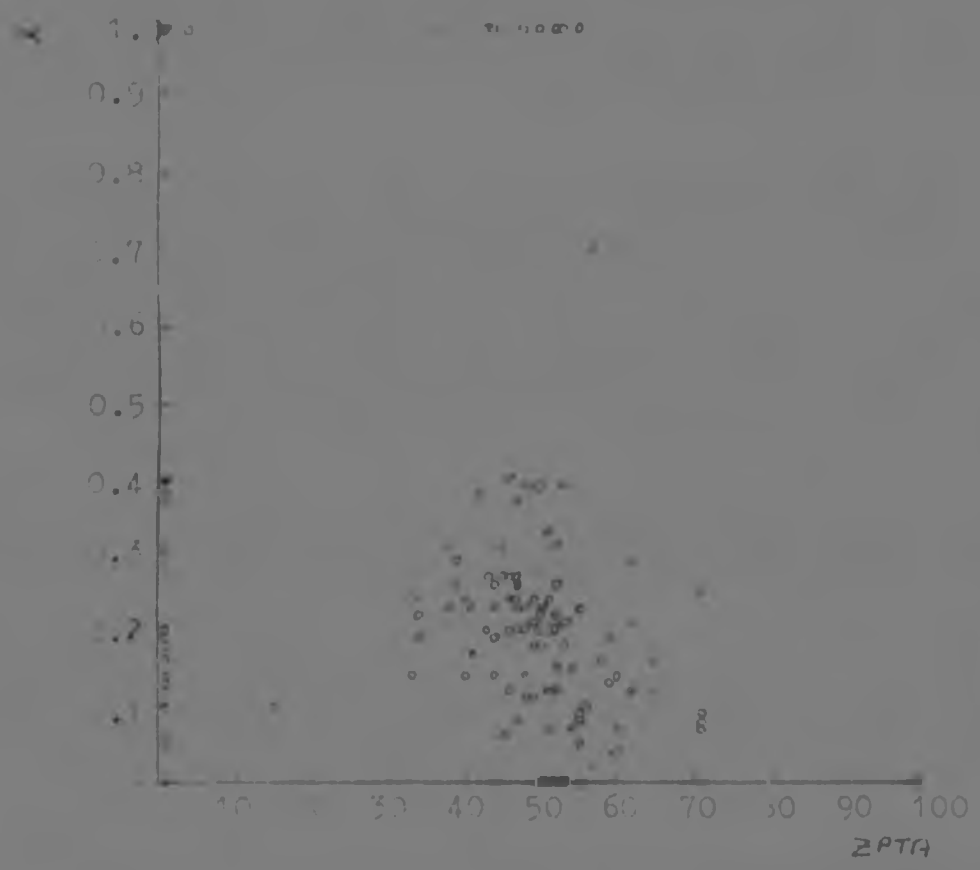

FIG. 5.12. α vs. Zonal peak public transport accessibility.

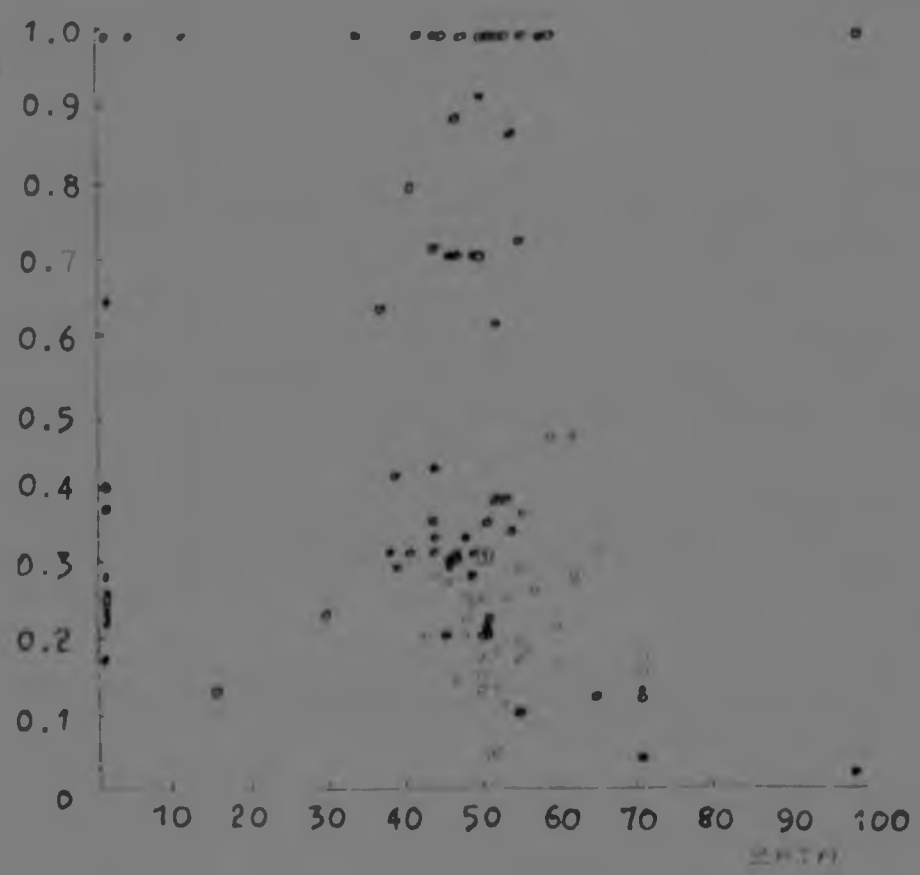

FIG. 5.13. β vs. Zonal peak public transport accessibility.

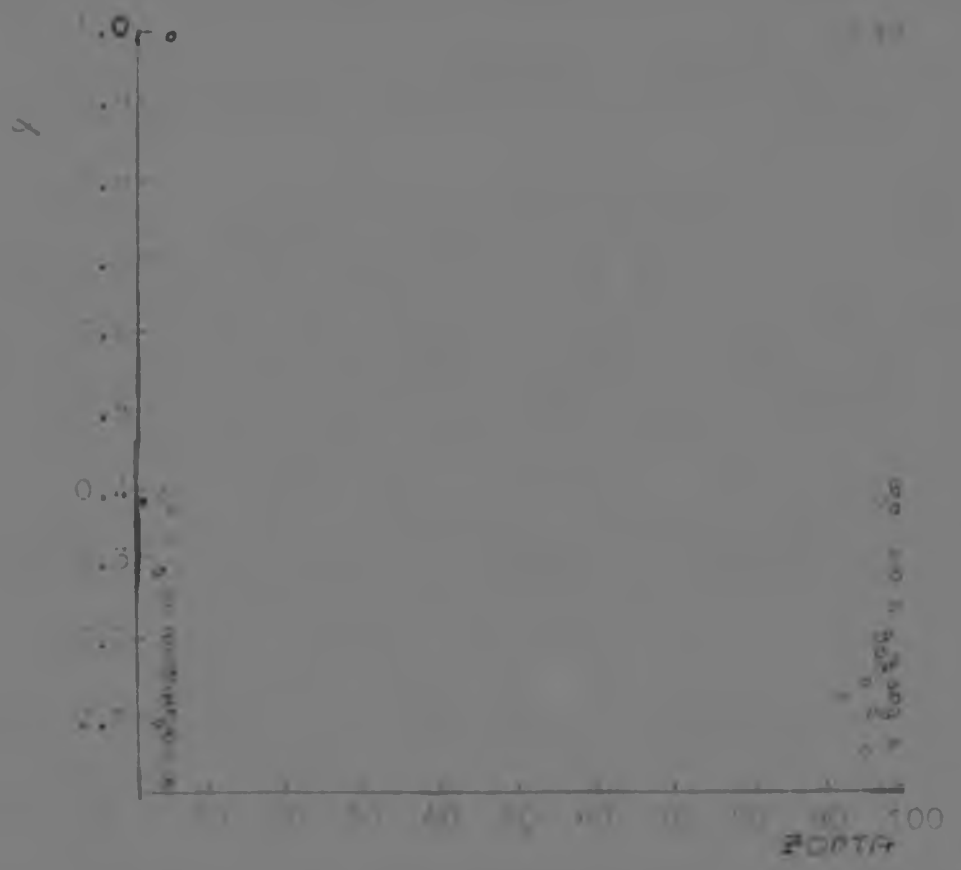

FIG. 5.14. α vs. Zonal off-peak public transport accessibility.

