TRIP GENERATION, MODAL CHOICE
AND TRAFFIC ASSIGNMENT
IN URBAN TRANSPORTATION PLANNING

BY

ABDUL HAMID AHMED AL-SARRAJ
B.Sc., M.Sc., M.I.H.E.

A thesis presented for the degree of
Doctor of Philosophy
in the Department of Civil Engineering
of the University of Strathclyde.

July, 1978

SYNOPSIS

This research work attempts to construct econometric models of the demand for travel. Basically, the models depend on a relationship between the amounts of travel demand and household income, but there is an inbuilt sensitivity to the level of service provided by different transport systems. To achieve this, a new method of valuing non-working time was developed. By applying the principle that the amount of travel is governed by household budgets of time and money it is possible to estimate the effect on the numbers of trips and their lengths caused by modifying the road system or by otherwise changing the cost of travel. The models therefore depart from the traditional four stage transportation planning techniques and they effectively combine modal choice with trip generation.

To complement these travel demand models a new approach to traffic assignment has been developed. The method uses concepts of "relative attractiveness" and "accessibility" of routes to simulate drivers' choice of route. Additionally, this process provides estimated values of parameters required as "feedback" to the travel demand models. An important feature of the work is that all models are simple in concept and application and they require relatively small amounts of data to be collected.

ACKNOWLEDGMENTS.

The author wishes to express his deep gratitude to his supervisor Mr. J.M. Aitken for his inspiration, encouragement and constructive suggestions throughout the period of this research, and for developing a new computer program used in this study.

Thanks are also due to Mr. P.B. Green, Head of Highway and Traffic Engineering Section for his help and guidance.

My thanks are extended to Professor D.J. McKinlay, Head of Civil Engineering Department, for providing the facilities for carrying out this project.

Thanks are also due to Iraqi Government, (Ministry of Planning) for their financial support.

Finally, thanks are due to Mrs. M. Aird for the effort taken in typing this dissertation.

CONTENTS

LIST OF TABLES

The tables can be found at the end of the text. There are some tables within the text, these are labelled with letters, for example Table 5.3 is at the end of the text while Table 5.h is within the text.

LIST OF FIGURES

The figures can be found at the end of the text. There are some figures within the text, these are named diagrams instead of figures.

CHAPTER 1

STANDARD URBAN TRANSPORTATION PLANNING PROCESS

1.1 INTRODUCTION.

Transportation improvements lessen transportation costs. This lowers the cost of goods and services thereby saving fixed available resources for application towards other needs.

Transportation improvements also generate broad social benefits by making a larger variety of goods,services and activities accessible to people. Thus, transportation has an influence on the form of urban developments and on the life style of urban citizens. People gain greater freedom to choose where they live, work and shop, they gain a wider range of choice in educational, cultural and recreational activities.

Transportation planning objectives must be to provide for the safe, rapid, comfortable, convenient, and economic movement of people and goods. To achieve this, acceptable methods are needed for forecasting and evaluation.

Like many other systems, urban transportation planning changes constantly. A twenty year transportation plan, based on the best forecasts and analyses available just a few years ago may be almost obsolete today. The main reasons for this are the unexpected changes in land use distribution and development and unexpected travel demands due to higher personal incomes.

1.2 HISTORICAL BACKGROUND OF TRANSPORTATION PLANNING.

Although the current methodology in transporation planning is relatively new, the problem of traffic congestion has existed for a long time; but it never grew so seriously until the car age. Both the size and pattern of urban development have been affected extensively by the existing transport technology (Stopher and Mayburg, 1975).

Undoubtedly the most revolutionary development in the whole field of transport occurred in the first half of the twentieth century with the growth of motor transport. Within the matter of a few decades the motor vehicle had become an integral part of the British transport system and it produced significant changes in the economic and social life of the country. In fact, not since the railway has any form of transport had such far-reaching effects. Not only did motor transport create a wide range of new opportunities, but it also brought with it many problems, solutions to some of which have still not been found today (Dyos and Alcroft, 1974).

A private car which cost £500 in 1922 could be bought for £325 in 1926 and the price of commercial vehicles fell by £100 during the same period. This rapid fall in price and improvement in the technical performance of motor vehicle together with the rise in real incomes were undoubtedly the main factors contributing to the growth of motor transport in the inter-war-years.

