URBAN POPULATION DENSITY DISTRIBUTION:

A CONTRIBUTION FROM THE

VANCOUVER CASE

By

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ABSTRACT

Colin Clark's model of the negative exponential population density decay function is applied to the Vancouver case. Though the model is claimed to hold true for all places at all times, it does not offer sufficient explanations why the process is occurring, nor does it pay due regards to the topographical effects. The application of the model to the east and south sections of Vancouver may throw some light to the rationale of the city growth process. We are able to compare the density gradient of the east and south due to the different timing of transportation improvement and physical morphology. By examining two sections of the same city we can isolate the effect of transportation on the density of development, since both sections are subject to the same growth pressures.

The density profiles of the whole city, and the eastern and southern sections of it (in the shape of ring, single airline, sector and band) are prepared; and for each plotting of population density, two parallel regression runs are made with regard to both radial distance and travel time. The model is tested at four points in time; and its goodness of fit is measured by the coefficients of determination.

The conclusions reached are as follows:

1. The quality of the model in replicating the Vancouver experience is similar to that found for a wide range of cities.
2. The east and the south are marked by the differential rates of density decline, which are mainly due to the date at which the development takes place.

3. The distance parameter measured in travel time from the CBD does not give a significantly better fit to the model than radial distance from the CBD.
4. The coefficients of determination of the model decline over time, suggesting variable pattern of population density within the city over time.
5. The imputed central density does not show a consistent decline over time.
6. The steepness of density decline decreases in the course of time.

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CHAPTER I

INTRODUCTION

Cities have similar characteristics in internal structure. Almost all of them have a clearly recognizable CBD, which is the region of heaviest concentration of economic activity and a major employment center. Residential development tends to follow a regular pattern. It is most dense in the immediate vicinity of the CBD, and the density declines towards the periphery. Development tends to take place at the periphery of the city, and so the dwellings of the inner city tend to be older than those of the suburbs.

Colin Clark [1] (1951) has produced an empirically-based model that seems to generalize the residential density pattern. The model effectively describes the density distribution of residential development of North American and European cities for many dates within the past 200 years. Further, when it is applied to the same cities at several points in time, it indicates that there is a common pattern to the change in the density distribution that has taken place in the modern era.

However, Clark's model is purely descriptive, and the processes that underly the growth pattern of the city are not clear. We may speculate that transportation factors and the setting of a city are important determinants of the form of the city.

It is apparent that transportation facilities can influence urban spatial structure by changing the relative accessibility of distant and central locations. However, the demand for transportation is itself influenced by spatial structure and land use. Any change in traffic facilities changes the relative accessibility and hence the relative attractiveness of various locations. On the other hand, the uses at those various locations generate trips, and these trips in turn define the transportation requirements for an area.

Transportation can also influence the sequencing of city growth. The history of urban development of almost all major cities is well marked by various "eras" of transport technology. First came the horse-drawn buses or street-cars; later, in the 1880s and 1890s, cable cars, electric surface cars and elevated lines. [2] The streetcars and the railroads allowed extensive ribbon development along the lines of the major radial arteries, and the subsequent advent of the motor-cars in the 1920s allowed the space between the arteries to be filled in. After World War II, extensive construction of highways and expressways facilitied the use of private automobiles. The increasing availability of the automobile also allowed easier access to distant locations, causing cities to "sprawl".

As for physical morphology, if a city is located on an infinite featureless plain, accessibility to the city center tends to be equal in all directions, theoretically at least. It is therefore likely that population density would be equal in every direction from the city center. In a spatially restricted city where growth in different directions from the central core is assymmetrical, regional centers may develop to cluster urban functions close to residential population and to minimize travel time. In any event, population density would not be the same for all points at a given distance from the center.

The effects of both transportation and physical morphology on urban form can be observed when the construction of new transportation facilities eases travel across substantial physical barriers. This has happened in Vancouver, a city with a highly restricted site, where development could take place with relative ease only towards the east.

Residential development was largely restricted to the Burrard Peninsula by the lack of adequate road crossings of the Burrard Inlet to the north and the Fraser River (North Arm) to the south until well into the 1950s. However, continuous development to the east has been relatively unrestricted by physical obstacles.

The different timing of transportation improvement in the east and the south has caused certain areas in and around Vancouver to be accessible for residential development at different times. As a consequence, the city is assymmetrical. This assymmetry enables some hypotheses concerning the nature of the city growth process to be examined. Hypotheses on city form, measures of accessibility (radial distance and travel time), and the validity of Clark's model, will be considered in this work.

CHAPTER II

MODELLING THE URBAN POPULATION DENSITY DISTRIBUTION

A. Scope of the Study

In this study we shall concentrate on the residential density distribution. Residential activity is by far the predominant land use of cities. The population density function of Colin Clark is taken as a departure. Clark found that for many cities, in the past and in the present, population density falls off exponentially as distance from the city center increases. He goes so far as to say: "That the falling off of density is an exponential function, appears to be true for <u>all times and all places studied</u>, from Los Angeles to Budapest". [3]

For the relationship between density and distance in Clark's model to hold true, the density profile should ideally be the same in all directions in inhabited parts of the city---where no "holes" (such as bodies of water) are present, this would result in a circular city, with the Central Business District (CBD) at its center.

Clark found that residential population density declines with increase of distance from the city center, and that the steepness of this decline becomes less over time. He argues that transportation improvement is responsible for this decline over time. However, the primary reasons for this density profile and its change through time are not clear. We will use evidence from the Vancouver case to improve our general understanding of this matter.

Specifically, the aims of the study can be outlined as:

1) <u>To test the validity of Clark's model for Vancouver</u>

The repeated confirmation of the validity of the negative exponential function of population density distribution has important implications for the planning of metropolitan regions. It has been found that the individual choice of residential locations conforms collectively to the regualr pattern. The negative exponential "law" of mass behaviour is not a result of externally imposed physical planning, or legal or administrative constraints.[4] "The observed behaviour is characteristic of urban societies responding to forces and subject to constraints that, although they are not consciously perceived, are nonetheless extremely strong".[5] Should this "natural" pattern of population density decay be the case in Vancouver, it must be taken into account in planning policies. However, it is important first to verify that it does in fact hold for Vancouver. The city is unusual when compared with other cities in that it is essentially elongated in shape and highly restricted in site. It is necessary to observe the effect of physical morphology and the restriction on development on the applicability of the model.

Cities that are located on sites that are not unduly restricted show many similarities of form. Vancouver has developed on a highly restricted site and from its shape it would appear to be exceptional. The slope of the density decline should be different in the east and the south. But if it is the same in every direction at one point in time, we can say that Vancouver is not so different from other cities.

2) <u>To observe the long-run trends on urban form</u>

It is necessary to consider whether the long-run trends in the development of urban form are in fact changing. As indicated in Clark's model, the urban form would in time change, showing a relative decline in imputed central density and a relative increase in suburban population density. It is to be expected that the introduction of planning policies and controls will affect the pattern of future development to some degree. Future urban form would also be affected by changes in the long-run trend for the type of housing constructed.

(a) Housing Trends:

A housing survey conducted in 1972 in Vancouver suggests that there will be more preference for smaller units in the future. [6] The National Housing Act (NHA) finances more multiple dwellings (apartments and row housings) than single family housing. [7] The cost of land has been increasing sharply since early 1972. [8] Other economic factors also discourage people from owning single detached housing. Further, the "assisted home ownership programme" of the Canadian Housing and Mortgage Corporation finances condomium units. [9] Ownership of single detached dwellings is becoming relatively more expensive as compared with multiple housing units, and as a result, apartments are more popular. One result is the emergence of high density living in suburban areas. Townhouses and apartment complexes now coexist with quarter-acre lots on the fringes of the city. This suggests suburban development in the future at densities greater than has been the case in the last two decades.

(b) The Livable Region Growth Strategy:

The major planning policy documented for metropolitan Vancouver is the so-called Livable Region Plan. This plan has substantial implications for the future applicability of the model. The major proposals adopted by the Policy are:

(1) The creation of four regional centers all to the east and southeast of the CBD: The regional centers are to be located in Burnaby, New Westminster, Surrey, and the North-east Sector (the exact location of this fourth area is as yet to be determined). These would act as foci for the generally formless, scattered development to the east of Vancouver. They would help the suburban communities reach a balance of employment and employable residents.

(2) Protection of agricultural land: The housing stock would be expanded primarily within the presently urbanized area by infilling and redevelopment. The net result of this policy is that densities would be somewhat higher in the urbanized portions of the outlying municipalities than would otherwise be the case.

(3) A light rapid transit system connecting the regional centers and downtown Vancouver: This would put the regional centers on a more equal footing with the present CBD in quality of services and accessible opportunities.

If these policies are implemented, several consequences can be envisioned. There would be an increase in suburban population densities, a less uniform pattern of densities for suburbs at similar distances from the CBD, a comparatively less dominant CBD than before, and improvement in accessibility to service activites and some of the CBD-type functions in the regional centers which may alter the location preferences of individuals.

In sum, there already appear to be trends towards higher densities in the urbanized areas of the outlying suburbs, and these trends will further be enforced by the Livable Region Policy.

It is doubtful whether the projected density pattern to be adopted by the Livable Region Plan fits Clark's negative exponential curve, and if Clark's model represents a behavioral "law", then the Plan might be more successful if it were consistent with this "law".

3) <u>To study the effect of transportation improvement</u>

The site of the city poses significant barriers to commuting, which have in the past restricted travel to the north and the south. There are still relatively few crossings of the major water barriers, and these are in fact the places where Vancouver experiences congestion at peak-commuting hours.

The CBD itself is close by the Burrard Inlet Waterfront and is connected to the northern suburbs by two bridges: one a few miles to the east of the CBD (the Second Narrows), and the other a few miles to the west (the First Narrows). To the south, the Fraser River is a major barrier. The Fraser River reaches tidewater across a delta to the south of the Burrard Peninsula. A few major bridges and one tunnel have been constructed in the last 20 years to improve access to the south. Nevertheless, the Fraser remains a substantial barrier.

Transport obviously is a very important factor in urban development, although its exact role is difficult to isolate because of the multiplicity of other factors. In Vancouver, improvements in transportation such as the bridges and highway programs of the 50s and 60s generally preceded residential spread. Also, improvements in transportation through the natural barriers in the east and the south have occurred at different times. Because of this, we are able to examine the effect of transportation on the density of development in comparison to other explanations of the density profile, such as the date at which development takes place.

Among the most important projects leading south were the new Granville Street Bridge, 1954; Oak Street Bridge, 1957; Deas Island Tunnel (later named George Massey Tunnel), 1959; Vancouver-Blaine Freeway, 1962, through Richmond, Delta and Surrey to the United States border; and Knight Street Bridge, 1974.

To the east and the south-east, the Fraser and its tributaries are significant barriers to travel in the outer suburbs of Vancouver and beyond. Bridges were built at Rosdale-Agassiz in 1956, and at Pitt River in 1957. The former provided much better inter-connections between the north and south banks of the Fraser River and permitted east-west through traffic to use the Lougheed Highway as an alternate route to the Trans-Canada Highway, through Burnaby, Coquitlam, Surrey and Langley, both opened in 1964. [10]

Since the travel restraints of the various sections of the city were eased at different times, we would expect the rate of population density decline to the south to be different from that to the east. This should be the case when the distance parameter in the model is measured in terms of travel time or radial distance. However, the locational decisions of households may be more responsive to the former than to the latter.

Clark's model is tested with respect to both travel time and radial distance in order to study the effect of the improvement of transport facilities on residential spread. It is used in the study because it is "the most appropriate sample descriptive model for representing the distribution of residential density".[11] It involves merely two parameters (A and b), which, at first glance, is simple but appealing. The density gradient b is the simplest descriptive measure of the spatial distribution of activity. It can be used to indicate the changes in city form. It is easily computed; and it represents a clearly understood descriptive summary about the spatial allocation of residents in an urban area.[12]

B. Description of the Model

Since Clark provided a mathematical expression for the population density distribution in 1951, other authors have worked with the model and come up with some other formulations. However, it is doubtful whether other models have shown an improvement over the original one.[13] Clark's model is:

$$D_x = D_o \, e^{-bx} \quad .... \quad (1)$$

$$\text{or : } \mathrm{Ln}\, D_x = \mathrm{Ln}\, D_o - bx \quad .... \quad (2)$$

This states that density is a negative exponential function of distance from the city center. D_o and b are the parameters of the equation.

Where: x is distance from the center of city;

D_x is the density of resident population at a distance x;

D_o is the extrapolated or imputed central population density;

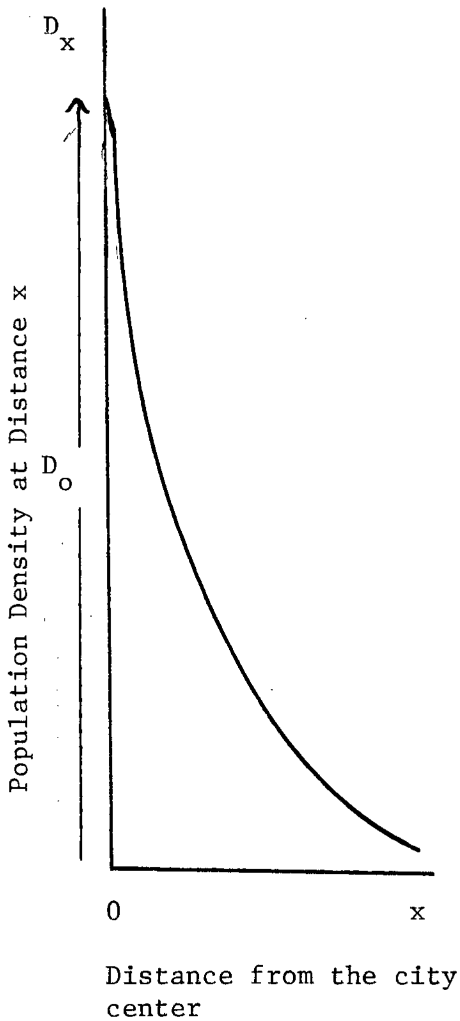
Ln denotes the natural logarithm;

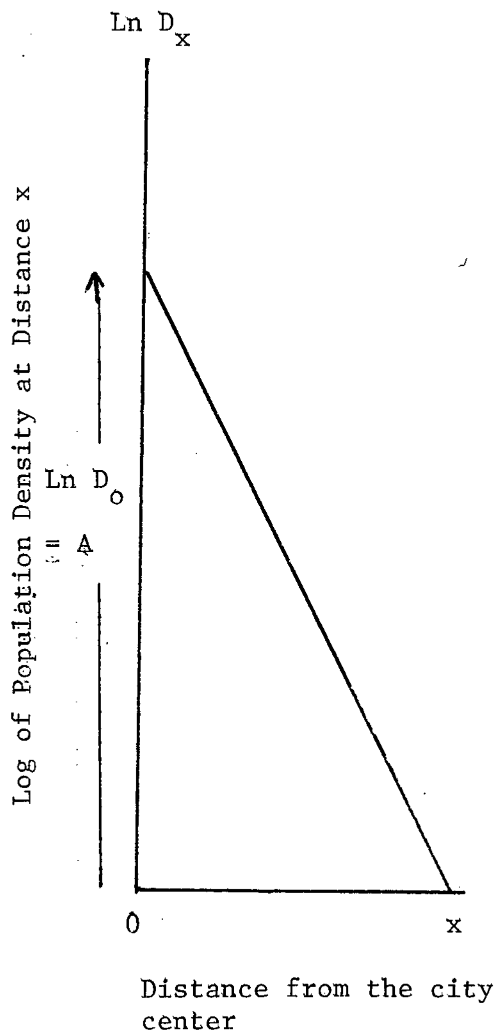
e is the natural logarithmic base;

b is the density gradient, or the slope of the curve.

D_o is the residential density imputed to the city core. Because the CBD is mostly non-residential, this density represents a hypothetical figure which is not realized. The non-residential CBD shows up as a (residential) "density crater" not explicitly taken into account in Clark's model.

Graphically, the model can be represented by:





Clark derived two generalizations from his study of 36 American and European cities:

1) In every large city, excluding the central business zone, which has few resident inhabitants, we have districts of dense population in the interior, with density falling off progressively as we proceed to the outer suburbs;

2) In most (but not all) cities, as time goes on, density tends to fall in the most populous inner suburbs, and to rise in the outer suburbs, and the whole city tends to "spread itself out".

At one static point in time, the fall-off in density from the city center to the periphery follows a negative exponential relationship with distance. However, density tends to decrease in the inner suburbs and increase in the outer suburbs with the passage of time, and this tendency is reflected in the parameter b in the model taking on smaller values over time. The density gradient may also be called the "coefficient of compactness". The larger the value of b, the more compact the city, and the smaller the more sprawled the city.[15] Clark argues that b is largely dependent upon the costs of intraurban transport, or the cost of travelling in relation to the average citizen's income.[16] In other words, it would get smaller when improvements in transportation allow people easier access to the suburbs.