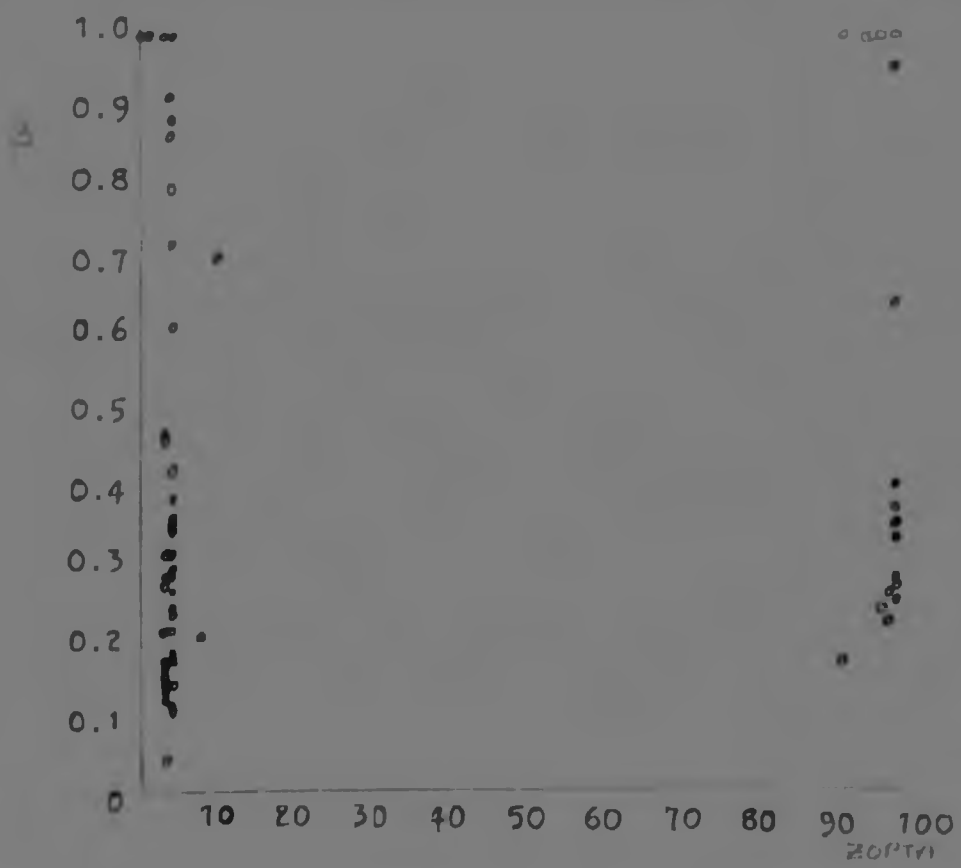

FIG. 5.15. β vs. Zonal off-peak public transport accessibility.