The necessity for transportation planning became obvious when increasing personal income, greater vehicle ownership, and associated increase in personal mobility gave rise to an increase level of congestion and delay. Planners came to realise that cities, in their traditional physical form, simply could not cope with the new mobility.

Before the early 1950's the method of forecasting was straight line projections of traffic counts; and planning depended on the comparison of the forecasted volumes with the existing capacities.

Serious attempts at urban transportation planning started in U.S.A. in the early 50's and later in Europe. The collected data was utilised to help develop methods for forecasting travel for as much as 25 years into the future. At this time the problems that face transportation today such as pollution were not recognised.

The changes of the 1960's saw an extension of pre war trends and brought about many new and sophisticated methods used in urban transportation studies. Large scale land use/transportation studies in major metropolitan areas were launched in North America during the years 1959-1968 (Batty, 1976). These studies led to the recognition of the problems in providing an adequate system of public transport services; urban areas are frequently faced with lack of financial support.

In the mid 70's the problems of energy shortage and higher oil prices seriously shook the economic balance of many countries. Some reconsideration of development programmes was undertaken and consideration of energy conservation began..In the future, it is likely there will be more restrictions on energy consumption, and research will concentrate on alternative energy sources, which may produce new concepts in transport.

1.3 TRANSPORTATION PLANNING STUDIES

Two main categories can be identified in transportation planning.

1. Short range studies (5 to 10 year plan)

Such projects tend to be specialised for a single site, a single mode, a single route or a single link in the network. Usually this deals with bottlenecks and congestion problems which occur in part of the network.

2. Long range studies (20 to 25 year plan)

These include those associated with developing transportation facilities for the long term needs. Such calls for integrated and continuous planning process. The fundmanetal objective of the long range study is to develop a plan to serve the community of the future and also to serve the changing needs of the community, the plan takes time to implement and communities will develop new requirements over time. The plan usually includes all transport networks together with parking facilities and terminals.

The method of long range study usually includes the following :

(a) Inventory

(b) Summary and analysis

(c) Forecast

(d) Testing of alternatives and proposals.

(a) The inventory stage deals with origin-destination survey, and data is collected by such methods as the home interview and the roadside interview. Other data needed concerns land use, bus services, rail facilities, parking spaces, road capacities, etc., on the network for the base year (year of survey).

(b) Summary and analysis often yields the base year travel characteristics in the form of O-D table and cost matrix which is based on speed measurement and network analysis. These two sets of information (O-D table and cost matrix) are used for calibrating the forecasting models in the following stage.

(c) Forecasting is necessarily an inexact science. However, forecasts are in use constantly and must be revised in the light of new information and new policies.

(d) Future development alternatives for the region become specific in terms of activities on zonal level. Different methods are used to forecast demographic and economic characteristics. Traffic forecasting is usually done by using models as described in the following section.

In order to obtain some guidance in preparing proposals for future transportation systems an estimation is first made of how the existing network is loaded when exposed to both the observed and forecasted traffic. The network proposals and testing of alternatives usually emerge from comparison of "demand" and "supply"; from objectives, and from engineering experience and judgement. An economic assessment can be a guide as to which alternative offers the better benefit.

However, the credibility of transportation planning is being taxed by the evidence of increased congestion and adverse environmental consequences of transport systems (McGrath, 1972). The increasing difficulty in implementing long.range transportation plans in urban areas, particularly during periods of rapidly changing human values, requires the planning process to be brought down from the regional long-range scale to shorter time frames and smaller areas (Wickstrom and Grant, 1972).

1.4 MODELS IN TRANSPORTATION PLANNING

In practical terms, models have generally been used to calculate future traffic on the road network. This calculation shows the bottlenecks and gives an idea of where the road network should be improved.

Models as used in transportation planning are mathematical equations and procedures which simulate relationships between socio-economic characteristics and land use. They also include transportation system parameters and resulting travel patterns. Not all such relationships are reduced to mathematical equations, e.g., most existing land use forecasting techniques are sequential procedures which are based on experience and knowledge. Models are developed and verified by applying them to existing parameters to "reproduce" current travel pattern. If the basic relationships are assumed to hold over a period of time, the planner can use the model sequence to test future alternative land use and transportation systems which may be developed. These are then evaluated in the light of the objectives to determine the best course of action.