Clark used the following methodology in his work: First, a series of concentric rings were drawn at one mile radius from the city center and the average density calculated for each ring using the net area exclusive of open spaces. Second, the density measure was then plotted against the mean distance of the ring from the center. (The population and net area were obtained for census tracts or similar administrative divisions and where the circles cut the boundaries of these divisions, apportionments of population were to be made). Third, the parameters D_o and b were obtained by regression analysis using the logarithmic form of the equation. Having adopted this method, Clark goes on to state that "it would be better to plot, for each tract, the recorded average density against its mean distance from the center of the city, as this would eliminate the errors due to the apportionment process, and give a better picture of the scatter about the regression line". This simpler and more effective procedure was adopted in this study.

C. Commentary on Clark's Model

In very sweeping terms, the model at best describes the population density distribution in a snapshot. Though it is not predictive, it has implications for the growth trend of a city. It brings forth the issue of the frictional effect of distance, i.e., accessibility or the ease of interaction between the place of residence and the core area, which is the primary center of economic activity. However, the model is not without its shortcomings. It is therefore the intent of this section to outline its deficiencies in brief, and to provide a theoretical justification to explain the relationship between density and distance.

Deficiencies

Deficiencies

The model has been claimed to be applicable to all places at all times. It is derived purely from empirical observations and it does not have within it anything to explain why the density distribution is as it is or why it has changed in such a consistent manner over the past century. It is apparent that as soon as planning institutions such as zoning, taxes, etc., are introduced, or a different set of market forces are in operation, or the factors affecting the choice of residential location change, Clark's "law" may no longer apply. On the other hand, if the "law" does apply, this shows that the "natural" forces may in fact be much stronger than these factors.

Theoretical Justification

The population density decay function can be explained in economic terms. In the abstract, individuals tend to base their residential location decisions upon a tradeoff between land cost, the cost of housing and transport or commuting costs. As distance from the city center increases, land costs tend to be lower because more land is available, and transportation costs to a range of activities and job opportunities are higher. As land costs less and less, it is likely that people will consume more of it. It is therefore logical to expect that the per capita consumption of land for housing increases with distance from the city center.

This expectation was confirmed by the findings of the study done by the Lower Mainland Regional Planning Board of British Columbia in 1963 concerning the intensity of land use and its associated land value of Vancouver. In the main, it was found that the curves of intensity of land use and land value are downward sloping. The curve of the ratio of occupied land to unoccupied land plotting against time-distance zones is very steep at the center and becomes flattened out at the periphery. This indicated that land is in high intensity use at the core and low intensity use at the periphery.[17]

Footnotes

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CHAPTER III

ANALYSIS METHODOLOGY

A. Hypotheses Investigated

Six explicit hypotheses are considered. The hypotheses are intended to explore certain determinants of city growth. They have direct relation to the model formula:

$$D_x = D_o\, e^{-bx}$$

i.e., $\text{Ln}\, D_x = \text{Ln}\, D_o - bx$ (in the form for linear regression)

where: x = distance to the city center (whether measured in radial distance or travel time)

D_x = population density at distance x

$\text{Ln}\, D_o$ = the natural log of the population density imputed at the city center

b = density gradient, or the slope of the curve in the linear regression model

Hypothesis 1: <u>The density gradient b will be larger for the South than for the East</u>.

Reasons: 1. The topographical constraints to the south are greater than to the east. The former is clearly marked by water bodies, i.e., the north and south arms of the Fraser River; while the east is not characterized by any major barrier in the landscape.

2. Development to the south has been relatively slower than to the east. If residential building density is primarily a function of the time of construction for new peripheral development, and the lower density is associated with later development, then the slower spread of the urban area to the south will be associated with a larger b value when density is measured against travel time. If, on the other hand, transport is the dominant factor in explaining density distribution, then the b value to the south should be similar to that to the east.

Hypothesis 2: <u>There will be a significant discontinuity in the scattering of data points at about six miles from the city center, where the north arm of the Fraser River is located</u>.

Reasons: Only in the '50s did high-capacity bridges over the Fraser River improve transportation links to the south. Population density should be higher between the city core and the north arm of the Fraser River than further south. Residential spread south of the river started at a later date, and should be marked by a lower density. There should thus be a sharp break in the scattering of data points. This break could be due to: (1) The fact that density depends on the date of development. The late development south of the river would then be responsible for the break in density at that point; or (2) to the fact that density responds to travel time and the detours and delays due to the few river crossings may cause a sharp leap in average travel time over a short increase in radial distance from the center. Evidence for the former explanation would be continued existence of a break when density is considered as a function of travel time as well as radial distance. For the latter to hold true, the discontinuity should be conspicuous only when density is a function of radial distance. When distance is measured in terms of travel time, there should not be a sharp discontinuity, and the residential density should be represented by a smoother profile.

Hypothesis 3: x measured in travel time will give a better fit (as evidenced by a higher R^2) to the data than x measured in radial distance.

Reasons: It seems reasonable to assume that residential location decisions are made on the related bases of accessibility and travel costs. Housing demand is directly related to accessibility and inversely related to travel costs. Since travel time is probably a better measure of travel cost and of accessibility than radial distance, it should be a better predictor of density.

Hypothesis 4: R^2 for the model should decline over time.

Reasons:

1. Decline in the relative dominance of the CBD: The CBD has been the major employment center. Since the journey to work is the most recurrent travel movement of all the daily trips, residences tend to be located around the CBD. It is often assumed that residential location is the result of the attempt to minimize the length of the journey to work, and therefore the costs of work travel incurred. However, the CBD has declined in relative importance as a center of economic activity and attractor of trips. It follows that residential location decisions are less influenced by the ease of access to the CBD, and other factors not connected with the CBD will be more influential in determining the density at which development takes place.
2. Rise of mobility in all directions: The increasing availability of private automobiles has freed personal travel from dependence on the primary transit network. Residences, workplaces and shopping centers can be located away from the major transportation routes.
3. Decline in the relative importance of transportation cost through time: Transportation has tended to

become a less and less significant factor in determining personal choice of the type and location of residence. This may be due to rising mobility caused by the increasing use of automobiles, the decentralization of employment, shopping and recreational opportunities, and the marked increase in the cost of available accomodation in recent years. These factors have acted to reduce the transportation cost savings possible from selecting one location over another.

A decline in the importance of accessibility to the CBD and the quality of transportation in general in location decisions should lead to a density pattern less and less influenced by these factors. This would result in a density distribution less conforming to Clark's "law", which would be evidenced by more dispersed pattern of data in the model. Thus, we would expect a lower R^2 over time.

Hypothesis 5: A should decline over time for Vancouver.

Hypothesis 6: b should decline over time for Vancouver.

Reasons:

1. Clark's empirical findings show that these two parameters decline through time for many cities.
2. In Vancouver, as in all major cities, transportation facilities have improved over time. As a consequence, distant locations have become more accessible relative to central locations, and so people have tended to settle in places other than the central area.

3. Greater efficiency in transportation has caused a decline in the relative importance of transport cost as compared to other locational considerations, as well as the relative advantage of one location over another in various sections of the city.

B. Methodology

In this section we shall focus on the procedure of the study. The source of data and its possible weaknesses, the method of aggregating the data and its justification will be discussed in turn.

Measures of Accessibility

The unit of observation for this study is the census tract, and distance in the model is taken from the census tract centroid to the city core. However, distance may be either spatial or psychological, so measurement is made with respect to both radial distance and travel time. (Since the dominant mode of transportation in Vancouver is the auto, "travel time" is measured by automobile travel time.)

Data Source

The model involves two variables: population density and distance (radial distance or travel time). The former is calculated by taking the total population count of a census tract divided by its total area. It should be borne in mind that the value obtained represents the gross residential density of the census tract. The distance "as the crow flies" from the city center is taken from the census tract map. The census statistics of 1956, 1961, 1966 and 1971, and the census tract maps of 1961 (for statistics of 1956 and 1961) and 1971 (for

(for statistics of 1966 and 1971) are used. The driving time from the city center for 1966 and 1971 is taken from the Travel Time Isolines Map of 1968 [1] and that for 1956 and 1961 is taken from the Travel Time Map of 1961. [2]

Data Weaknesses

The data used have some weaknesses: First, the sizes of the census tracts vary considerably. They are small at the city center, but become large towards the periphery. Second, measurement of radial distance is made from the city center to the centroid of the census tract concerned. However, the location of census tract centroids are determined by intuitive judgment. Third, in this study research is not done to locate the exact city center. It is taken to be the Granville-Georgia intersection, which is generally agreed to be the "high-value corner" or the center of the CBD. There has been debate on the method of locating the city center exactly. However, it has been shown by Genest that the exact center does not significantly affect the quality of the model [3], and the search for it is therefore not a worthwhile undertaking. Fourth, the travel time from the center to the census tract is an approximation, since travel-time study years were not always the same as the census years. Also, we assume that there were no major changes in the road network in the census years from which the respective Travel Time maps are adopted.

Manipulation of Data

Analyses are made for four geographical set-ups (rings, lines, pie-slices, and bands), two measures of distance (radial distance and travel time) and four points in time (1956, 1961, 1966 and 1971). Population density of the four types of geographical set-ups are aggregated as follows:

1) Rings: The whole metropolitan area of Greater Vancouver is divided into rings at each mile from the city center (Diagram 1). Population density for each ring is plotted against the distance of the inner ring boundary and against travel time from the center. (The ring boundary is used in the study rather than the mean distance of each ring as suggested by Clark, since the distance between the successive intervals of the ring boundary and the mean distance of each ring is equal.) Population density of each ring is found by aggregating the population counts of all the census tracts that fall within the limit, divided by their total areas. Density plotting of rings is done for 1966 and 1971 only.

2) Lines: Straight lines are drawn from the center towards east and south to the periphery (Diagram 2). The lines so drawn are along Broadway and Granville Streets, which are two of the major primary arteries in Vancouver. The radial distance for each tract that falls on the lines is taken from the centroid of the tract to the city center, and population density is plotted against this radial distance. It is also plotted against travel time.

3) Pie slices: Sectors are drawn along Hastings and Granville at some angle at the center to include a considerable portion of the metropolitan area in the east and south directions (Diagram 3). Density plotting is done for each individual census tract against distance and

travel time from the tract centroid to the city center.

4) Bands: Bands are drawn along Hastings and Granville: (1) one band between Hastings and Broadway, and (2) one band of one-mile width with Granville in the middle (Diagram 4). Any census tract whose centroid falls within the boundary of the band is included; and the same plotting is done as formerly.

Since an objective of the study is to observe the changes in residential spread before and after the construction of the bridges and highways, the census years of 1956 and 1961, which are considered as closest to the dates of the construction, are chosen. The statistics computed for these years can be compared with those of the later census years. In this way, we can see the changes in the residential spread over time.

It is apparent from the Census Tract Map of 1961 (See Appendix IV, Map 1) that a great number of the tracts have undergone redistrictings and boundary changes through the decade. The Census Tract Map of 1971 (See Appendix IV, Map 2) shows a more refined breakdown. The census tracts had the same boundaries in 1956 and 1961; and they were subdivided in 1966. Pie-slice sectors and bands along Hastings and Granville are drawn on the Census Tract Map of 1961. The census tracts that fall within the boundary are taken.

<u>Justification for the use of gross residential density and various geographical set-ups</u>

The gross residential density measure is much simpler than that of the other land use data, such as the net residential density or floor-space density, and is used because the data are more readily available, and the quality is sufficiently close to that of net residential density. [4]

The use of lines, sectors, and bands has a fairly straight-forward rationale. A relatively small sample is involved in the use of lines, which may accidentally pass through the regional centers of high population density and therefore biases the results. However, the lines may serve as a yardstick against the improvement, or lack thereof, of the statistics computed in the larger samples used in the case of pie-slice sectors and bands.

The pie-slice sectors and bands enlarge the sample, and more accurate estimates of the parameters would presumably be obtained. The pie-slice sector includes in its sample an approximately equal number of tracts at the center and at the periphery, since the tracts at the center are small, and those in the outlying areas larger. The use of sectors may average out the effects of the contribution of high population concentrations to the density gradient. The theoretical central density is, for the pie-slice sectors and lines, a value obtained for a point at the center. On the other hand, bands would include relatively more tracts at the center and fewer at the periphery. The central density estimate is then found not for a single point, but for a band of some width.

It is interesting to find how the various geographical set-ups would give an estimate of the central density and how the density gradient in the model differs according to the use of these geographical set-ups.