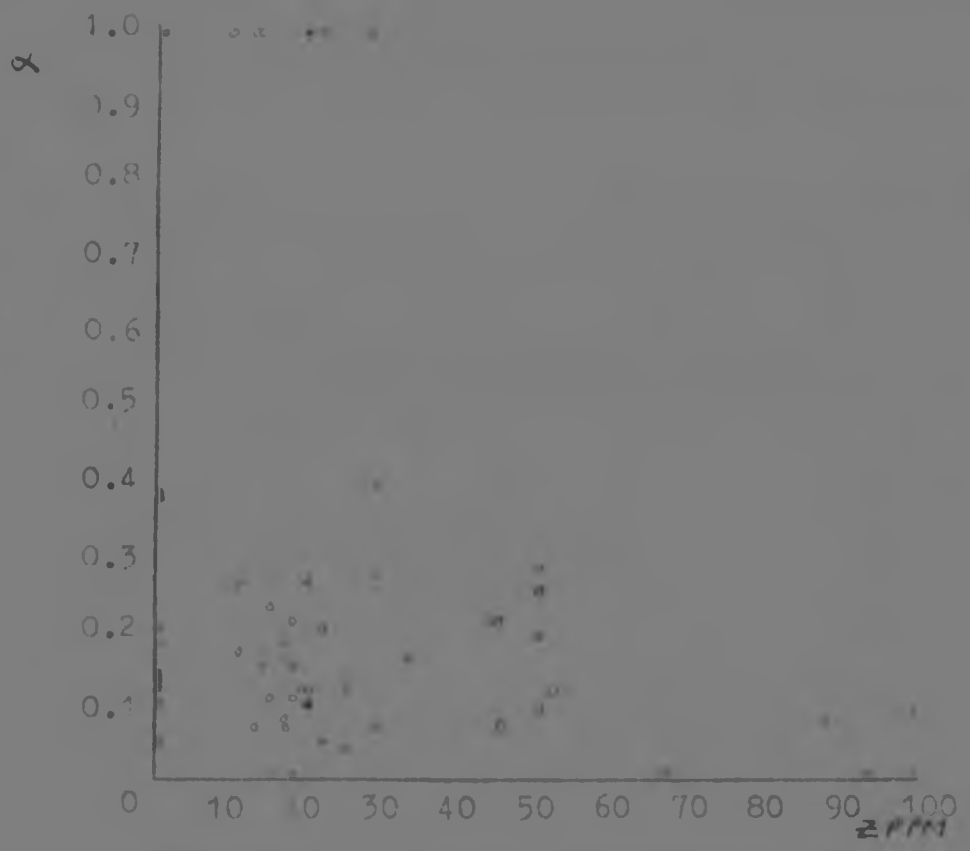

FIG. 5.16. α vs. Zonal peak period mobility

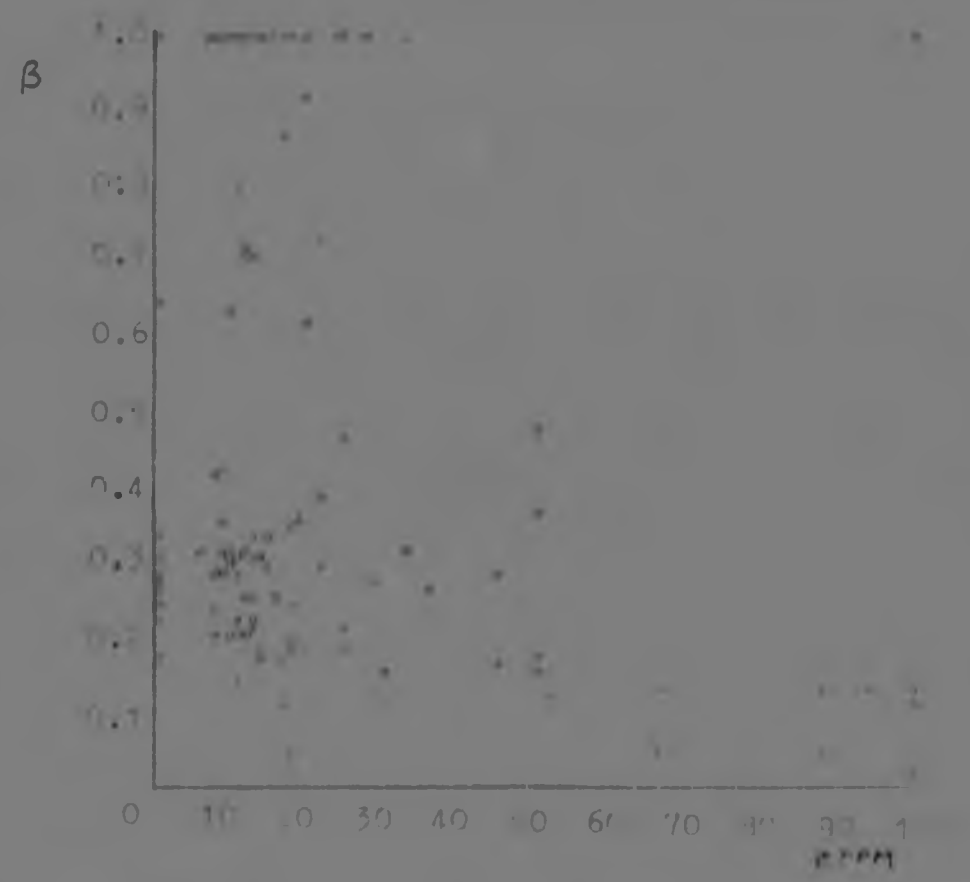

FIG. 5.17. β vs. Zonal peak period mobility

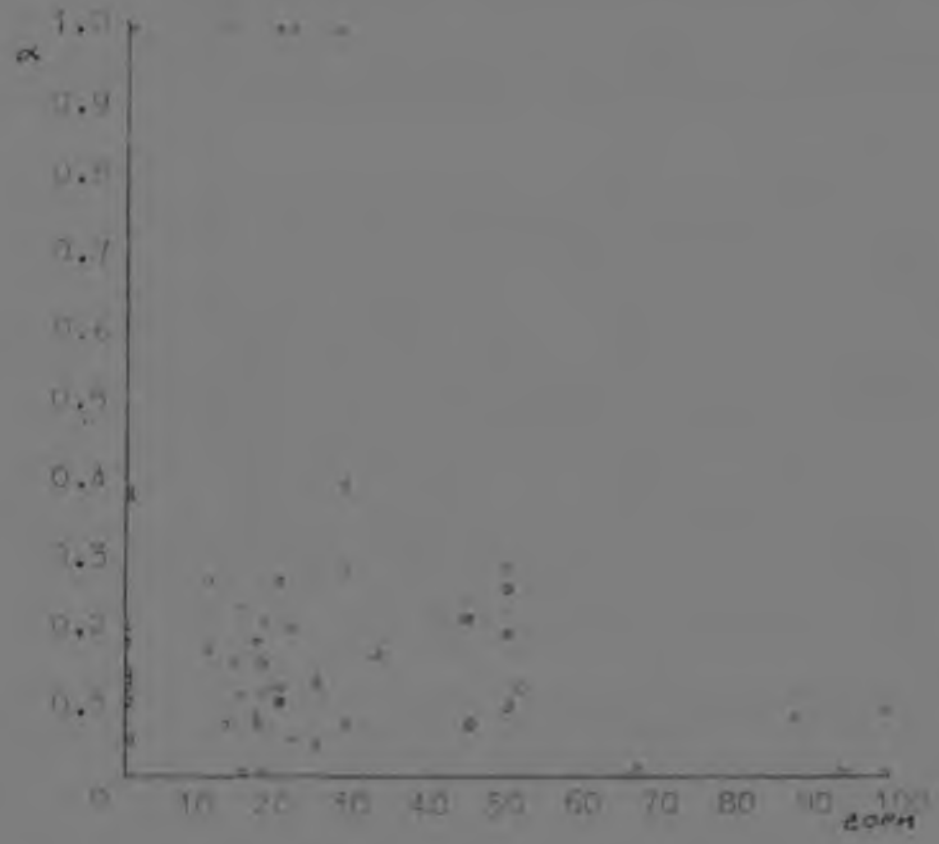

FIG. 5.18. α vs. Zonal off-peak mobility

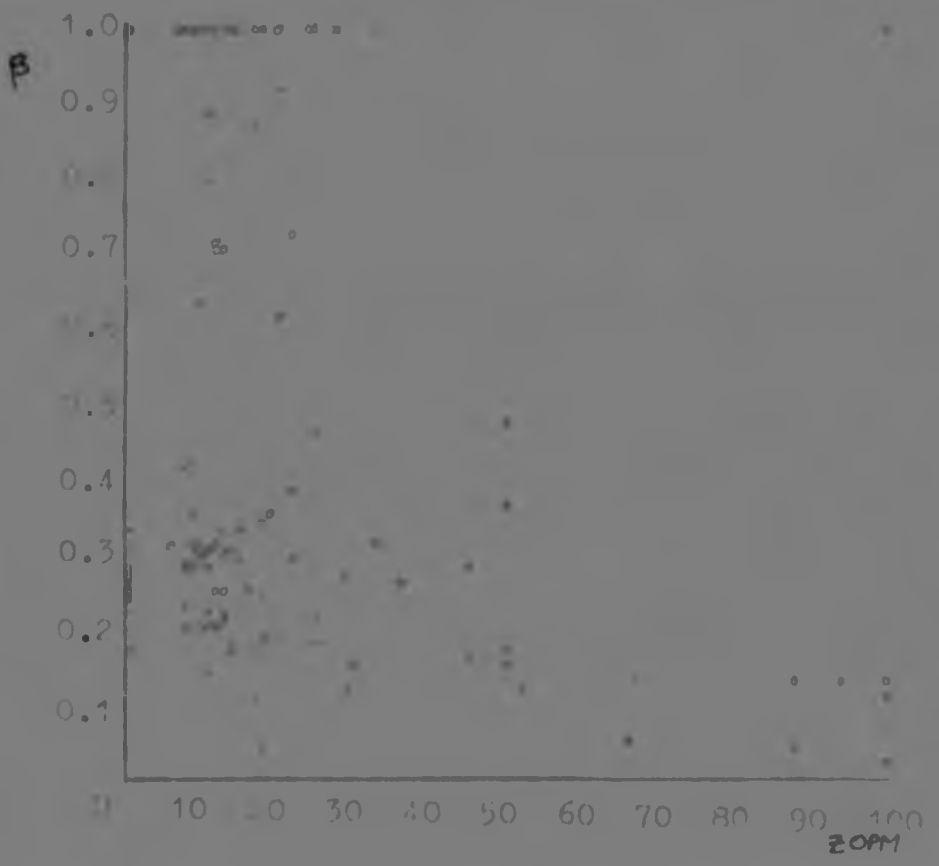

FIG. 5.19. β vs. Zonal off-peak mobility

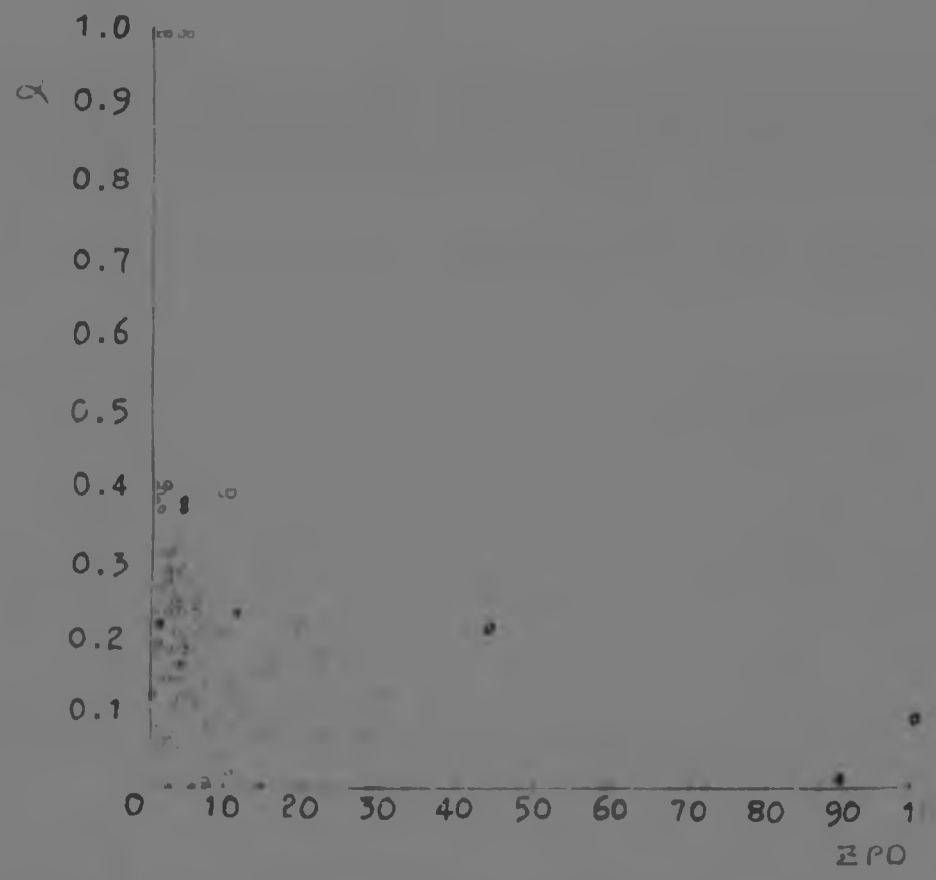

FIG. 5.20. α vs. Zonal population density

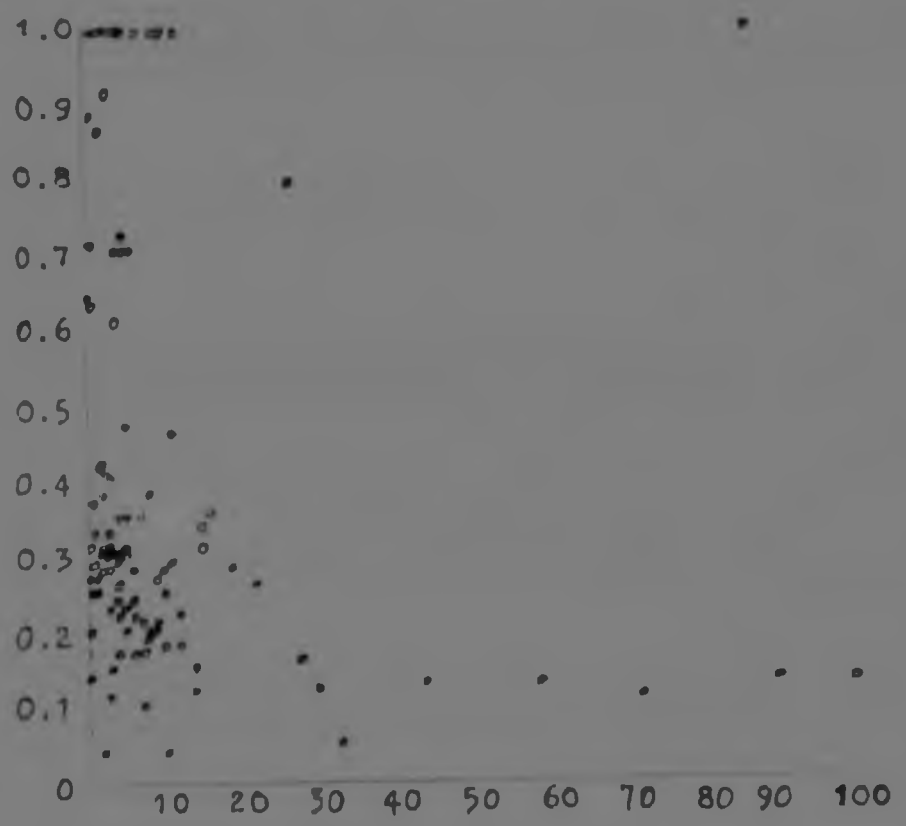

FIG. 5.21. β vs. Zonal population density

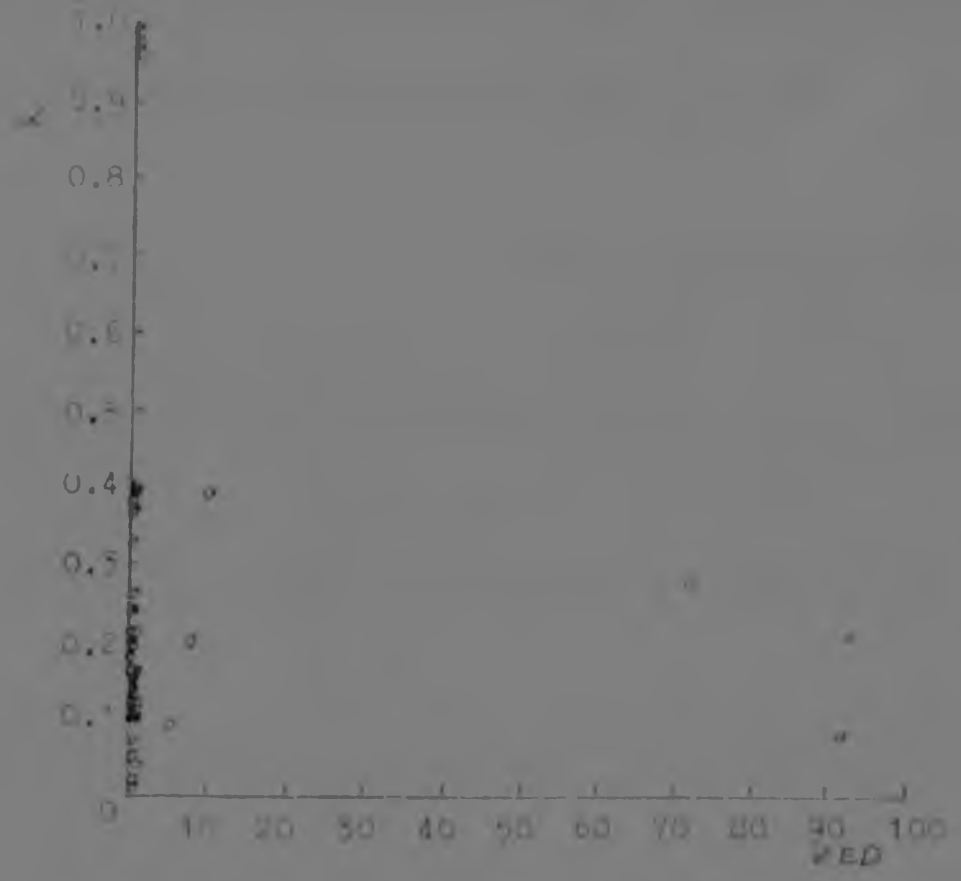

Fig. 5.23: ∝ vs. Zonal employment density

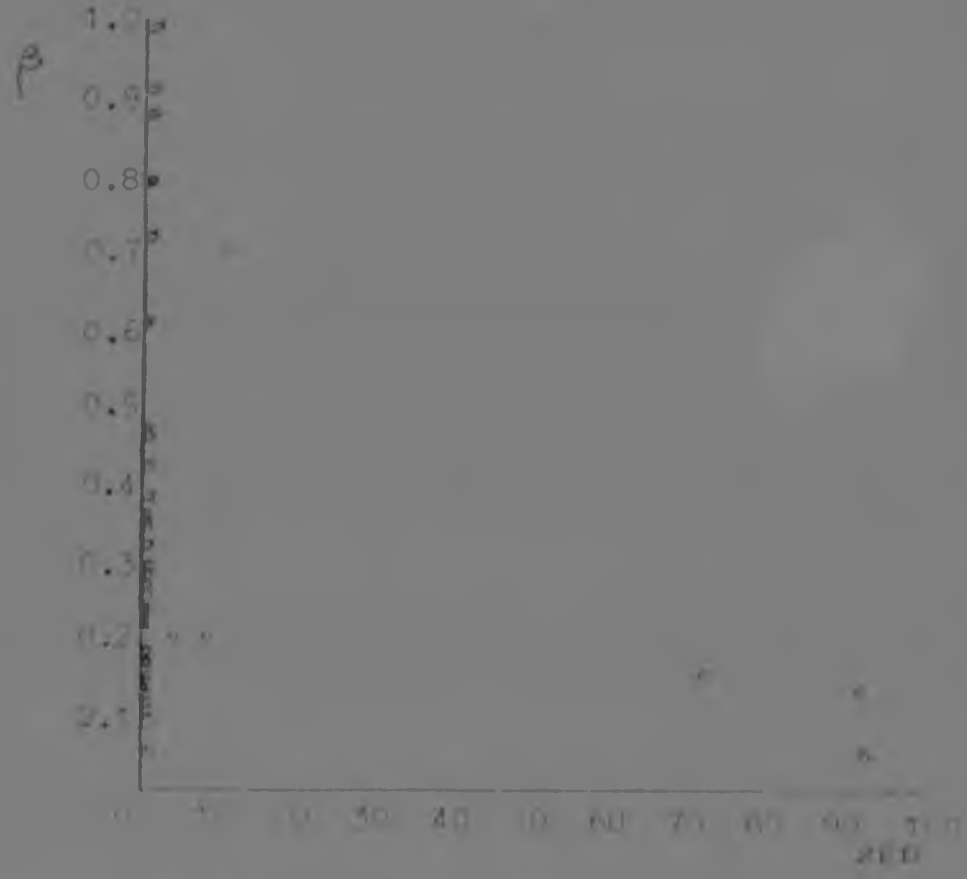

Fig. 5.24: β vs. Zonal employment density

Table 5.4 : % variation explained by parameters

	% variation explained	
	α	β
Peak Period Accessibility	10,7	18,9
Off Peak Accessibility	12,0	10,8
Peak Period Mobility	7,1	6,3
Off Peak Mobility	4,3	5,6
Population Density	12,9	15,4
Employment Density	2,6	7,6
Peak and Off Peak Accessibility	16,6	20,7
Peak Accessibility Population Density	18,2	26,0
Employment Density Population Density	13,1	17,2