The processes of modelling are :-

1. Model theory.
2. Data collection.
3. Calibration.
4. Testing.
5. Prediction.
6. Evaluation of performance of the model.

Properties of a good model are : simplicity, sensitivity, stability and validity.

The model must be simple in concept and application.

The process of transportation planning with conventional models has become unwieldly inflexible and slow and it's not certain that the level of detail and accuracy is well matched to the planning phase concerned (OECD Report 1974). The model must be sensitive to the parameters involved. This will naturally call for using parameters which can be measured or estimated fairly accurately.

Besides stability and consistency, validity is the most important feature of the model; a model to have validity, must specify the causal sequence in which events occur. In other words, the range and applicability of the model must be known. It follows from requirements of prediction that not only a relation form, but "correct" cause and effect are needed for a valid model.

Traditionally, transportation planning consists of four stages, each treated separately by a model especially formulated to deal with that stage (Figure 1.1). The stages are :

1. Trip generation.
2. Trip distribution.
3. Model split.
4. Assignment of traffic to facility pattern.

Each stage will be described in detail later.

The distinct problem which limits the accuracy of transportation forecasting models is the cost. A transportation model is a cumbersome exercise in repetitive mathematics, made possible only by the development of computers. It is not a cheap process and in many instances a decrease in accuracy has to be accepted to save excessive expenditure on computation (Lane et al, 1971).

However sophisticated the model, it is essentially an aid to decision-making rather than an answer in itself. The results of a transport model are normally of little use without someone trained to interpret them and combine them with good engineering judgement.

Model building processes are complex and transportation models are actually a part of system analysis or urban planning, land use and transportation as in Figure 1.2. When objectives and resources are changed, new considerations must be put forward and because these two inputs (objectives and resources) are always changing, continuous transport planning is needed.

1.5 URBAN TRAVEL CHARACTERIATICS

The social, demographic and land use characteristics of the modern urban region influence the travel behavior of its residents and the demand for transportation facilities. The modern urban region is usually characterised by a continuing rapid rate of growth both in population and area of urbanisation, a proliferation of commercial and industrial centres, and increase in car ownership which outpaces population growth, and a relative decline in many types of CBD attraction (Levinson, 1976).

Each urban area reflects historical, social, and economic antecedents. Likenesses and differences among cities mainly relate to economic base, topography and age. Population density patterns generally reflect city age and the modes of interurban transport that prevailed during formative years. Consequently cities in Europe, Asia and South America generally exhibit higher densities and lower car ownership than American cities. In most cities, net residential density declines with increasing distance from city centre. Car ownership increases with rising income and with decreasing density.

In most American cities more than three-quarters of all personal trips are made by car. The proportion of trips made by public transport tends to increase as the population and/or density increases.(Levinson, 1976). In 20 years in Britain the total amount of passenger transport has grown by more than 300percent (Transport Policy U.K., 1976), with the largest share of the total and all of the growth coming from the use of cars. By 1974 cars and taxis accounted for 79 percent of all passenger travel (measured in passenger kilometres), and 90 percent for vehicle kilometres (Figures 1.3 and 1.4).

From these figures the following effects may be observed:

1. The trend of car and van use rose almost continuously throughout the last twenty years reaching about 90% of total vehicle kilometres travelled on all roads by 1974)

2. The use of other modes, especially buses, is declining and it represented a small amount, only about 1.5% of total vehicle distance in 1974. This relatively small distance travelled by buses contributed a greater amount - expressed in passenger journeys and passenger distance. In 1974 buses and coaches accounted for about 24 percent of all passenger journeys and around 12 percent of total passenger kilometres (Ball and Percival, 1978).

3. The use of car related to economic growth (Gross Domestic Product GDP and national disposable income and their reflections on personal income and retail prices. The effect of petrol price on car usage can be realised by the fact that when petrol price index started to rise sharply in 1973/74 the car passenger kilometres fell down correspondingly.

1.6 ZONING SYSTEM

Commonly in transportation planning processes, the area under study is divided into a number of zones, the reasons for this are :

1. To simplify the presentation and collection of data.
2. To reduce computation and minimise the computer time and storage needed for processing.
3. To understand better the structures of the area in terms of land use and activity.