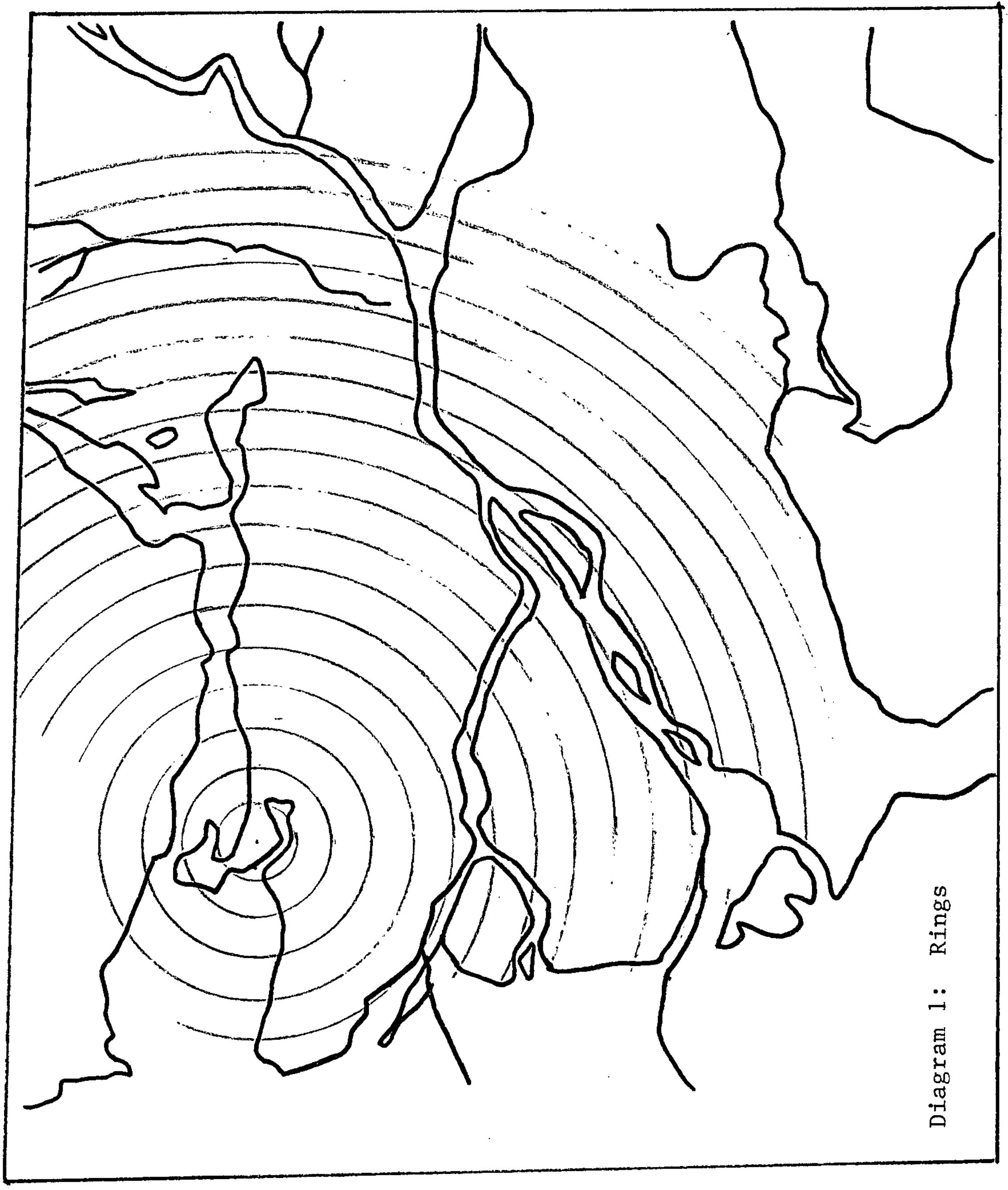

Diagram 1: Rings

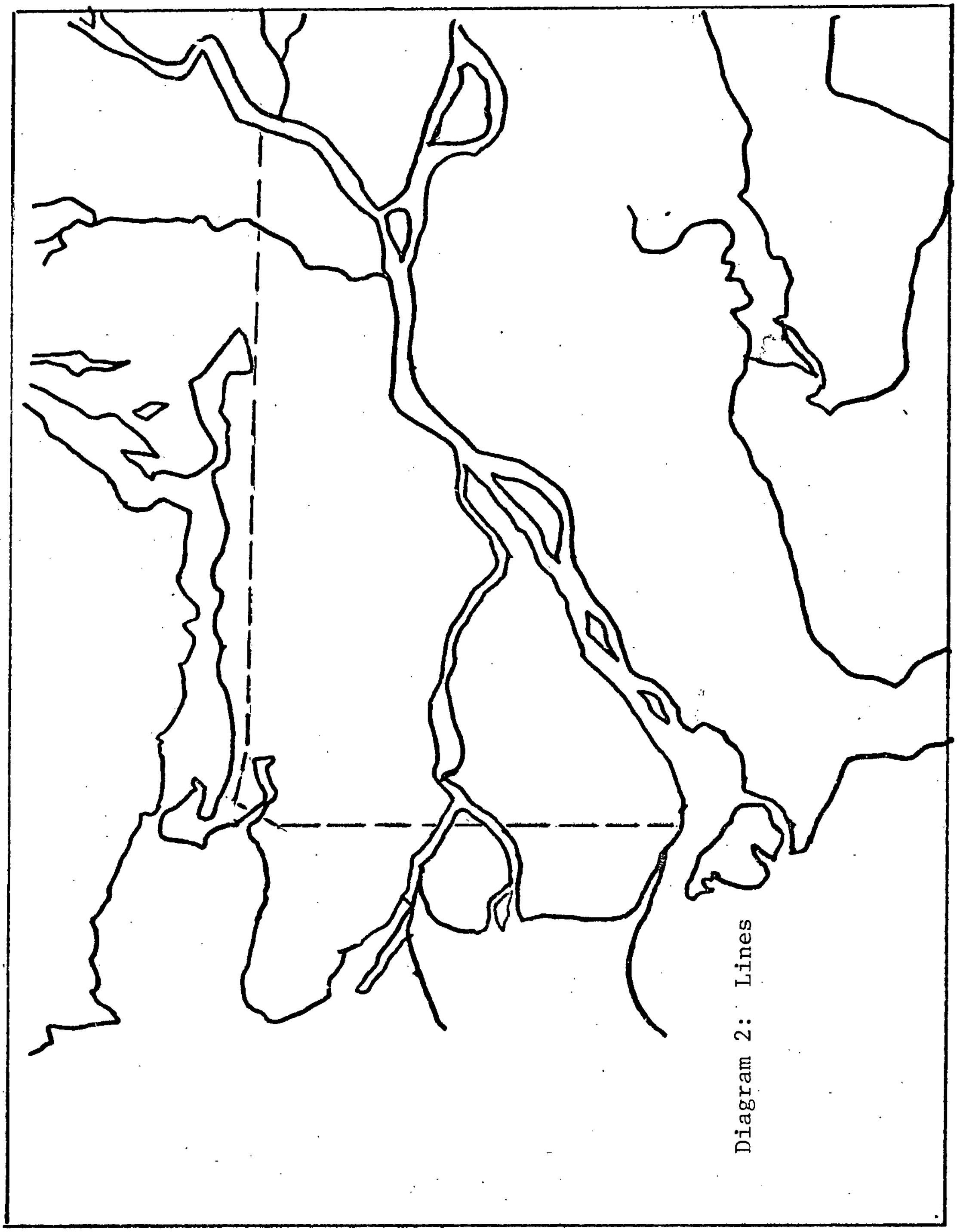

Diagram 2: Lines

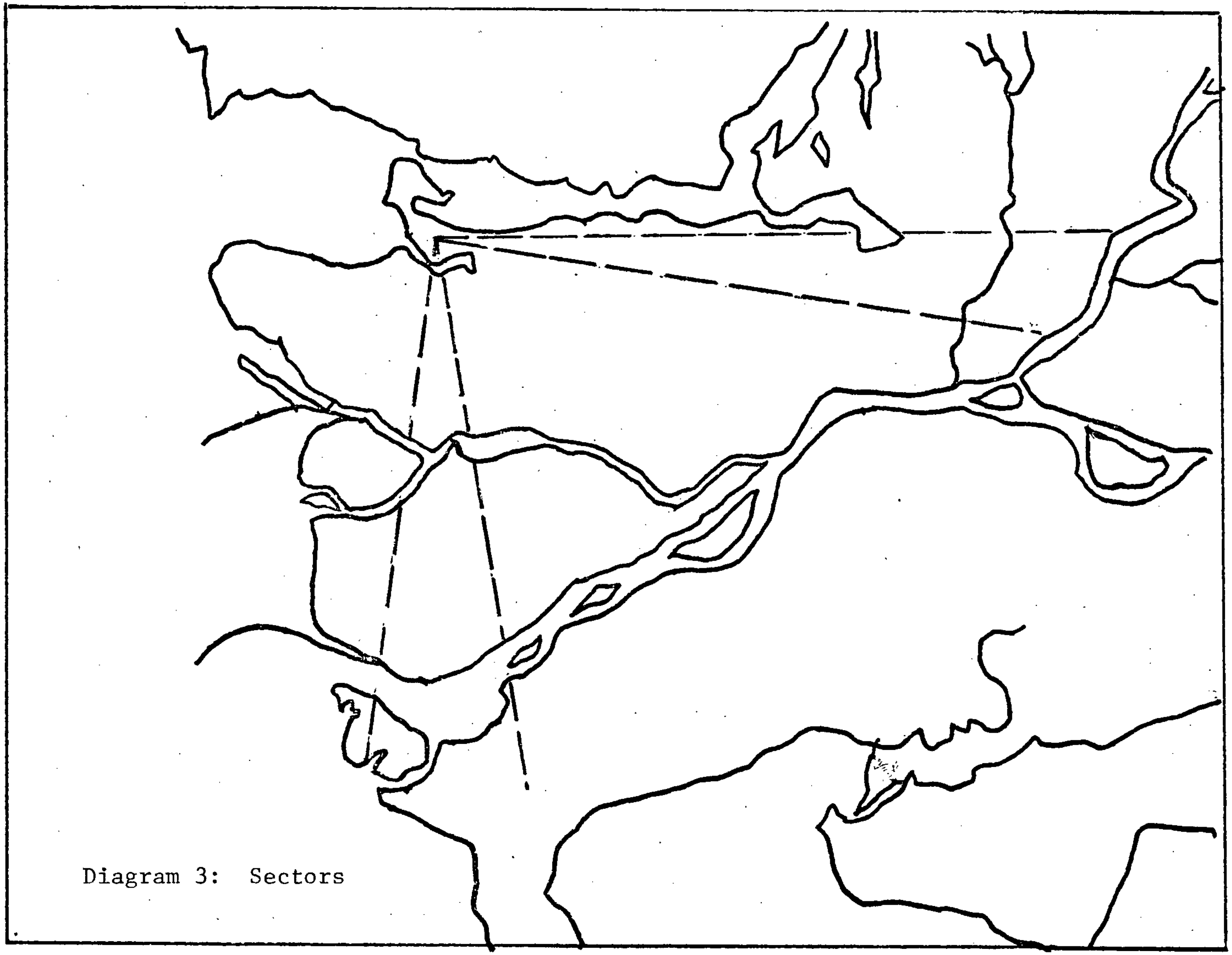

Diagram 3: Sectors

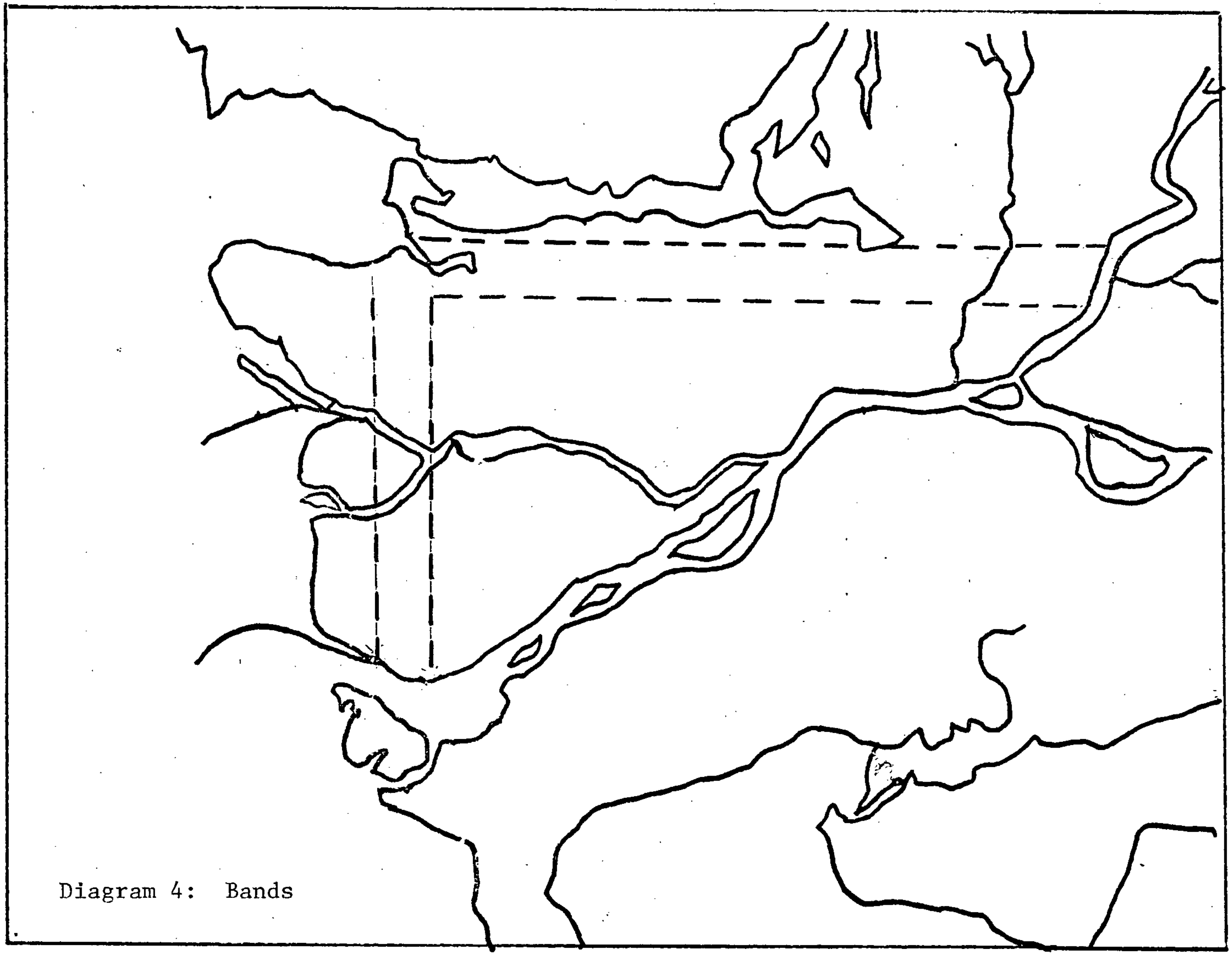

Diagram 4: Bands

Footnotes

1. Travel Time Map, GVRD, Summer 1968

2. Dynamics of Residential Land Settlement, Lower Mainland Regional Planning Board of B.C., Supp. Study 2 to Land for Living, 1963

3. B-A. Genest, op. cit., p. 14

4. Ibid.

CHAPTER IV

ANALYSIS OF DATA

A. Description of Graphs

The model we employed in the study is empirical by nature and statistical by design; and the method of analysis is by simple regression. (For a general description of regression analysis, see Appendix I.)

Computation of regression analysis for the study is by means of the SPSS (Statistical Package for the Social Sciences) computer package of the University of British Columbia. (For graphs, see Appendix II)

Graphs 1 & 2

The graphs of 1966 and 1971 show a fluctuating pattern of scatter points. Population density declines gradually from Ring 1 to Ring 5. These rings incorporate mostly tracts of the City of Vancouver, the density of which are comparatively higher than the rest of the other municipalities, indicating a "crest" at the center. The ring which is next highest in density is composed of census tracts of Coquitlam, Richmond, and New Westminster---three major urban centers.

Graphs 3 & 4

Density plotting of 1966 and 1971 is made with respect to the travel time from the city center. All the census tracts of the whole metropolitan region are included (151 observations).

Graphs 5 & 6

The graphs represent the density plotting of census tracts along Hastings to the east of the region. A sample of 12 census tracts is considered. Density is highest at the center; Burnaby has a relatively higher density in one of the tracts within its municipality. The density fluctuates in Port Moody, Port Coquitlam and Coquitlam.

In general, density declines with distance from the center, but not uniformly. There is a sharp discontinuity at some census tracts in the Burnaby municipality, which may be due to the vacant developable land of the Burnaby Park.

Graphs 7 & 8

Three clusters of data points are apparent from the graphs for the southerly portion of the region. The census tracts at the center undoubtedly occupy the highest density with that of Richmond next in magnitude and Delta still next. Richmond has been growing at a substantial and steady pace in population and industry in the past decade. Delta has recently experienced the fastest growth among the municipalities in Canada, yet it belongs to the lowest density category in metropolitan Vancouver. Delta is made up of five geographically distinct areas: the residential communities of South Delta (Tsawwassen), Ladner and North Delta, the agricultural lands, and the Annacis Island industrial estate.[2]

Graphs 9- 12

These graphs show the density plotting against travel time in the east and south directions for both census years 1966 and 1971. Approximately the same pattern of dispersion of data points is depicted when compared to the corresponding density plotting against radial distance.

Graphs 13 & 14

The graphs show the density plotting of the census tracts of the pie-slice along Hasings against radial distance. The data points are clustered about the regression line. No sharp discontinuity is apparent in Burnaby. A census tract in Port Coquitlam at some 17 miles from the city center records the lowest density. The data points become more dispersed from 1966 to 1971 as evidenced by the decreasing R^2.

Graphs 15 & 16

The pie-slice sector of the south is well marked by three clusters of points for the year 1966. There is some discontinuity in the scattering of data points at about six miles from the center. The sampled census tracts in Richmond and Delta have relatively low density. However, density increases considerably in Delta from 1966 to 1971.

Graphs 17 & 18

The way in which the cloud of data points is scattered for the pie-slice sector along Hastings using travel time as a parameter is more or less the same as compared to that when radial distance is used. The data points are clustered relatively close to the regression line for 1966. They become more dispersed through the years. The sampled census tracts of Port Coquitlam at about 50 minutes' driving time from the center records the lowest density.

Graphs 19 & 20

There is more compact scattering of data points for the pie-slice sector in the south. No discontinuity is apparent in the regression line at about 20 to 25 minutes' driving time from the center, where the north arm of the Fraser River is located. Two census tracts in Richmond record relatively low density.

Graphs 21 $ 22

The plotting of residential density in the band between Hastings and Broadway against radial distance involves 19 observations. The number of census tracts included in the band is obviously less than that of the pie-slice sector. As seen from the scattering of data points, the density pattern has changed considerably over the years at 10 miles from the center to the periphery. The density of the census tracts of Coquitlam, Port Moody, and Port Coquitlam is higher in 1971 than in 1961. The R^2 obtained is lower than its corresponding pie-slice sector value using radial distance as a parameter. The data points also show more dispersion over time.

Graphs 23 $ 24

The graphs of the band to the south for both years show a continuous fall-off of density against radial distance. The R^2 value for both years are insignificant.

Graphs 25 $ 26

The R^2 values drop off considerably from 1966 to 1971 for the band to the east using travel time as a parameter. Density increases at some 20 minutes' driving time from the center outwards to the periphery. One census tract in each of Burnaby and Port Coquitlam has very low density. The Burnaby tract contains vacant land around Central Park. The data points also show a consistent pattern of increasing dispersion over time. The R^2 for the regression using travel time as a parameter is higher than the corresponding value using radial distance.

Graphs 27 & 28

For the band to the south, the R^2 values are very much higher when the model is regressed upon travel time than when radial distance is used. Two clusters of data points are apparents in the graphs. Density is highest around the city core from 2 to 8 minutes' driving time from the center. The second bundle of data points, relatively lower in density, consists of tracts that are 15 to 22 minutes from the center, which corresponds to about 4 miles in radial distance. The density pattern shows great variability. It fluctuates considerably; there are data points that have different levels of density at the same travel time from the center.

Graphs 29 & 30

The pie-slice sector along Hastings for the years 1956 and 1961 also show a consistent pattern of decreasing R^2 values through time. It is a relatively better fit for the former year ($R^2 = 0.80$); however, the latter year also gives some support for the model ($R^2 = 0.55$). The sampled census tracts show higher density around the city core, dropping off with distance from the center. A tract in Burnaby at about 9 miles from the core drops off in density through the years, while Port Coquitlam increases in density considerably. The data points are clustered about the regression line from the core to about seven miles out, and become more dispersed towards the periphery.

Graphs 31 & 32

Some discontinuity in the scattering of data points is depicted at the north arm of the Fraser for the pie-slice sector along Granville. A tract at about 11 miles from the center falls off in density noticeably from 1956 to 1961. The R^2 values slightly decrease through time.

Graphs 33 & 34

The density plotting for the band to the east for both years 1956 and 1961 show a regular relationship betweeen density and distance. Data points are relatively more dispersed in Burnaby, Coquitlam and Port Coquitlam. R^2 decreases over time.

Graphs 35 & 36

For the band to the south, the graphs show that there is a sharp break in the scattering of data points at the north a of the Fraser for the years 1956 and 1961. A census tract at the periphery almost doubles in density through the census years. The R^2 value is higher for 1956 (0.64) than for 1961 (0.46).