Off Peak Accessibility Population Density	16,5	18,3
Peak Accessibility Off Peak Accessibility Population Density	21,2	28,2

Table 5.5 : Regression correlation coefficients for Zonal α and β

Variable(s)	α				β			
	1	2	3	4	1	2	3	4
Peak Period Accessibility	12,0	16,4	22,1	15,8	16,4	18,2	24,6	17,8
Off Peak Accessibility	11,7	12,1	11,9	13,2	11,8	12,2	12,5	11,9
Peak Period Mobility	10,5	19,4	36,8	25,5	6,0	17,2	34,9	22,1
Off Peak Mobility	10,3	19,2	35,8	24,8	5,9	16,9	34,5	22,0
Population Density	13,0	20,6	38,4	21,3	16,2	25,4	42,2	28,1
Employment Density	4,1	10,3	12,6	11,8	12,0	18,4	18,2	17,4
Peak and Off Peak Accessibilities	14,2	18,3	25,6	17,5	18,0	21,2	30,5	20,8
Population Density and Peak Period Accessibility	16,6	22,5	46,4	24,6	20,3	28,8	51,2	33,9
Employment Density and Population Density	14,8	25,4	25,5	26,3	21,2	27,8	33,1	29,2
Peak Accessibility and Off Peak Accessibility and Population Density	22,0	32,8	35,4	24,3	29,5	28,6	26,4	32,7

1. Linear
2. Semi Log (α or β)
3. Full Log
4. Semi Log (independant variable)

Table 5.6 : % variation in number of cars explained