Graphs 37 & 38

When the log density is plotted against travel time for the pie-slice sector along Hastings, density drops off considerably in the census tracts from 19 to 27 minutes' driving time from the center. It is fair to say that there is more vacant developable land in Burnaby, which should account for the low average density. The model

a good fit to the data, as evi [illegible] is a good fit to the data, as evidenced by a consistent relationship between the log of density and travel time.

Graphs 39 & 40

These graphs show the plotting of log of density against travel time for the pie-slice sector to the south. Density drops off for the census tracts at the immediate vicinity of the water bodies, continues to decrease in Richmond, but rises again in Steveston. The R^2's for 1956 and 1961 are lower than their corresponding values when the model is regressed upon radial distance, a finding contrary to expectation.

Graphs 41 & 42

In the band to the east for 1956 and 1961, the graph using travel time shows roughly the same pattern of scatter as that using radial distance. Data points fluctuate considerably at about 25 to 45 minutes' time from the center. The model also shows a decreasing R^2 over time.

Graphs 43 & 44

The graphs of density against travel time for the band to the south show that density drops off continuously from the city center outwards. R^2 decreases through time; it is 0.57 and 0.43 for 1956 and 1961 respectively.

B. Hypotheses Discussed

Hypothesis 1

Residential density to the south of the CBD falls more steeply than that to the east.

Results:

For the hypothesis to be confirmed, the b value in the model ($D_o e^{-bx}$) for the cases considered in the south should be larger than for the east. Data was analyzed for four census years and the b values were computed. These are listed in Table (1) along with the relevant R^2 and the A values obtained from the regression equations.

Table (1) A & b and the relevant R^2 values of the model for various geographical set-ups of the four census years using radial distance; and their corresponding values for travel time in parenthesis

Geographical set-ups	A	b	R^2
1956			
Sector, S.	9.94927 (10.76976)	0.11472 (0.13485)	0.67279 (0.57734)
Sector, E.	9.49519 (10.38463)	0.06640 (0.09815)	0.55393 (0.77662)
Band, S.	9.82152 (10.25926)	0.10423 (0.10467)	0.64310 (0.57180)
Band, E.	9.63216 (10.15263)	0.08405 (0.09559)	0.83600 (0.73655)
1961			
Sector, S.	10.33737 (11.35954)	0.11730 (0.14123)	0.63460 (0.48898)
Sector, E.	9.73567 (10.21197)	0.07428 (0.08117)	0.80048 (0.71855)
Band, S.	9.63519 (9.97566)	0.07486 (0.07699)	0.45852 (0.42761)
Band, E.	9.58201 (9.99301)	0.06982 (0.07835)	0.77033 (0.66084)

1966			
Line, S.	9.66111 (10.24456)	0.28895 (0.09650)	0.54199 (0.45645)
Line, E.	9.84693 (10.35397)	0.24061 (0.08934)	0.71590 (0.70386)
Sector, S.	9.85094 (10.65679)	0.25702 (0.09359)	0.43456 (0.48201)
Sector, E.	9.84228 (10.40791)	0.22191 (0.08326)	0.66800 (0.65105)
Band, S.	9.54759 (10.57283)	0.16530 (0.08065)	0.17092 (0.59724)
Band, E.	9.38258 (9.84140)	0.14716 (0.05737)	0.62008 (0.65125)
1971			
Line, S.	9.44072 (9.92064)	0.23078 (0.07769)	0.40133 (0.34340)
Line, E.	9.45773 (9.82351)	0.18097 (0.06660)	0.58316 (0.56324)
Sector, S.	8.95351 (10.37837)	0.08114 (0.07684)	0.35411 (0.39530)
Sector, E.	9.59935 (10.24331)	0.17807 (0.06994)	0.51984 (0.55583)
Band, S.	9.62282 (10.63269)	0.17242 (0.08287)	0.18107 (0.52402)
Band, E.	9.28304 (9.64117)	0.10425 (0.04143)	0.43038 (0.43859)

The hypothesis is generally confirmed. In all but one case (Sector, S., 1971), the b value to the south is larger than to the east by 10 to 50 percent. The coefficients of determination obtained account for over 50 percent of the variability for 13 cases out of 20. Since the b values for the south are generally larger than for the east, we suggest that the difference in density in various directions of the city is due mainly to the age of residential activity rather than to the transport factor.

Hypothesis 2

There will be a sharp discontinuity in the scattering of data points at six miles south of the city center where the north arm of the Fraser River is located.

Results:

The hypothesis is not entirely confirmed, since the scattering of data points is sensitive to the way they are aggregated; i.e., different geographical set-ups may show different patterns of the dispersion of data points even for the same section of the city. However, when distance is measured in terms of travel time, there is almost no discontinuity. (For radial distance, see graphs 7, 8, 15, 16, 23, 24, 31, 32, 35, 36; and for travel time, see graphs 11, 12, 19, 20, 27, 28, 39, 40, 43, 44.)

Hypothesis 3

Travel time would give a better fit to the model than radial distance.

Results:

The hypothesis is not confirmed, since only 7 out of 20 cases (35.0 percent) have R^2 higher than when radial distance is used. The results are listed in Table (2) along with the corresponding A and b values.

Table (2) R^2 for the model when regressed upon travel time and radial distance

Geographical set-ups	R^2(Travel time)	R^2(Radial distance)
1956		
Sector, S.	0.57734	0.67279
Sector, E.*	0.77662	0.55393
Band, S.	0.57180	0.64310
Band, E.	0.73655	0.83600
1961		
Sector, S.	0.48898	0.63460
Sector, E.	0.71855	0.80048
Band, S.	0.42761	0.45852
Band, E.	0.66084	0.77033
1966		
Line, S.	0.45645	0.54199
Line, E.	0.70386	0.71590
Sector, S.*	0.48201	0.43456
Sector, E.	0.65105	0.66800
Band, S.**	0.59724	0.17092
Band, E.*	0.62125	0.62008
1971		
Line, S.	0.34340	0.40133
Line, E.	0.56324	0.58316
Sector, S.*	0,39530	0.35411

Sector, E.	0.55583	0.51984
Band, S. *	0.39530	0.35411
Band, E. *	0.43859	0.43038

The geographical set-ups with asterisks have R^2 higher for the model when it is regressed upon travel time than against radial distance.

Hypothesis 4

R^2 in the model should decline over time.

Results:

There is a consistent pattern that the R^2 for the log-linear equation decreases over the years. As the graphs revealed to us, the data points become more dispersed through time. This pattern would be further dispersed by the creation of the regional centers in the future. The R^2 values of various geographical set-ups of the four census years are presented in Table (3) when x in the model is measured in terms of radial distance, and in Table (4) when x is measured in terms of travel time.

Table (3): R^2 for the model when regressing upon radial distance

Geographical set-ups	1956	1961	1966	1971
East				
Line			0.71590	0.58316
Sector	0.80048	0.55393	0.66800	0.51984
Band	0.83600	0.77033	0.62008	0.43038
Average	0.8182[illegible]	0.66218	0.[illegible]6799	[illegible]
South				
Line			0.54199	0.40133
Sector	0.67279	0.63460	0.43456	0.35411
Band	0.64310	0.45852	0.17092	0.18107
Average	0.65795	0.54656	0.38249	0.3[illegible]

Table (4): R^2 for the model when regressing upon travel time

Geographical set-up	1956	1961	1966	1971
East				
Line			0.70386	0.56324
Sector	0.77662	0.71825	0.65105	0.55583
Band	0.73655	0.66084	0.65125	0.43859
Average	0.75659	0.68969	[illegible] 6687[illegible]	[illegible]
South				
Line			0.45645	0.34340
Sector	0.57734	0.48898	0.48201	0.39530
Band	0.57180	0.42761	0.59724	0.52402
Average	0.574[illegible]	0.4582[illegible]	0.51190	[illegible]

The R^2's for the GVRD when x is measured in terms of radial distance are 0.56914 and 0.51460 for 1966 and 1971 respectively; and when x is measured in terms of travel time, they are 0.43245 and 0.38894 respectively.

Hypotheses 5 & 6

A & b values in the fitted model should decline over time.

Results:

There is not a consistent pattern that A value in the model declines over time. However, in almost all cases, the b value shows a decrease as time progresses. This indicates that population density gradient has become flatter. The A and b values for the various geographical set-ups at four points in time when the model is regressed upon radial distance are to be found in Table (1), page 41. As for the A and b values when the model is regressed upon travel time, they are listed in Table (5).

Table (5) A & b values in the model when regressed upon travel time

Geographical set-ups	A	b
1956		
Sector, S.	10.76976	0.13485
Sector, E.*	10.38463	0.09815
Band, S.	10.25926	0.10467
Band, E.	10.15263	0.09559
1961		
Sector, S.	11.35954	0.14123
Sector, E.	10.21197	0.08117
Band, S.	9.97566	0.07699
Band, E.	9.99301	0.07835
1966		
Line, S.	10.24456	0.09650
Line, E.	10.35397	0.08934
Sector, S.*	10.65679	0.09359
Sector, E.	10.40791	0.08326
Band, S.*	10.57283	0.08065
Band, E.*	9.84140	0.05737

1971		
Line, S.	9.92064	0.07769
Line, E.	9.82351	0.06660
Sector, S.*	10.37837	0.07684
Sector, E.	10.24331	0.06994
Band, S.*	10.63269	0.08287
Band, E.*	9.64117	0.04143

The relative increase in suburban densities would lower the b value. The results obtained are comparable to previous experience with Clark's model. Thus, it seems fair to conclude that Vancouver is similar to other major cities , at least as far as the b value is concerned, and Clark's model applies to Vancouver fairly well.

CHAPTER V

CONCLUSION

The application of the model to the Vancouver case enables us to highlight the nature of the city growth process, and to offer explanations for the population density distribution. In a capsule, the findings can be outlined as follows:

1. The differential rates of density decline:

The model is found to apply to the south and east sections of the city at various points in time. However, the b value to the south is larger than to the east. A higher b value means that density declines more sharply with increasing distance from the city center; and a lower b value means that density declines more slowly.

The different b values of both sections of the city suggest that residential density is more a function of the age of development than transport factor. In the past residential development in the south has been largely restricted to the Burrard Peninsula as a result of the water barriers. Though improvements in transportation occurred in the late 50s, residential building activity has not been able to grow fast enough to compensate for its late start of development. For transport to be a relatively more important factor than the time at which development took place, the b value to the south should be similar to that towards the east when separation from the CBD is measured in terms of radial distance or travel time. In fact this is not the case.

The higher b value to the south is also associated with a higher A value in the model. For 15 out of 20 cases considered, the south has higher imputed central density than the east. The relatively higher A and b values for the south indicate that density is more clustered and concentrated between the city center and the north arm of the Fraser River as a result of the topographical restriction.

2. Travel time vs radial distance:

Density in the south seems to respond more to travel time than to radial distance. There is almost no discontinuity in the scattering of data points in the region where the north arm of the Fraser River is located when the model is regressed upon travel time. On the other hand, there is no conclusive evidence that travel time gives a better fit to the model than radial distance.

3. The model as a good fit:

The fairly good fit of the model for 1966 and 1971 is indicative of the fact that the negative exponential decay function can describe the density distribution even for a city which is highly restricted in site and elongated in shape. However, there is evidence that the model has declined in its applicability over time, which is reflected by the declining R^2 values. Data have become more dispersed and random. The more dispersed pattern of data may reflect the appearance of nodes of population concentration in some of the outlying municipalities, such as Burnaby and New Westminster.

4. The A and b values in the model:

The A value has not shown a consistent pattern of decline over the years even within the same geographical set-up.

The b value has shown a decline as time progresses. There is a relative increase in suburban densities, which is a result of the improvement in transportation and the relative decrease in importance in transport cost as compared with other locational considerations. As Clark says: "[There are]....... two possibilities for development, if the population is increasing. Either transport costs are reduced, enabling the city to spread out, or they cannot be reduced, in which case density has to increase at all points."

5. Methodology:

There is no decisive evidence as to the superiority in the use of one geographical set-up over the other. Conceptually, the use of sectors is best because it is able to incorporate similar numbers of census tracts at different distances from the center. An approximately equal number of census tracts both at the center and at the periphery is included in its limit. The size of census tracts usually reflects its density, i.e., a smaller parcel of tract is usually associated with a higher density; and vice versa. The sector would therefore be a more representative spatial zone for the model to be tested. However, the use of sector is not entirely empirically justified, since in some cases the lines and bands obtain a higher R^2.

With regards to the goodness of fit of the model, it can possibly be improved by using a more detailed data base, 1/4 mile grid or enumeration area, for instance. Perhaps it could be improved by using net residential density.

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Appendix I: Regression Analysis

REGRESSION ANALYSIS

Regression analysis is concerned with the problem of describing or estimating the value of one variable, called the "dependent variable", on the basis of one or more other variables, called "independent variables". It is hypothesized that the behaviour observed for a dependent variable can be accounted for by the independent variables. The model used in this work involves two parameters: extrapolatedd central density and density gradient, which are used to indicate the negative exponential decline of population density with the increase in distance. It is important to note that the inferences from the data are derived from a conceptual and theoretical interpretation of the statistical results; and from a statistical standpoint, there should not be any implication of causation, or direction of "cause and effect" involved. [1]

The Method of Least Squares is most often used in determining the probable values of the dependent variable from the independent variable(s). It requires fitting a central line, or the best-fitting line, to the data, where the sum of squares of the vertical deviations of the observations for the dependent variable from the line is a minimum. In other words, the Method of Least Squares gives the minimum error variance for the purpose of predicting one property from a knowledge of the other. [2] The regression equation can be identified by:

$$y = a + bx + u$$

where: y is the dependent variable

x is the independent variable

a, b are constants, which are to be determined from the equation

u is the "disturbance" or "error" term, which may take on positive or negative values.

Among the many factors that contribute to the insertion of the u term, the more important ones are the measurement error and specification error; the latter means that the actual phenomena may not be fully represented by the expression. The specification error is inversely related to the number of variables involved in the expression, while the measurement error is directly related to the number of variables. The assumptions involved in the specification of the disturbance term are homoscedasticity and independence, that, is, the variance is a constant and independent of x, and the values are independent of one another.[3]

It is usually a common practice to give a full appraisal of the relationship by means of a "scatter diagram" or "cor-relation diagram". The central line fitted to the data points is called a "regression" line. The relationship between the dependent variable and the independent variables (s) is expressed by a tendency for one to increase or decrease with an increase in the other. For the variables to be highly correlated, all the data points are clustered about the regression line, or nearly so. Often in the case of non-linearity, a transformation by way of logarithm, reciprocal, or square root of one or both variables can be made to eliminate the curvature.[4] Referring to the model we applied, there is a logarithmic transformation of the population density at a distance x. (D_x), and imputed central density (D_o).

The extent of the precision of the regression depends on the following facors: 1) the number of observations; and 2) the extent of the scatter about the regression. For any value of y, there is a corresponding value of x, where $y_1 = a + bx_1 + u_1$ .....$y_n = a + bx_n + u_n$. The discrepancy between the theoretical value of y, denoted by $\hat{y}$, and the observed value of y may be regarded as errors, the measure of which is known as the "variance".

Footnotes

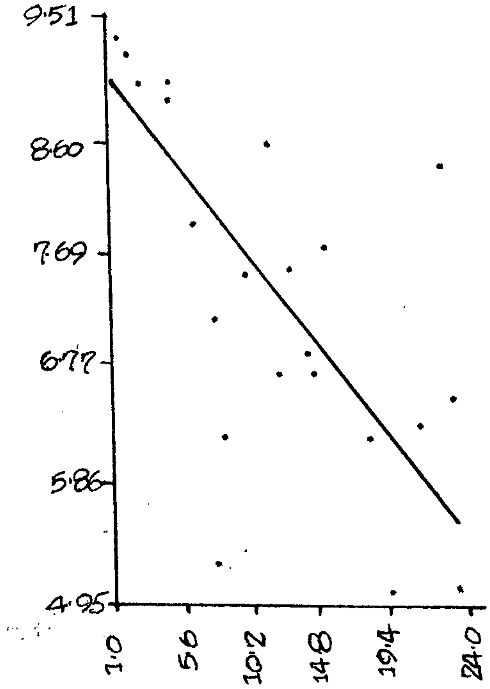
1. Donald J. Bogue & Dorothy L. Harris, "Comparative Population and Urban Research via Multiple Regression and Covariate Analysis", Scripps Foundation for Research in Population Problems, 1954, p.7

2. Owen L. Davies (ed.), Statistical Methods in Research and Production, Oliver and Boyd, Edingburg, 1947, p.123

3. J. Johnston, Econometric Methods, McGraw-Hill Book Co., New York, 2nd Ed., 1972, pp. 8-12

4. Owen L. Davies, op. cit., p. 120

Appendix II: Graphs



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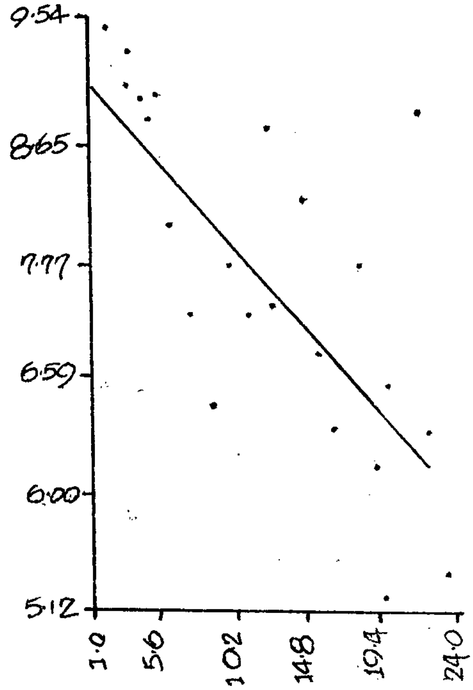
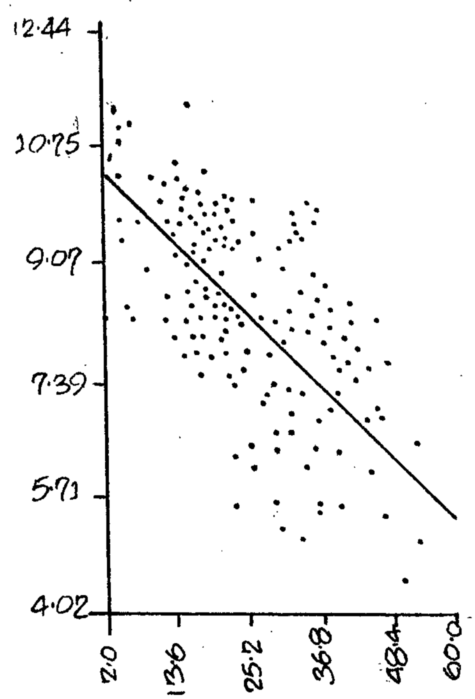


(2) Rings, Radial Distance, 1971



(3) GVRD, Travel Time, 1966

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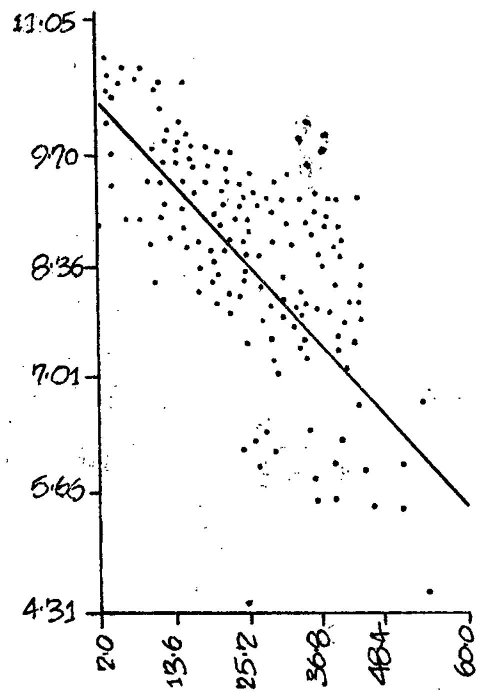

(4) GVRD, Travel Time, 1971

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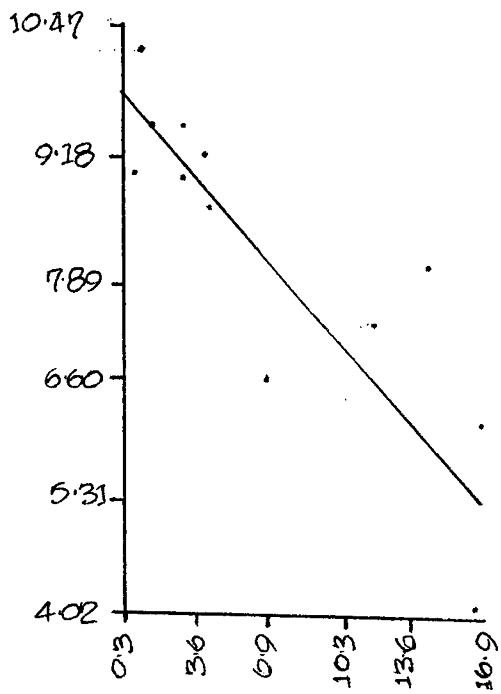
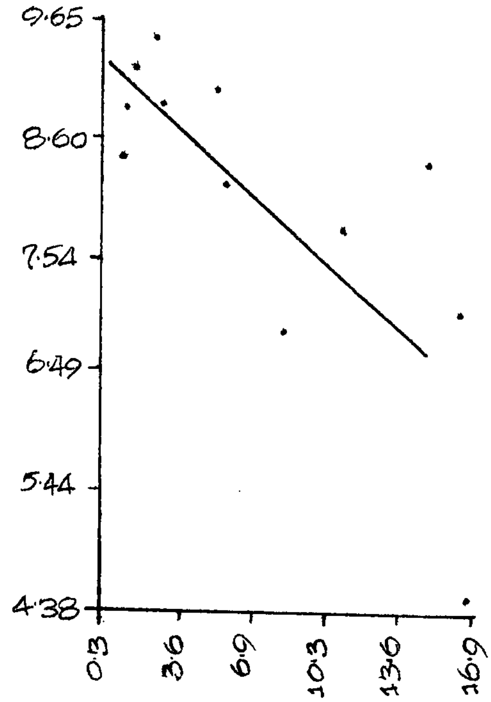
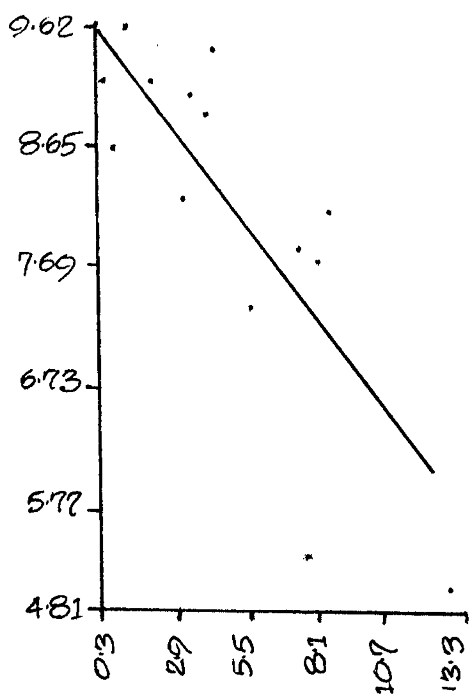


(5) Line, East, Radial Distance, 1966



(6) Line, East, Radial Distance, 1971



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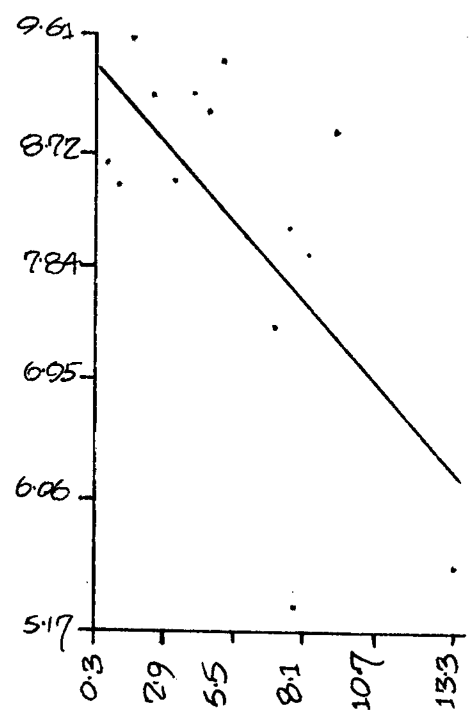

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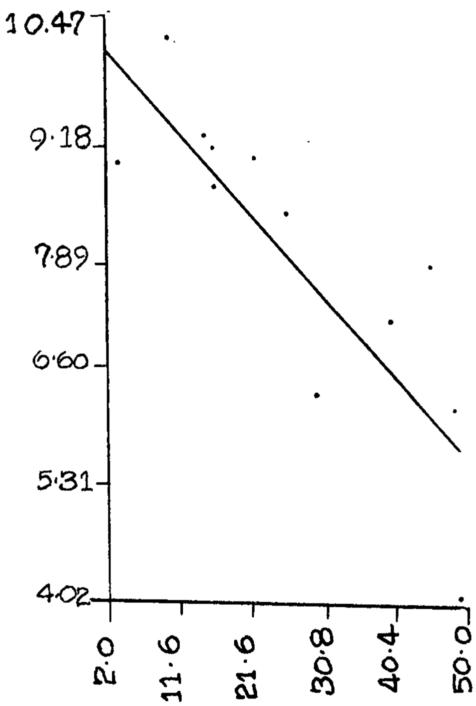

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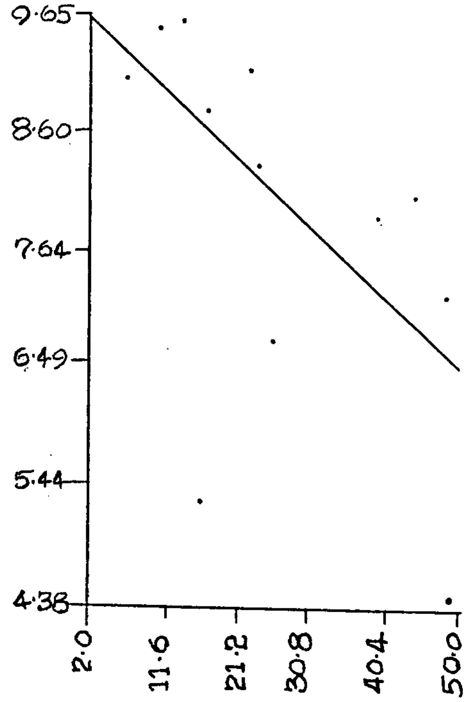

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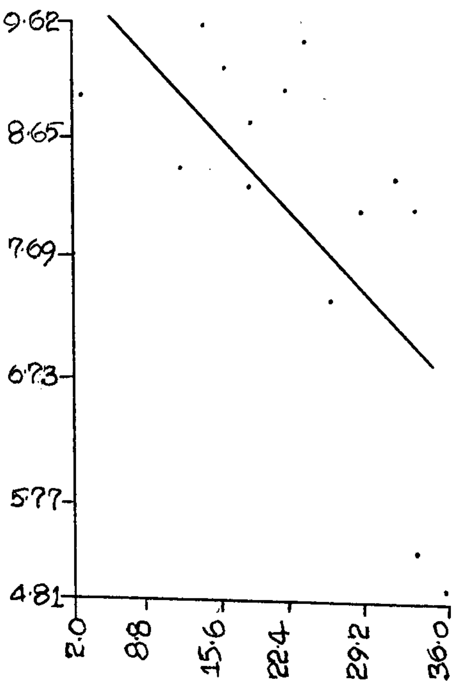

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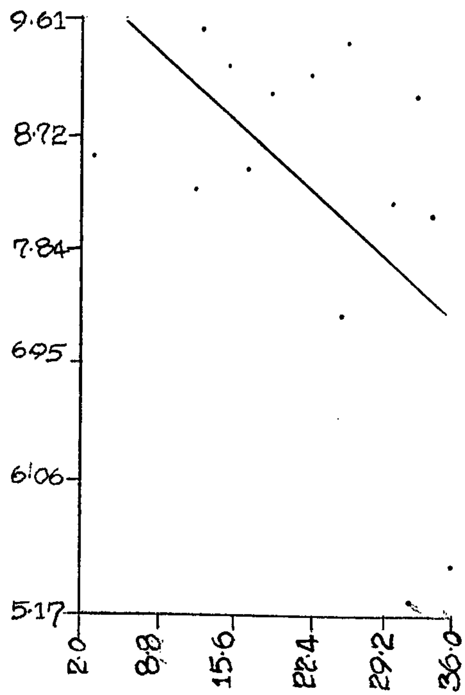

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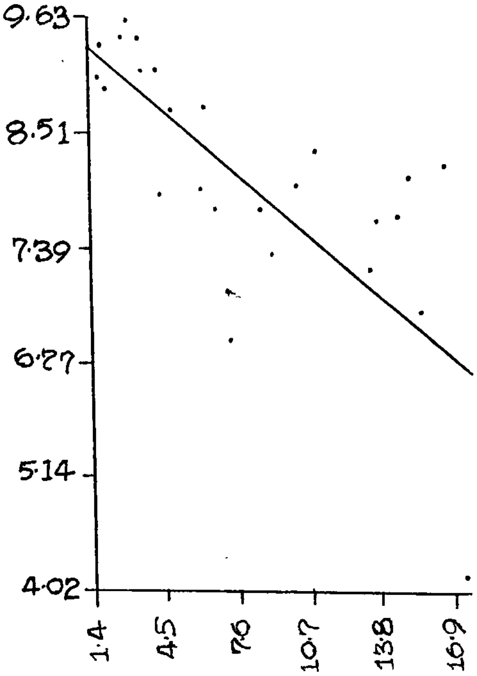

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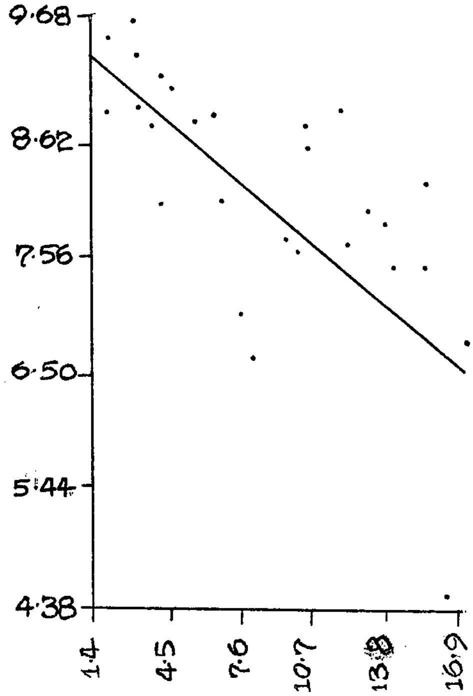

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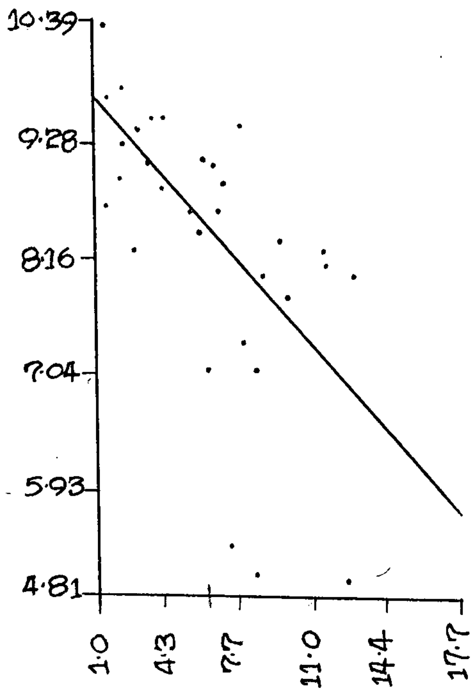

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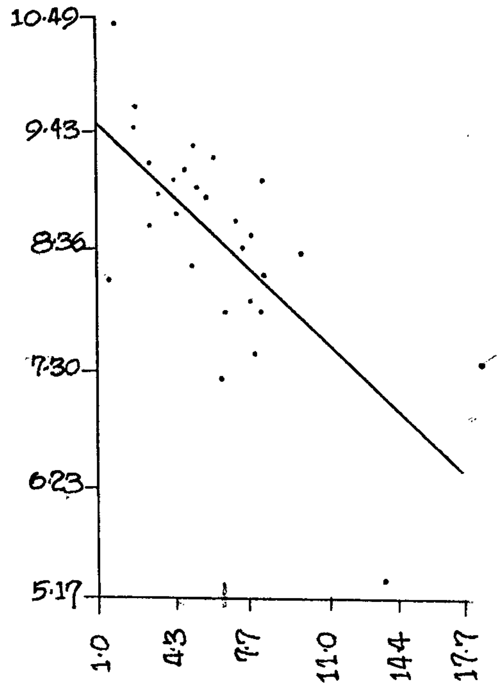

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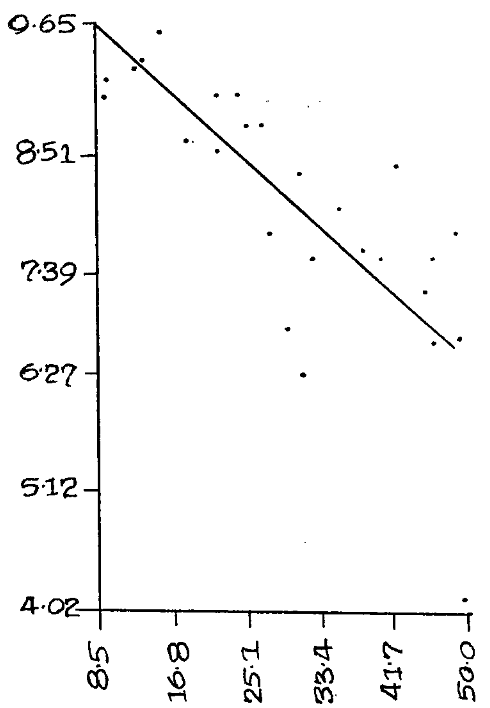