	% variation in number of cars explained
INCOME	41,2
STAGE IN FAMILY CYCLE	3,9
HOUSEHOLD SIZE	5,7
PUBLIC TRANSPORT ACCESSIBILITY	3,9

Table 5.7 : % variation in α and β explained

	% variation explained in α	% variation explained in β
INCOME	7,5	7,6
STAGE IN FAMILY LIFE CYCLE	2,9	1,7
HOUSEHOLD SIZE	3,9	3,0
PUBLIC TRANSPORT ACCESSIBILITY	2,4	2,5
H / HS AND PUBLIC TRANSPORT ACCESS.	6,1	5,3
H / HS AND STAGE IN FAMILY CYCLE	4,2	3,5
PUBLIC TRANSPORT ACCESSIBILITY AND STAGE IN CYCLE	3,8	3,0

REFERENCES : CHAPTER [illegible]

1. Jomet Study Team. Unpublished calculations

2. Sandrock, [illegible] Hurwitz, S. 'Distribution of Household Income', Jomet Working Planning Research Manual 78.

CHAPTER SIX : DISCUSSION OF RESULTS

In this chapter, the implications and validity of the [illegible] in the study are examined.

6.1 The Role of Income

The role of income in determining α and β values was not tested formally, because α and β for each unit were calculated using income directly. In fact, one can determine the behaviour of α and β, with respect to income, analytically.