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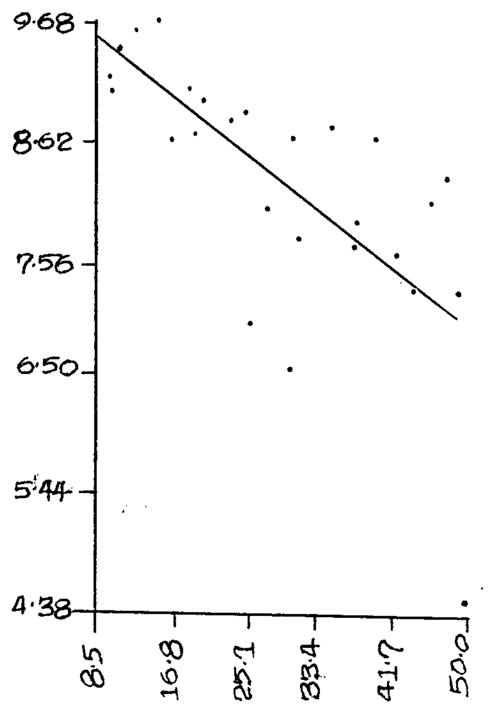

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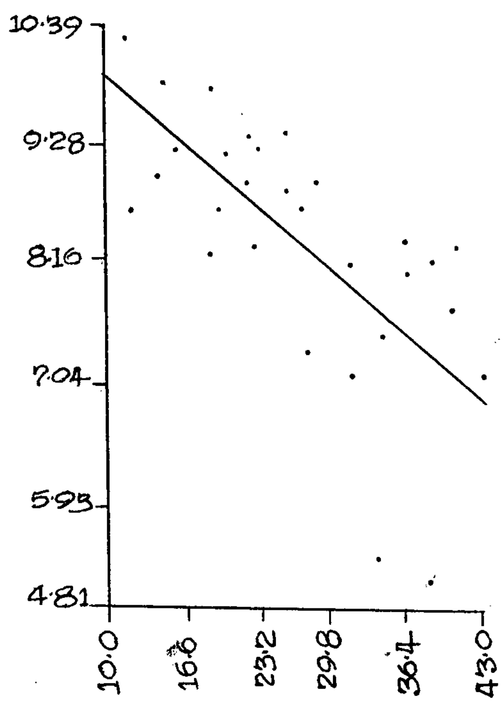

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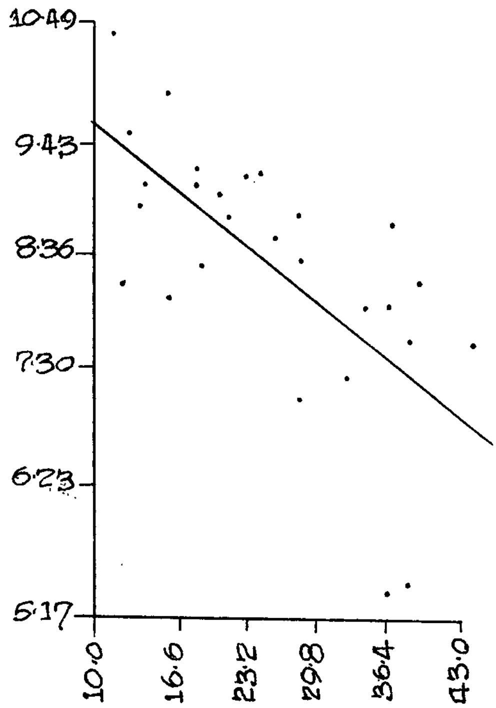

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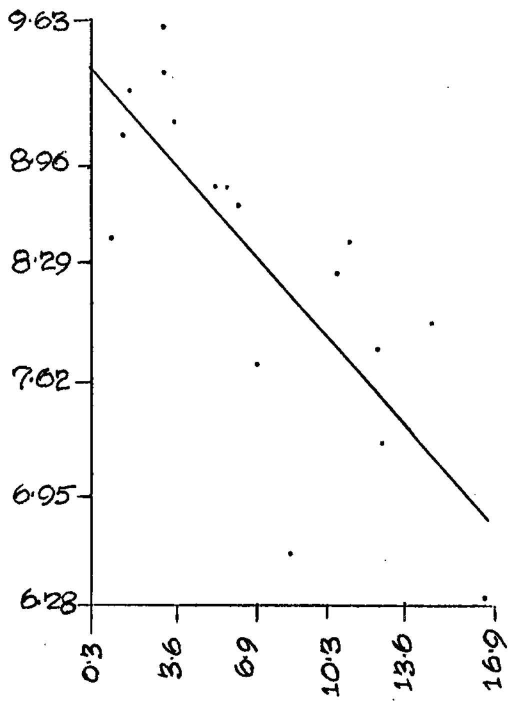

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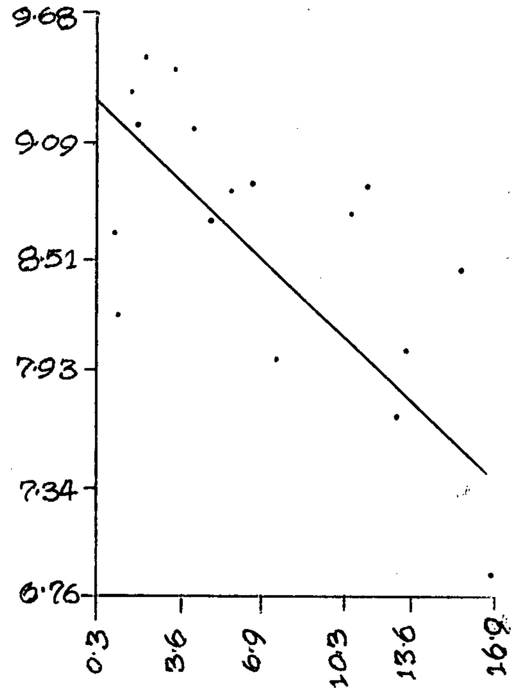

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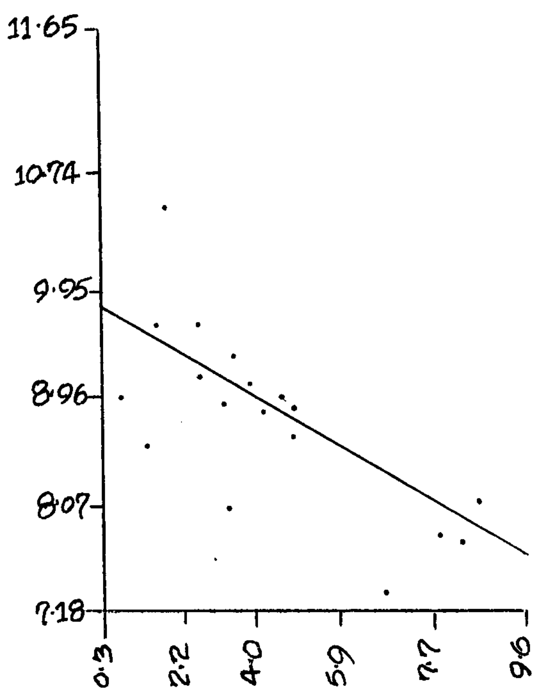

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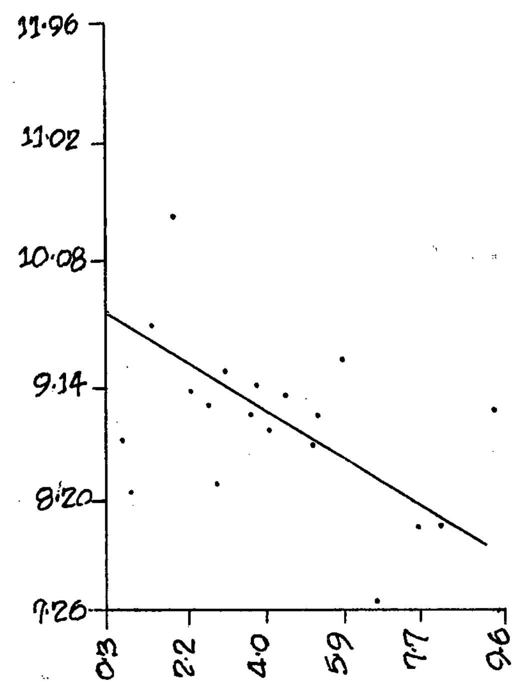

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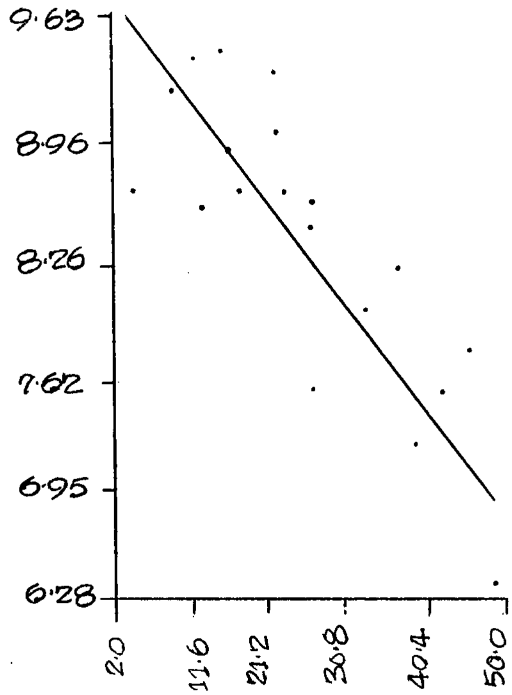

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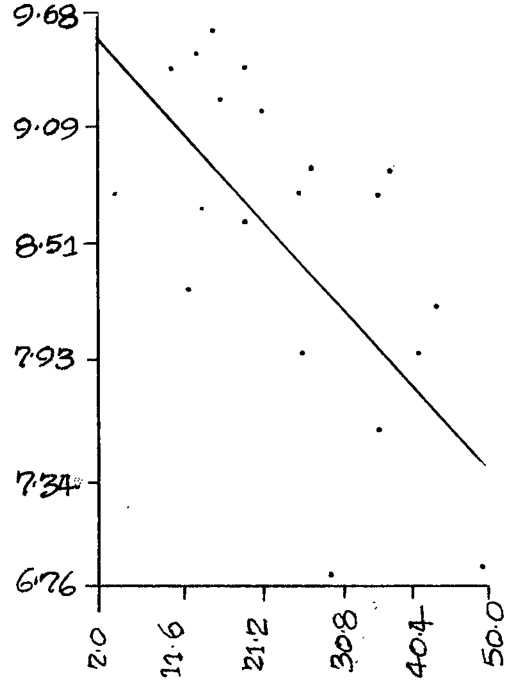

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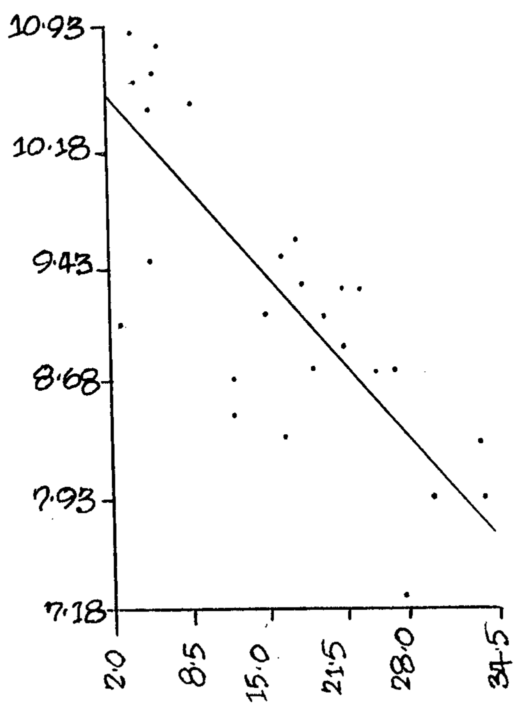

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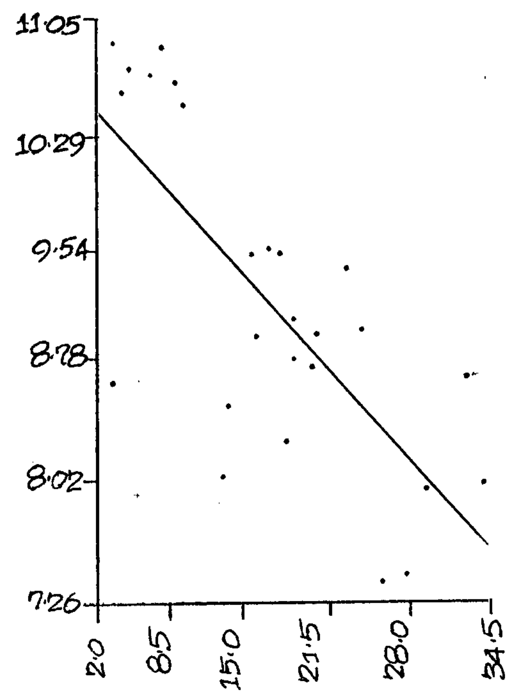

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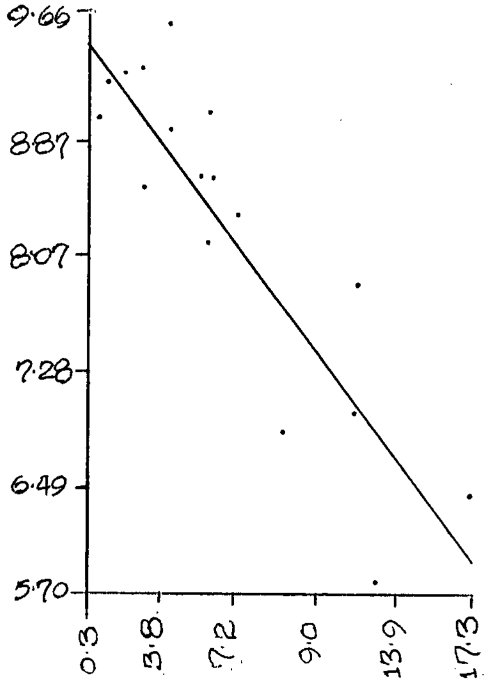

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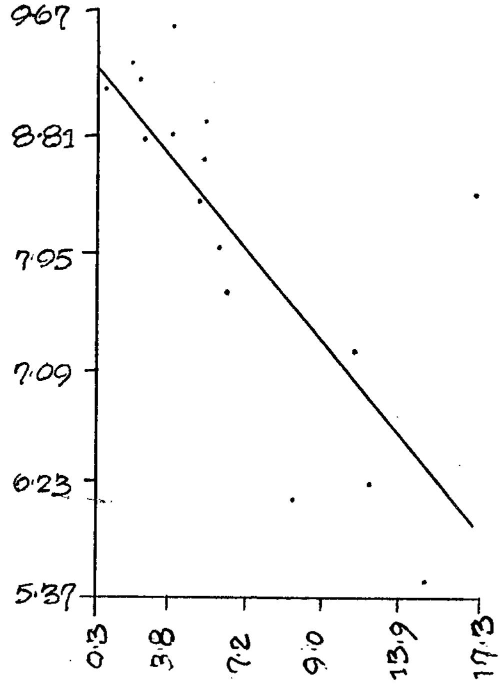

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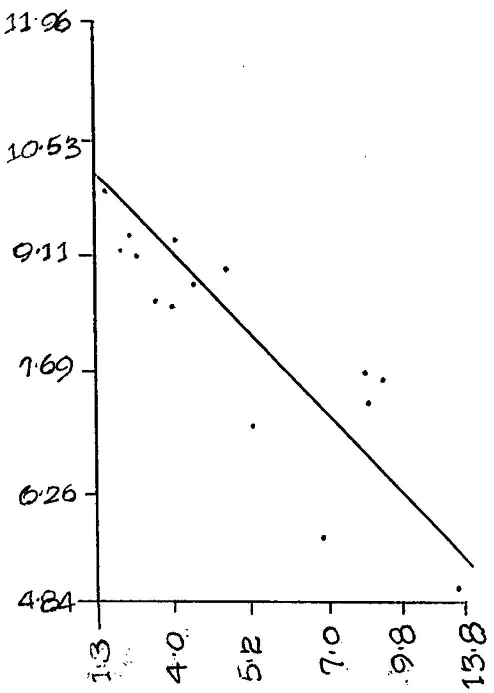

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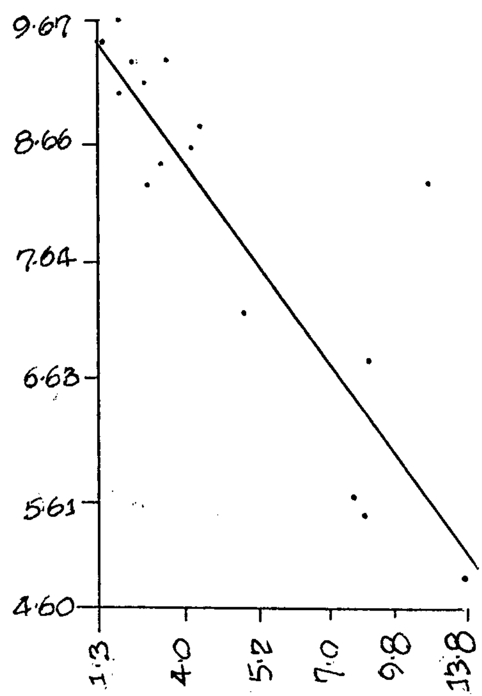

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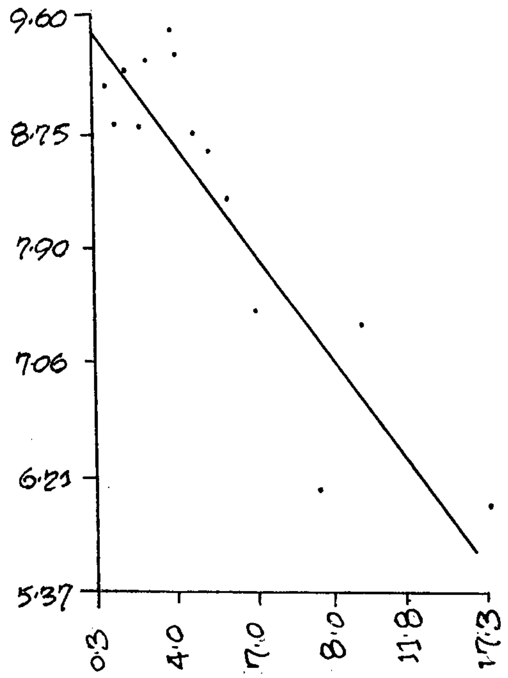

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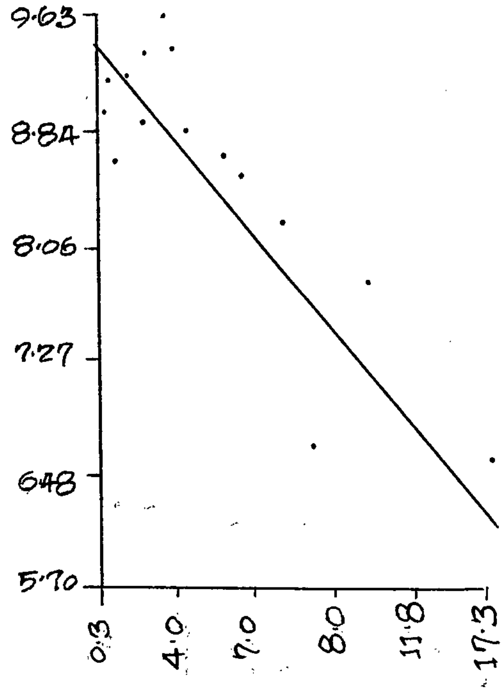

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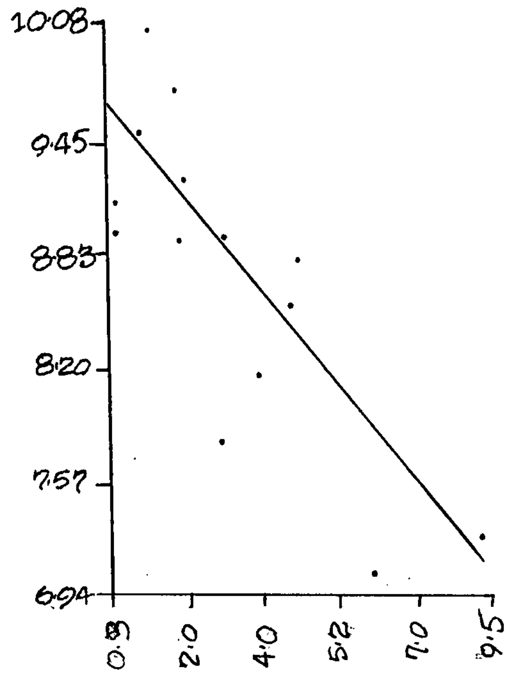

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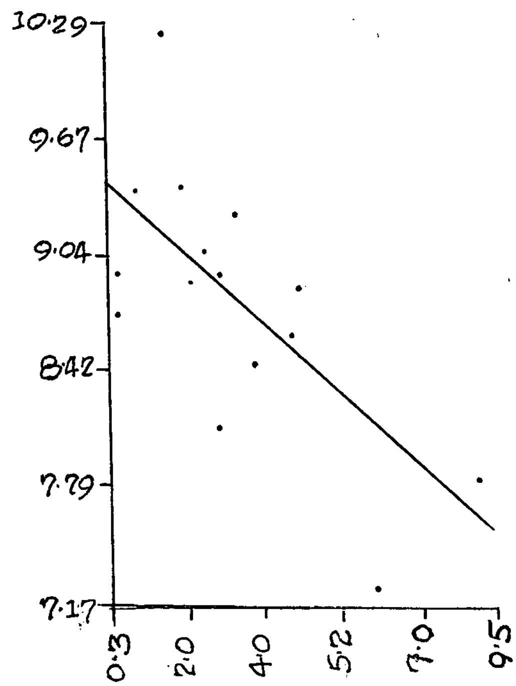

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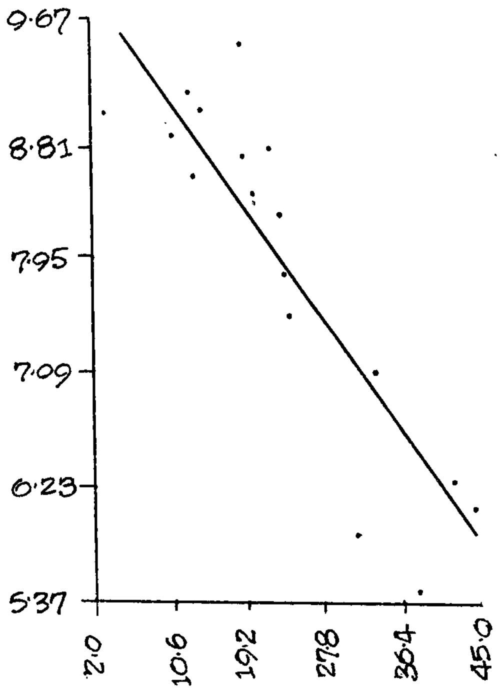

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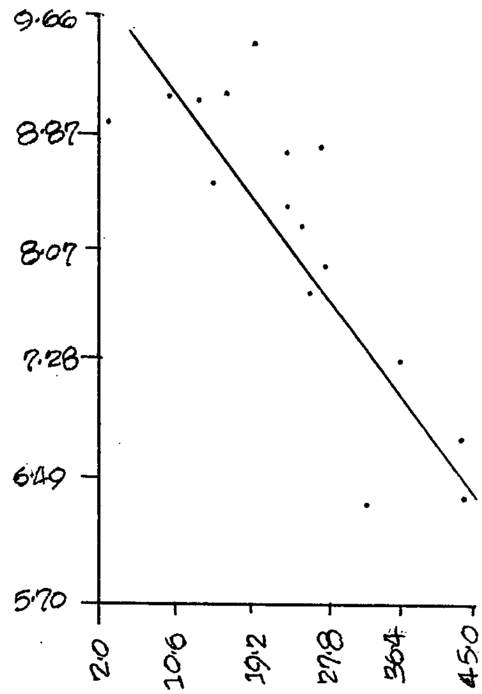

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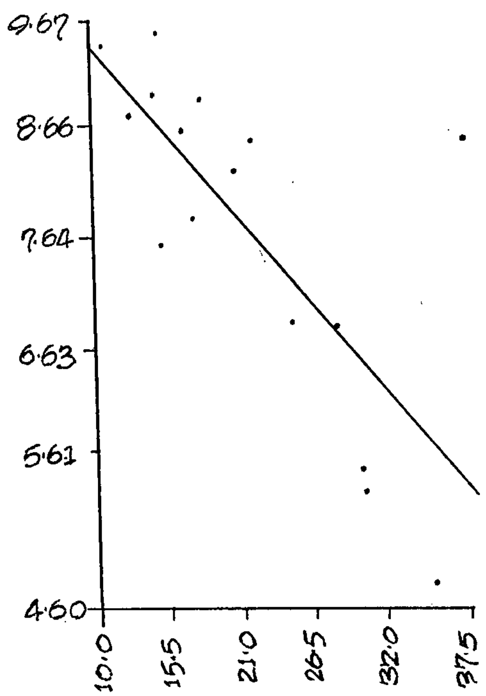

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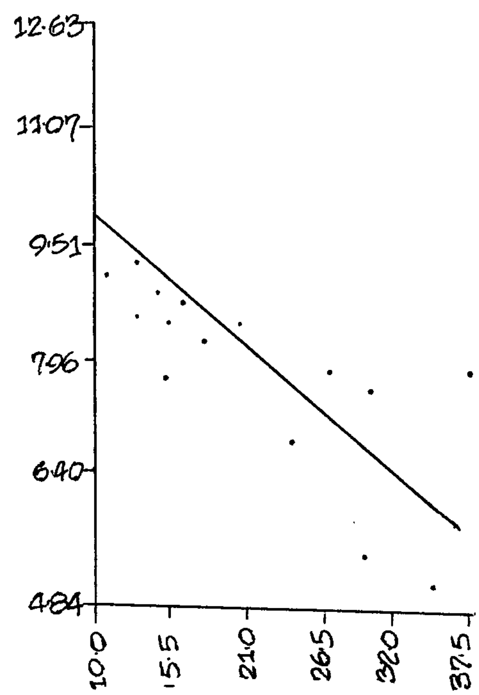

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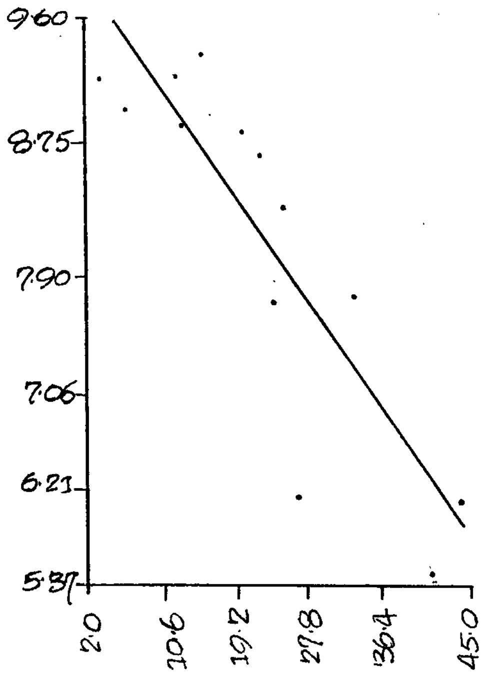

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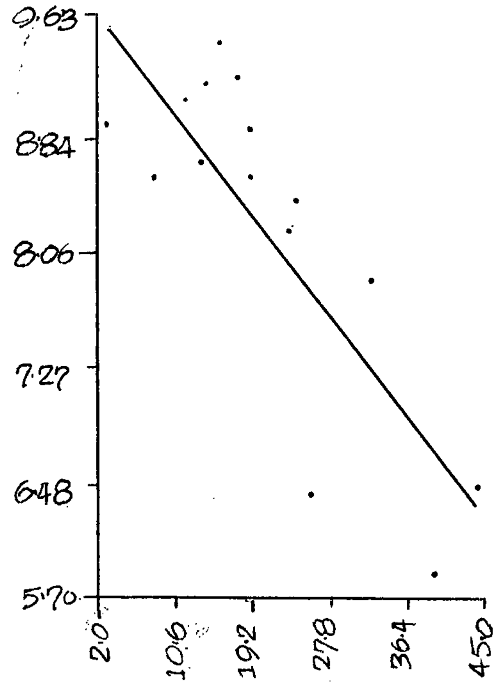
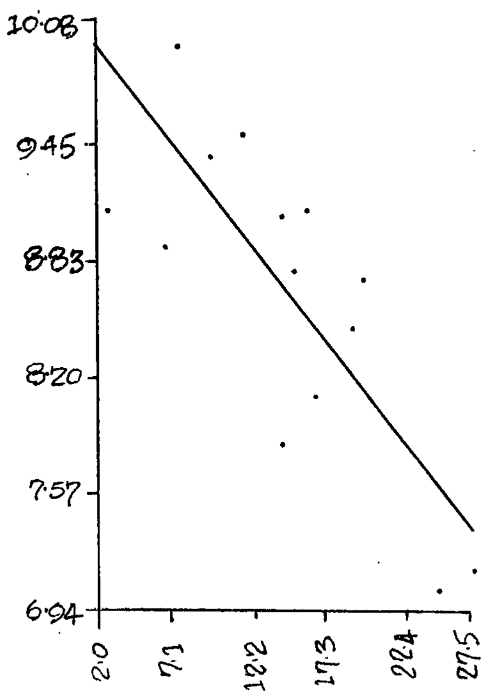
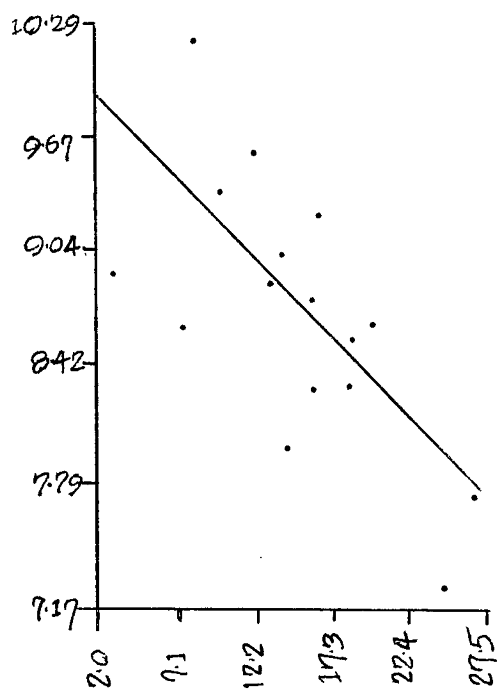


(42) Band, East, Travel Time, 1961



(43) Band, South, Travel Time, 1956



(44) Band, South, Travel Time, 1961

Appendix III: Statistical Tables

Table-1

Relationship Between Density and Radial Distance From the City Centre

Geog. Set-ups/1966	A	b	r	No.	R^2	Graph
GVRD	9.12414	0.14715	-0.75441	23	0.56914	1
LINE, E.	9.84693	0.24061	-0.84611	12	0.71590	5
LINE, S.	9.66111	0.28895	-0.73620	14	0.54199	7
SECTOR, E.	9.84228	0.22191	-0.81731	33	0.66800	13
SECTOR, S.	9.85094	0.25702	-0.65921	32	0.43456	15
BAND, E.	9.38258	0.14716	-0.78745	19	0.62008	21
BAND, S.	9.54759	0.16530	-0.41343	21	0.17092	23

Table-2

Relationship Between Density and Radial Distance From the City Centre

Geog. Set-ups/1971	A	b	r	No.	R^2	Graph
GVRD	9.15360	0.13229	-0.71736	23	0.51460	2
LINE, E.	9.45773	0.18097	-0.76365	12	0.58316	6
LINE, S.	9.44072	0.23078	-0.63350	14	0.40133	8
SECTOR, E.	9.59935	0.17808	-0.72100	33	0.51984	14
SECTOR, S.	8.95351	0.08114	-0.59507	32	0.35411	16
BAND, E.	9.28304	0.10425	-0.65603	19	0.43038	22
BAND, S.	9.62282	0.17242	-0.42552	21	0.18107	24

Relationship Between Density and Travel Time From the City Center---Table 3

Geog. Set-ups/1966	A	b	r	No.	R^2	Graph
GVRD	10.41882	0.08161	-0.65761	151	0.43245	3
LINE, E.	10.35397	0.08934	-0.83896	12	0.70386	9
LINE, S.	10.24456	0.09650	-0.67561	14	0.45645	11
SECTOR, E.	10.40791	0.08326	-0.80688	26	0.65105	17
SECTOR, S.	10.65679	0.09359	-0.69427	29	0.48201	19
BAND, E.	9.84140	0.05737	-0.78820	21	0.65125	25
BAND, S.	10.57283	0.08065	-0.77282	28	0.59724	27

Relationship Between Density and Travel Time From the City Center---Table 4

Geog. Set-ups/1971	A	b	r	No.	R^2	Graph
GVRD	10.26468	0.07217	-0.62365	151	0.38894	4
LINE, E.	9.82351	0.06660	-0.75049	12	0.56324	10
LINE, S.	9.92064	0.07769	-0.58600	14	0.34340	12
SECTOR, E.	10.24311	0.06994	-0.74554	26	0.55583	18
SECTOR, S.	10.37837	0.07684	-0.62873	29	0.39530	20
BAND, E.	9.64117	0.04143	-0.66226	21	0.43859	26
BAND, S.	10.63296	0.08287	-0.72389	28	0.52402	28