From the expression for the conditional probability of a household owning 0 cars, β can be found.

$$P(0/x) = 0{,}97e^{-\beta x} \qquad (6.1)$$

From which

$$\beta = \frac{1}{x} \log\left(\frac{0{,}97}{P(0/x)}\right) \qquad (6.2)$$

For a given value of $P(0/x)$, the expression becomes

$$\beta = K_1 \frac{1}{x} \qquad (6.3)$$

where K_1 is a constant equal to $\log\left(\frac{0{,}97}{P(0/x)}\right)$.

This means that the relationship between β and household income is a hyperbolic function.

From Jomet's expression for the conditional probability of a household owning more than one car, an expression for α can be found.

$$P(2+/x) = 0{,}9e^{-1{,}5e^{-\alpha x}} \qquad (6.4)$$

Thus

$$\alpha = \frac{1}{x} \log\left[\frac{-4{,}5}{\log\left(\frac{P(2+/x)}{0{,}9}\right)}\right] \qquad (6.5)$$

For a given value of P(2+/x),equation (6.5) takes a hyperbolic form as follows :

$$\alpha = K_2 \frac{1}{x} \qquad (6.6)$$

where

where $K_2 = \log\left[\frac{-4,5}{\log\left(\frac{P(2+/x)}{0,9}\right)}\right]$

It can now be seen,from equations (6.3) and (6.6),that if income,x, is high,the α and β will be low,and vice versa. In actuality,one expects the α and β values to be directly proportional to the income. That is,one expects car ownership to be directly related to income. This apparent paradox can be explained by the fact that the values of P(0/x) and P(2+/x) are likely to change with a change in average household income. Thus,equations (6.3) and (6.6) will give rise to a family of curves,one curve for each possible value of P(0/x) or P(2+/x). Therefore,for each value of household income there is no unique value of α or β ,and these values can only be determined if P(0/x) and P(2+/x) are known.

Results of ANOVA tests of income on α and β are shown in table 6.1. It can be seen,then,that income has a dual influence on α and β : one direct (through the $\frac{1}{x}$ term),and one indirect,through one of the conditional probabilities. A statistical analysis of the influence of income on values of α and β should yield poor results-as is evident in tables 5.4 and 5.5. Variation in household income explains 41% of the linear variation in number of cars available to a household,whereas the corresponding figure for α and β is only 7,5% and 7,6% respectively.

6.2 Acceptability of Values of Variables Obtained

The main problem in determining values for α and β ,is the necessity of knowing the relevant conditional probabilities. Thus,α and β cannot be found for individual households,because a sample of households must be taken. Consequently,the assignment of a zone's α or β value to households in that zone introduces an element of doubt into any results from that exercise. Furthermore,the larger the sample,the more

Table 6.1 : Effect of income on α and β

Level of Aggregation	Variable	Correlation with α (%)	Correlation with β (%)
DISTRICT	Income	32	30
	Income plus Public Transport Accessibility	40	36
	Income plus Population Density	41	38
ZONE	Income	12	14
	Income plus Peak Public Transport Accessibility	15	25
	Income plus Population Density	14	18

representative will be the conditional probabilities estimated by the sample. Therefore,the α and β values found using a large sample,will be more acceptable than those found using a small sample. It follows, then, that the α and β values for the Jomet districts are the most acceptable in this study. As one examines more disaggregate quantities the sample size decreases, and each α and β value becomes less accurate.

A further factor of doubt lies in the fact that the values of α and β for the zones and districts are not evenly spread out over the whole range of possible values. In all cases,there are very few occurrences of values between approximately 0,5 and 0,99. This means that the behaviour of the variables in the 'unmapped' area must be deduced. While this may reasonably be possible,any conclusions reached will be open to an element of doubt.

The Hansen accessibility indices and the mobility measure have,as their basis,the principle of generalized costs. Therefore,each measure suffers from the same limitations as do the generalized costs themselves. If,for example,the value of time in the generalized cost expression is incorrect,then the value for accessibility and mobility will also be incorrect.

An insurmountable problem was found in the fact that,for certain of the accessibility or motility measures,there is little or no spread of values. In some cases,there were merely two categories-very high and very low. Figures 5.7 and 5.8 are examples of this occurrence.

It has already been mentioned that income determination in a home interview survey is a sensitive issue. However,the author wishes to emphasize that the importance of the role played by income in any transportation study warrants a more reliable determination of household income. One possible method would be to conduct an expenditure survey,rather than to simply request the household income from the interviewee. The household income may then be deduced fairly accurately. A family expenditure survey was conducted in Great Britain in 1972,with considerable success.

Among South African Whites,the company car is common. Thus,a car becomes available to a household,irrespective of the income of that household. This factor could have an important,and undetermined,effect on the values of α and β.

6.3 Implications of Results

The results of each level of aggregation will be discussed seperately.

6.3.1 Household level

The most outstanding feature of the results obtained in the household level of aggregation,is the poor correlation obtained between α or β and all other variables tested. In fact,on studying the correlation coefficients,the natural conclusion to be reached is that none of the variables are related to α or β.

The poor results may,however, be attributed to a number ofreasons, including poor survey data,etc. The author's suggestion follows. In determining household values for α and β ,it was necessary to assign the values of α and β for a zone to all households in that zone. Thus a number of households,in the same zone,have the same α and β values, but may have different values for all other variables. Therefore, within a zone,the exercise actually compares a 'constant' (α or β) with a variable. The value of the 'constant' changes from zone to zone completely independently of any other variable. So the large errors generated within a zone are compounded by these unrelated changes between zones. Unfortunately,this problem could not be overcome,as there was no method to obtain better values of α and β for households.

6.3.2 Zonal level

Once again,correlation coefficients obtained are low,in this case probably due mainly to unreliable values of α and β caused by small sample sizes in each zone. However,within the limits of statistical errors,some conclusions may be reached in this exercise.

The most surprising result at this level of aggregation, is the relatively poor performance of the mobility measures. One would expect mobility to have a greater correlation to α and β than accessibility, since the Hansen index introduces employment in a zone, a factor which should not affect the household's decision to buy a car.

It has been argued that β is more dependent on peak period accessibility than on off peak accessibility, since β is concerned with the probability of a household owning at least 1 car. If public transport accessibility in an area is very poor, households in that area must have at least 1 car for the journey to work (usually during the peak period). The purchase of the first car is more likely to be as a result of a need in travel to work than that in social or even shopping trips. Similarly it can be argued that off-peak public transport accessibility affects the decision of a household to purchase the second car, more than does the peak public transport accessibility. So α should be more dependent on the off-peak accessibility. The results confirm these assumptions. (See tables 5.3 and 5.4). The correlation coefficient between β and peak public transport accessibility is almost double that between β and the off-peak public transport accessibility. The value of the correlation coefficient between α and off-peak public transport accessibility is higher (albeit marginally) than that between α and peak public transport accessibility.

In addition, the best correlation coefficient for α was obtained by a combination of peak and off-peak public transport accessibility and residential population density. The highest correlation coefficient for β also occurred in this case, but had off-peak public transport accessibility been ommitted, the correlation coefficient decreased only marginally. These facts support the assumptions discussed in the previous paragraph.

6.3.3 District level

One need only examine the scattergrams obtained for the districts to note that there is good correlation between α or β and both public transport accessibility and residential population density. The results obtained by both ANOVA and regression confirm this impression, as

correlation coefficients are much higher than at household or zonal levels of aggregation. Furthermore,the results (tables 5.1 and 5.2) show that public transport accessibility is more dominant as a single factor in explaining variation in values of α and β,than is population density. The increases in correlation coefficient gained by combining the two factors are relatively small.