Relationship Between Density and Radial Distance From the City Center---Table 5

Geog. Set-ups/1956	A	b	r	No.	R^2	Graph
SECTOR, E.	9.73567	0.07428	-0.89469	17	0.80048	29
SECTOR, S.	9.94927	0.11472	-0.82024	16	0.67279	32
BAND, E.	9.63216	0.08405	-0.91433	15	0.83600	33
BAND, S.	9.82152	0.10423	-0.80193	15	0.64310	35

Relationship Between Density and Radial Distance From the City Center---Table 6

Geog. Set-ups/1961	A	b	r	No.	R^2	Graph
SECTOR, E.	9.49519	0.06640	-0.74426	17	0.55393	30
SECTOR, S.	10.33737	0.11730	-0.79662	16	0.63460	31
BAND, E.	9.58201	0.06982	-0.87769	15	0.77033	34
BAND, S.	9.63519	0.07486	-0.67714	15	0.45852	36

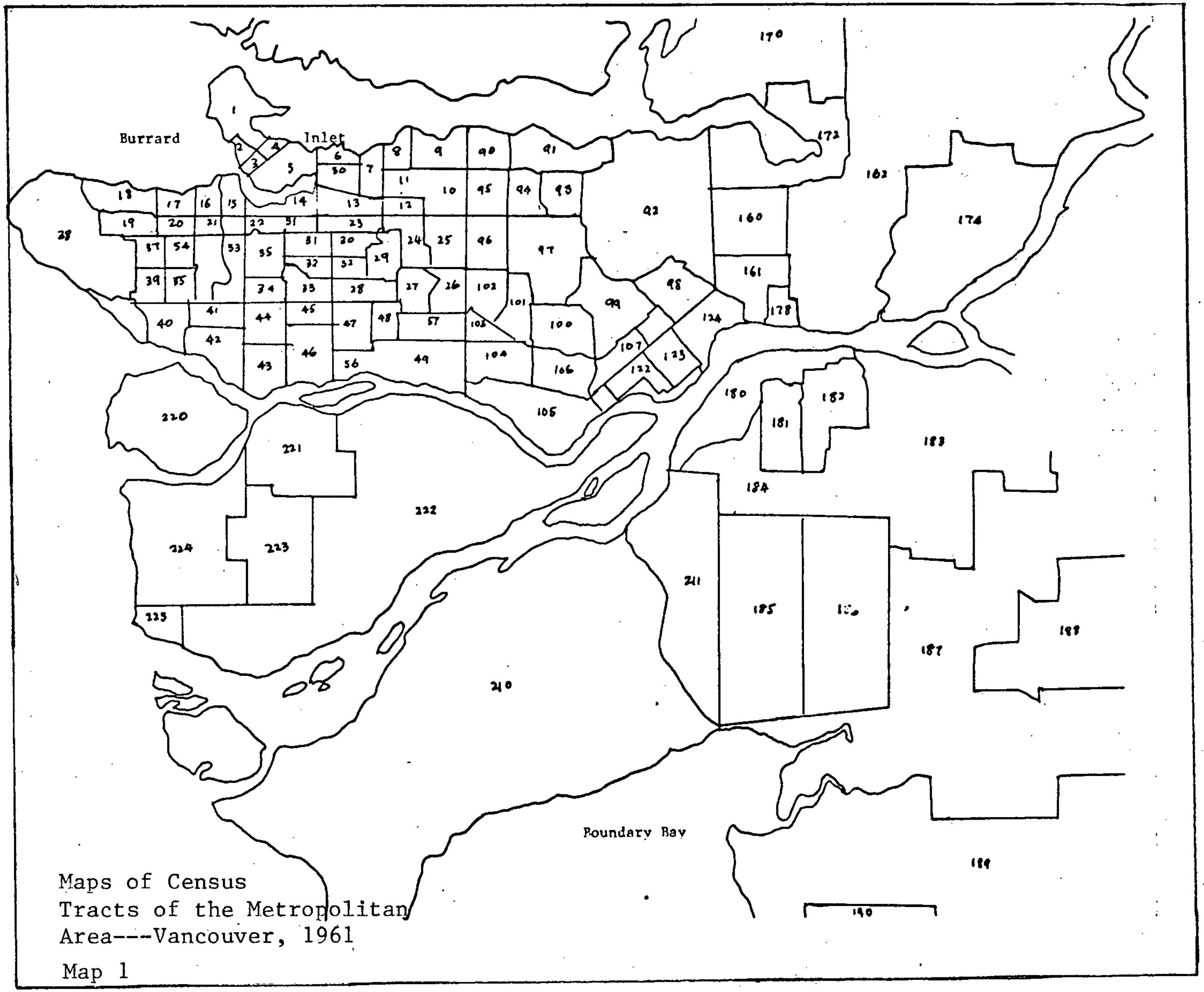
Relationship Between Density and Travel Time From the City Center---Table 7

Geog. Set-ups/1956	A	b	r	No.	R^2	Graph
SECTOR, E.	10.38463	0.09815	-0.88126	17	0.77662	37
SECTOR, S.	10.76976	0.13485	-0.75983	16	0.57734	39
BAND, E.	10.15263	0.09559	-0.85823	15	0.73655	41
BAND, S.	10.25926	0.10467	-0.75618	15	0.57180	43

Relationship Between Density and Travel Time From the City Center---Table 8

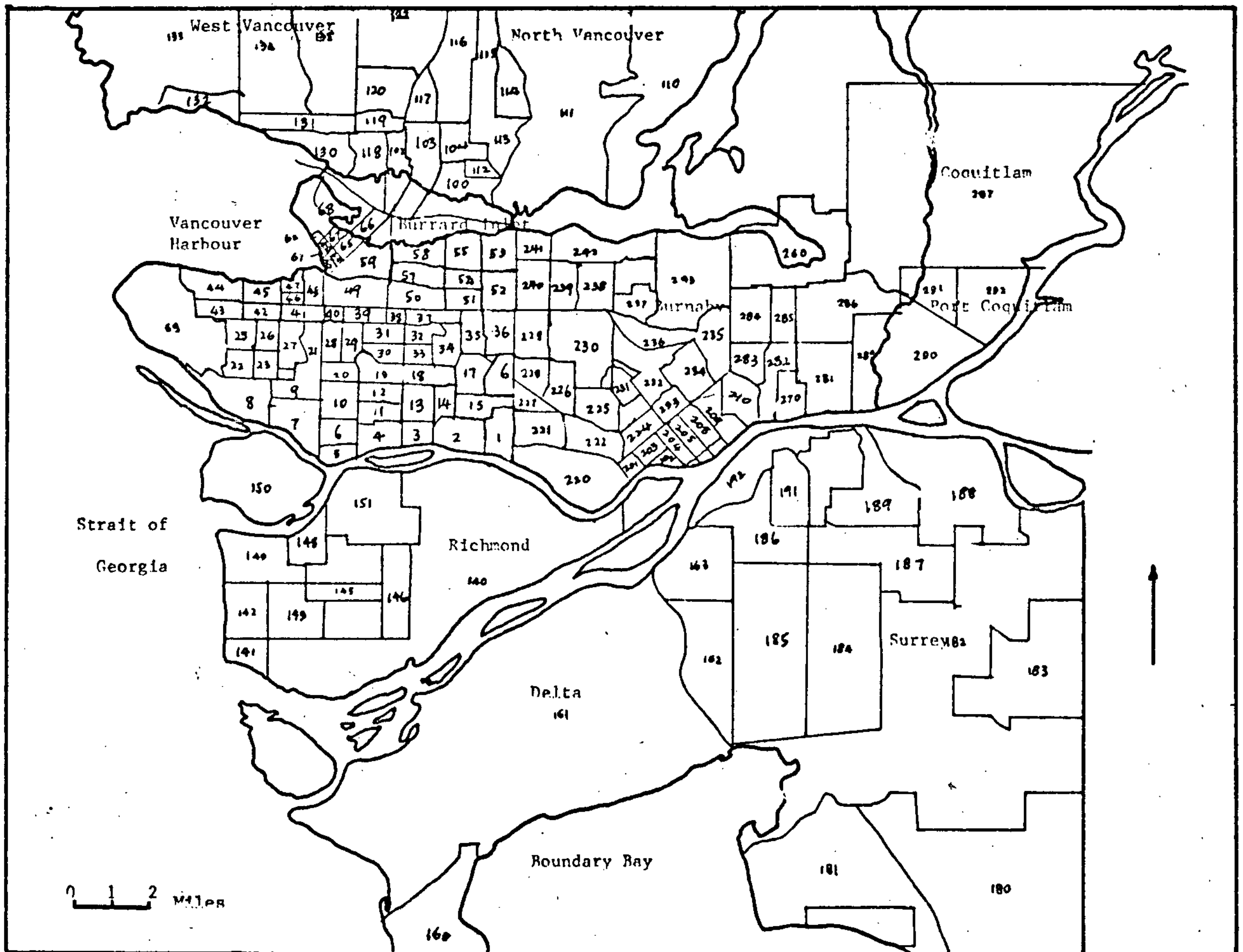
Geog. Set-ups/1961	A	b	r	No.	R^2	Graph
SECTOR, E.	10.21197	0.08117	-0.84767	17	0.71855	8
SECTOR, S.	11.35954	0.14123	-0.69927	16	0.48898	40
BAND, E.	9.99301	0.07835	-0.81292	15	0.66084	42
BAND, S.	9.97566	0.07699	-0.65392	15	0.42761	44

Appendix IV: Maps

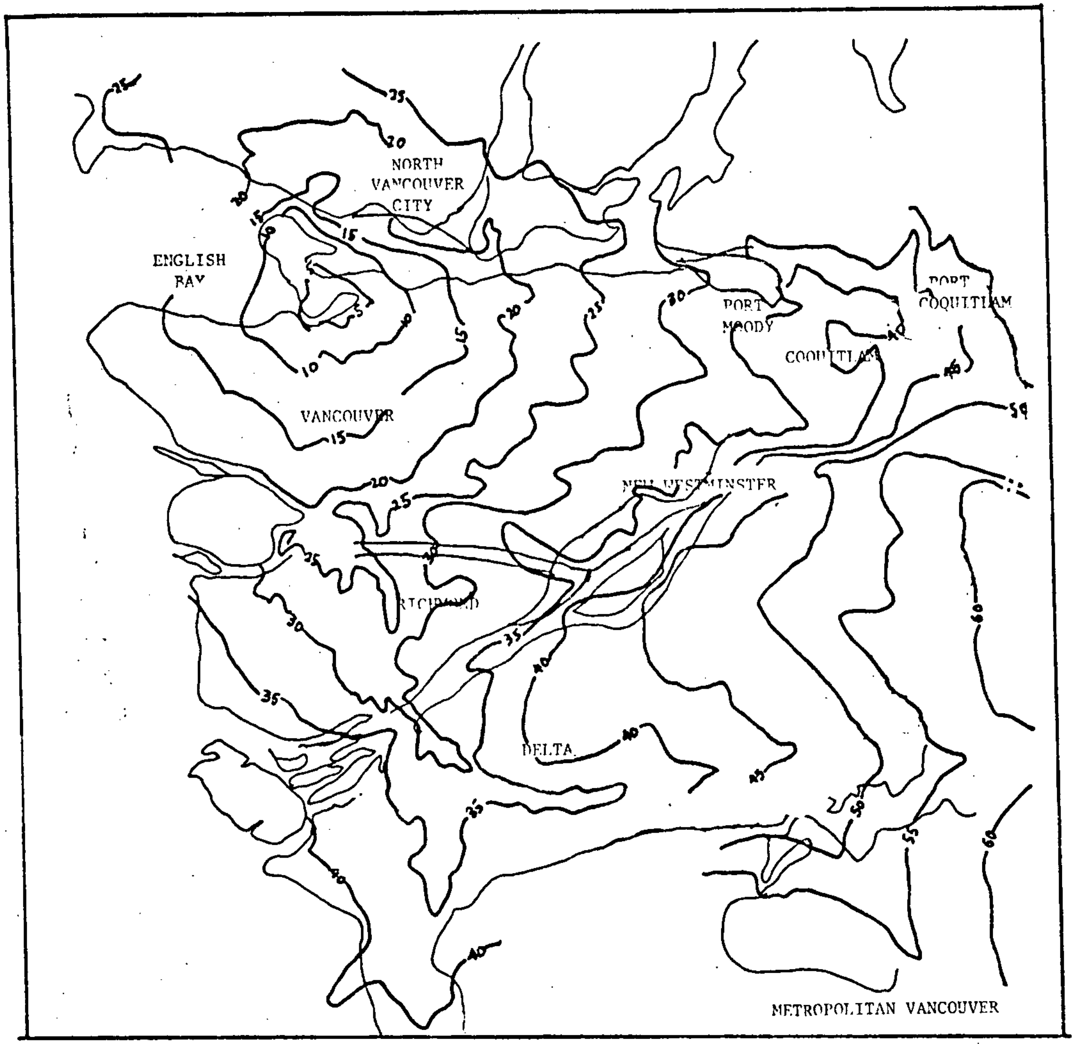


Maps of Census
Tracts of the Metropolitan
Area---Vancouver, 1961

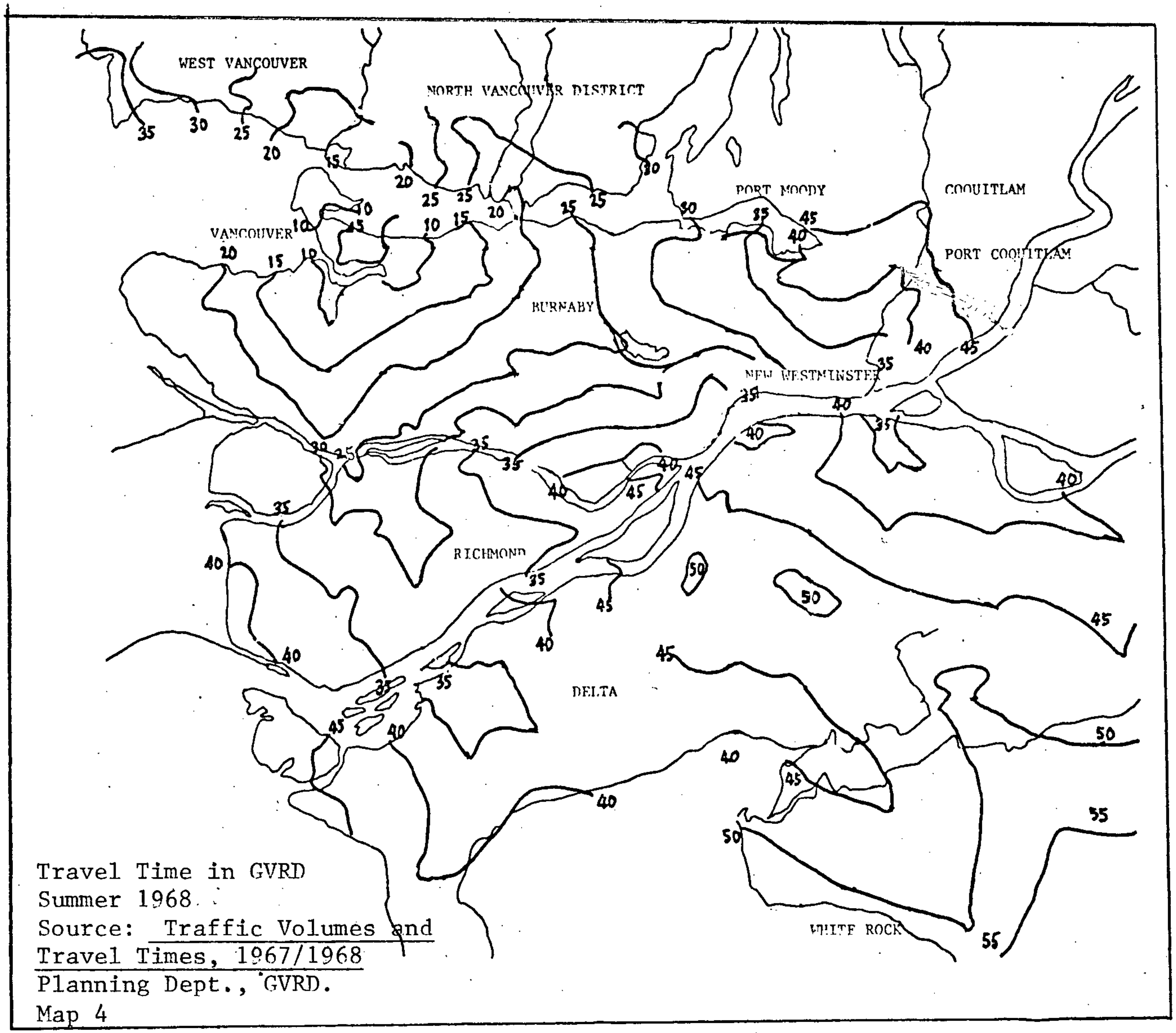
Map 1



Map of Census Tracts
of Metropolitan Vancouver,
1971 Map 2



Travel Time in GVRD
Source: <u>Dynamics of Residential Land Settlement</u>, LMRPB of B.C., 1963 Map 3



Travel Time in GVRD
Summer 1968
Source: Traffic Volumes and Travel Times, 1967/1968
Planning Dept., GVRD.
Map 4