The better results at this level of aggregation may be attributed to the better estimates of the conditional probabilities yielded by larger samples. Also,at the district level ,the interaction between accessibility and other variables (eg. household size,income) probably plays an important part,but is masked by the coarse level of aggregation. So,for example,the fact that larger families may live in more accessible areas is not taken into account.

A point to be noted about the form of the relationship suggested by the scattergrams (figures 5.1 to 5.2) is the steep descent of the curve at low values of public transport accessibility,followed by a long,flat 'tail' at higher accessibility values. This suggests that if the α and β values can be controlled by changing the public transport accessibility,there is little advantage to be gained by increasing the accessibility beyond a certain value. The α and β values reach a minimum.

6.4 The Meaning of α and β

In order to understand the implications of α and β in the Jomet model, the decision to purchase a car must be understood. It seems logical that a household will require a car when it becomes economically advantageous to do so ('economically' in terms of financial,time and convenience factors). That is,the household will weigh up all the factors pertaining to travel by public transport. If an advantage is envisaged in purchasing a vehicle,the household will do so. The advantage may be in terms of time saved,money saved,convenience or a combination of these. This economic advantage may be expressed as a fraction of the household income using α and β factors.

Thus if β for a zone or household is 0,25,then the economic advantage in purchasing a car is a quarter of the household income.

So,β can be regarded as the propensity to buy a car,while α may be the propensity to buy any further cars. Unfortunately,no figures can be forwarded to support these claims,as the data necessary to determine the advantage or disadvantage of purchasing a car are not available. However,this view of α and β illustrates that each is not only dependent on public transport accessibility,but rather on a complex interaction of household size,household income,stage in the family life cycle and public transport accessibility.

As such,the values of α and β change from zone to zone,as has been shown in this report. The author feels that full advantage was not taken of the flexibility of the model in the Jomet study,because α and β were assumed to be constant over the entire study area,for any one population group. If the spatial changes in α and β were taken into account the model becomes very realistic,and it should be possible to calibrate more finely.

6.5 A Further Suggestion on the Meaning of α and β

The starting point of the suggestion is the basic conditional probability expressions.

$$P(0/x) = ae^{-\beta x} \qquad (6.7)$$

$$P(2+/x) = ce^{e^{-\alpha x}} \qquad (6.8)$$

If equation 6.7 is differentiated with respect to income the following expression is obtained:

$$\frac{dP(0/x)}{dx} = -\beta ae^{-\beta x} = -\beta P(0/x) \qquad (6.9)$$

Similarly,if equation 6.8 is differentiated with respect to income one obtains the follcwing expression :

$$\frac{dP(2+/x)}{dx} = -\alpha P(2+/x).\log\left(\frac{P(2+/x)}{b}\right) \qquad (6.10)$$

Expressions for α and β may be found from equations 6.9 and 6.10.

$$\beta = -\frac{1}{P(0/x)} \cdot \frac{dP(0/x)}{dx} \qquad (6.11)$$

$$\alpha = -\frac{1}{\log\left(\frac{P(2+/x)}{b}\right)} \cdot \frac{1}{P(2+/x)} \cdot \frac{dP(2+/x)}{dx} \qquad (6.12)$$

Examining the function of P(0/x) with respect to income, it can be seen that a change in income of Δx will result in a change of $\Delta P(0/x)$. Therefore, the percentage change in P(0/x) caused by the change in income is $\frac{\Delta P(0/x)}{P(0/x)}$. The elasticity of this function can be defined as follows:

$$E_o = \frac{P(0/x)}{\Delta P(0/x)} \cdot \frac{\Delta x}{x} \qquad (6.13)$$

In the limit as Δx approaches 0, equation 6.13 becomes:

$$\mathcal{E}_o = \frac{dx}{dP(0/x)} \cdot -\frac{P(0/x)}{x} \qquad (6.14)$$

where $\mathcal{E}_o$ is the point income elasticity of the P(0/x)-x relationship.

Using equations 6.11 and 6.14, it can be shown that

$$\beta = -\frac{1}{x} \cdot \frac{1}{\mathcal{E}_o} \quad \text{(cf. eqn 6.3)} \qquad (6.15)$$

Similarly, it can be shown that

$$\alpha = -\frac{1}{x} \cdot \frac{1}{\log\left(\frac{P(2+/x)}{b}\right)} \cdot \frac{1}{\mathcal{E}_{2+}} \qquad (6.16)$$

where $\mathcal{E}_{2+}$ is the point income elasticity of the P(2+/x)-x relationship.

It can now be shown that, ceteris paribus, α and β are inversely proportional to the income elasticity of demand for cars, since the

elasticities defined above should be proportional to the income elasticity of demand for cars. Factors affecting α and β may now be studied in the light of this suggestion.

-Price of cars relative to income :

The higher the relative price of cars with respect to income, the greater will be the elasticity of demand for cars (ceteris paribus). Consequently, because of the relationship discussed above, α and β will be low, reflecting low car ownership rates. This factor should affect α more than β, because α is the measure of multi-car ownership, and the purchase of a second car will depend on the price of the car to a greater extent than will the decision to buy the first car.

-Price and availibility of public transport :

High costs of travelling by public transport will lower the income elasticity of demand for cars. Poor availibility of public transport will have the same effect on the elasticies as high costs. Thus, α and β values will be high, reflecting high car ownership rates.

-'Luxury' or 'necessity'

At low incomes, a car purchased may be a 'luxury', while at a high income, it is less so. In fact, a car may be a 'necessity' to a high income household. If a car is regarded as a 'luxury', the income elasticity of demand for cars is high, resulting in low α and β values. Income plays an important role in this factor, and exerts an indirect influence on α and β as well as the direct influence shown in equations 6.15 and 6.16.

While this interpretation of α and β is not very useful in practice, since the elasticities of the functions may be difficult to calculate, it provides a theoretical base for understanding the behaviour of α and β.

CHAPTER SEVEN : CONCLUSIONS AND RECOMMENDATIONS

Conclusions and recommendations are now made based on evidence which has been presented in this report.

7.1 Conclusions

7.1.1 Car ownership levels of an area may be defined by means of the parameters α and β. If β is high, the proportion of car owning households is high and vice-versa. If the α value for the area is high, the proportion of multi-car owning households is high.

Thus, β may be defined as propensity to own a car, and α may be defined as the propensity to own more than one car.

7.1.2 A relationship exists between α and β values and public transport accessibility, such that when public transport accessibility is high, α and β values are lower. This relationship is strongly evident at the district level of aggregation, and less prominent for more disaggregate levels. This phenomenon is caused by the combined effects of other other variables such as household size, income, stage in the family life cycle, in addition to the public transport accessibility. At more disaggregate levels, the combined effects are removed, and the relationship between car ownership and public transport accessibility appears to be weaker.

7.1.3 The form of the relationship between α or β and public transport accessibility may be specified as a log or semi-log form. There is no value in drawing conclusions from the regression equations obtained, because the equations probably change in time and location. Furthermore, the equations depend on the measure used in regression. Accessibility measures can be defined in many ways, each definition yielding a different regression equation.

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conditions ten years apart. Thus, the

over that period may be examined with respect

accessibility over the same period.

ed idea of the strength of the relation-

public transport accessibility, and

of that these two factors have on

term plan update, the

ownership model uses α and β values for individual districts. Substantial spatial variation in α and β were found in this study, and the use of one value for the whole study area seems to result in a loss of accuracy in forecasting future car ownership levels.

APPENDIX A : Program to find most likely beta and alpha values

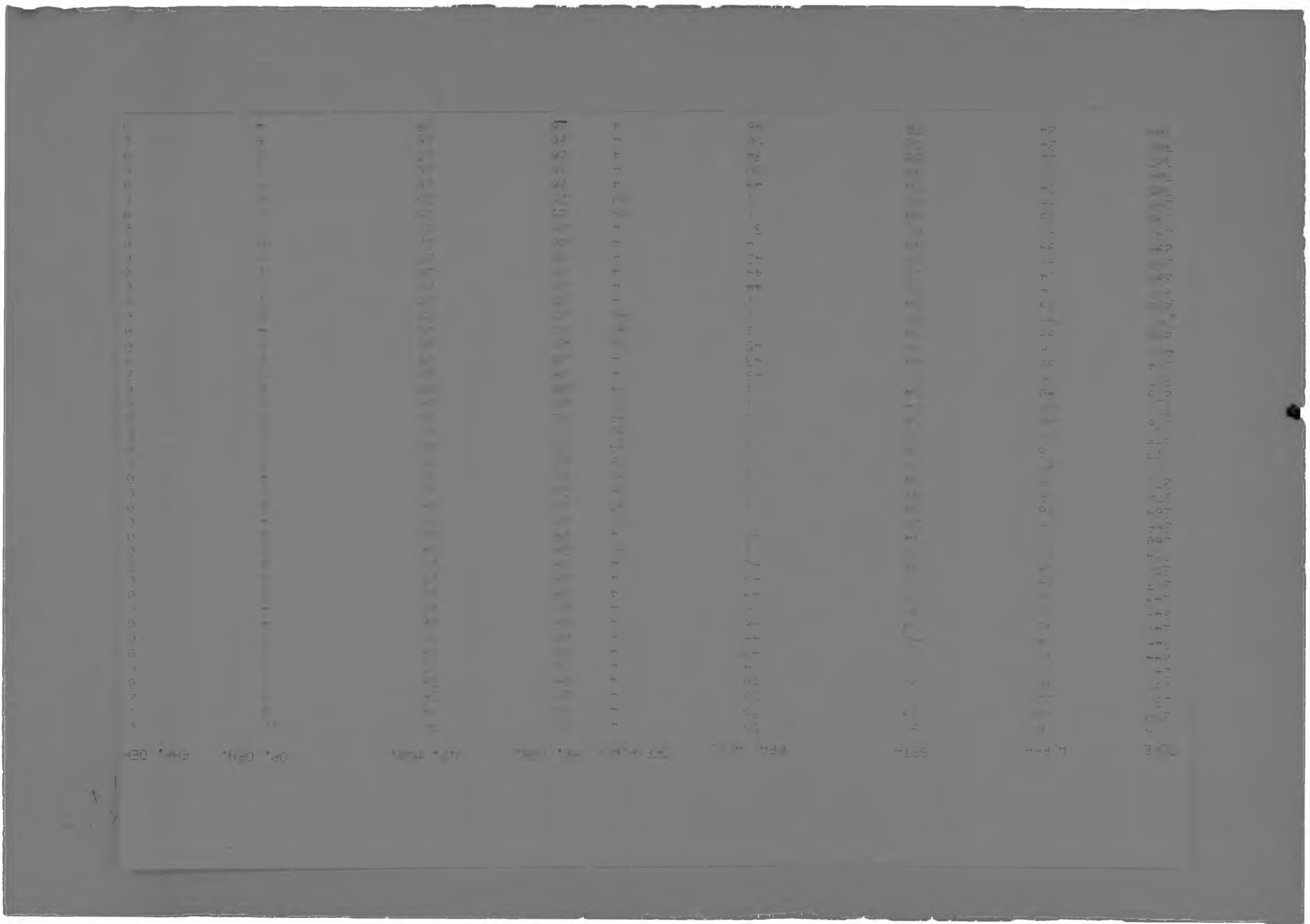
```
5  [illegible]
7  DEF [illegible]
8  DEF [illegible]
9  GOSUB 1000
10  GOSUB 2000
20  GOSUB 6000
55  GOSUB 10000
60  CLEAR : GOTO 2
999  END
1000  INPUT I,P(0,I),P(1,I),P(2,I)
1001  IF I = 0 THEN GOTO 1005
1002  GOTO 1003
1005  FOR I = 0 TO 2
1010  FOR J = 1 TO 12
1012  TN = TN + P(I,J)
1015  NEXT J
1020  NEXT I
1025  FOR I = 1 TO 12:PD(I) = P(0,I) + P(1,I) * P(2,I): NEXT I
1030  FOR I = 0 TO 2
1035  FOR J = 1 TO 12
1037  IF P(I,J) = 0 THEN GOTO 1040
1040 P(I,J) = P(I,J) - PD(J)
1045  NEXT J
1050  NEXT I
1055  FOR I = 1 TO 12
1060 IN = IN + PD(I) * (I * I) - 100)
1065  NEXT I
1070 IN = IN / TN
1071 IN = ( INT (IN - 10 * .5)) * 10
1072  PRINT [illegible]
1099  RETURN
2000  REM  FIND LIKELY RETN
2001 DL = 99:DD = 0:DI = 0
2005  FOR K = -.01 TO 1 STEP .01
2007 DN = 0
2010  FOR I = 1 TO 12
2015  IF P(I,I) = 0 THEN GOTO 2020
```

```
2020 ON = ON + (P( 0,I ) -  FN C0( )
2025  NE T I
2030  IF ON < OL THEN  GOTO 2100
2035  IF ON   OO THEN  = V + 1
2040  IF V > 10 THEN  G TO 2998
2045 OO = ON
2050  NEXT K
2055  GOTO 2995
2100 OL = ON:BL = K
2105  GOTO 2035
2995 BL = ( INT (BL * 100) / 100)
2998  PRINT BL
2999  RETURN
6000  REM  FIND LI ELY ALPHA
6001 OL = 99:OO - 0:V = 0
6005  FOR K =  - .01 TO 1 STEP .01
6007 ON = 0
6010  FOR I = 1 TO 12
6015  IF PI( I ) = 0 THEN  GOTO 6025
6020 ON = ON + (P(2,I) -  FN C2(K)) ^ 2
6025  NE .T I
6030  IF ON < OL THEN  GOTO 6100
6035  IF ON > OO THEN V = V + 1
6040  IF V  10 THEN  GOTO 6998
6045 OO = ON
6050  NEXT K
6055  GOTO 6995
6100 OL = ON:HL = K
6105  GOTO 6035
6995 HL = ( INT (HL * 100) . 100)
6998  PRINT HL
6999  RETURN
10000  REM  PRINT
10005  INPUT "ZONE
10010  PR# 1: PRINT Z; TAB( 14);IM; TAB( 13);HL; TAB( 23);BL
10025  PRINT "AGAIN
10030  IF  =  N" THEN  GOTO 999
10999  RETURN
```

APPENDIX 8 : District data

Page 88 omitted in pagination.

Appendix C : Zonal Data



Author Fransos AC
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