First the region would be circumscribed by a cordon line. The cordoned region is then divided into zones (internal zones) whose areas are small enough for most problems to be pinpointed fairly accurately, and yet large enough so that the study does not become inundated with data. The surrounding area represents a number of external zones. The type and intensity of land use must be considered in zone size definition, as general rule and the average radius of internal zones should be less than the mean trip (Broadbent, 1969(. The size of zones, if it is done on this basis, will appear as irregular shapes, smaller zones concentrated in Central Business District (CBD) area and large zones in outskirts of the city (Figure 1.5). Apart from the nature of the study the size and shape of zones depend on : administrative boundaries, topgraphy, population, trip generation potentials, together with existing and proposed road network. However, there are possibilities of zoning on a grid system using ordnance survey maps.

To facilitate rapid identification and machine processing of detailed trip information collected in the surveys, the traffic zones must be delineated and coded numerically.

1.7 DATA COLLECTION

Data is collected in each transportation study mainly for the following :

1. to calibrate models
2. to identify more precisely problems, domains, objectives and constraints
3. to yield some travel characteristics which may help identifying and solving the problem.

The data collected usually consists of :

1. Origin-Destination (OD) Survey, which yields matrices of travel between zones, classified by journey purpose, type of vehicle and by time of day.
2. Cordon and Screen line counts relate to the number and type of vehicle passing certain points of Cordon and Screen line.

Figures are recorded on daily, or preferably on an hour basis.

3. Speed and flow measurement, for as many links as possible of the network, delays at junctions. Parking spaces and related aspects must be listed.
4. Land use survey related to the type and intensity of land use in each zone needed for analysis. Associated

surveys also needed concern demographic and economic status, population car-ownership, employment, retail sales, number of dwelling units and income of households etc.

1.8 DATA CHECKS

After the survey work has been completed it is necessary to tabulate and check the information recorded to determine the reliability of sample information. Planning data checks, screen line and cordon line checks are necessary to fulfil this aim.

In planning data checks, a comparison between O-D survey data and independently derived estimates (which can be obtained from recent census) of population, dwelling units and labour force etc. is made. Screen line checks are the best means of determining the completeness and accuracy of trip reporting. In this check the number of trips from one part of the study area to another across natural barriers, as determined from actual ground counts, is compared with the number of trips having origin on one side and destination on the other as determined from survey data. The cordon line accuracy check involves the comparison of expanded data for trips made by study area residents crossing the cordon line as recorded in the survey with roadside counts.

The pattern and amount of work trips, by length distribution shows a greater degree of stability than for other trip purposes. In respect of the reliability of data, it is possible to place greater emphasis on work trips.

1.9 TRIP PURPOSES

Different considerations have led transporation planners to define "trip purpose" which are groups of activities that may require travel from home for their excursion. These trip purposes are defined first as a basis for determining the price and utility of activities. Secondly, they form a means of identifying activities that have fairly common response patterns to transport system changes. The set of trip purposes usually employed by the transporation planner is :

1. Work trip
2. Shopping trip
3. Business trip
4. Social trip
5. Educational trip
6. Recreational trip
7. Other personal travel

Since "trips" are defined as one-way movements, an additional purpose of "home" is added to this set. Finally, other intermediate trip purposes may be defined, these relate to changes of travel mode.

1.10 HOUSEHOLD AS BASIC UNIT FOR TRIP GENERATION.

Characterisation of travel behaviour at the individual level, and related aggregation questions, led most transportation planners to define the behaviour unit of analysis to be a household.

A "household is a collection of individuals who choose to reside together". Oi and Schuldiner (1967) postulated that the household is the major decision making unit, as opposed to an individual person or an individual tripmaker. In this work the consumer unit is household.

1.11 SUMMARY.

The conventional "four-step" transportation process framework has been briefly presented in this chapter, and the current state of art in urban transportation models outlined. Some emphasis has been put on the basic data and requirements for such study.

Attention has been drawn to the behavioural unit "household" and its travel characteristics. The effect of income, general national economic growth and oil price change on travel is also introduced.

In the following chapter, the conventional transport models will be discussed. Their practicability and shortcomings will be highlighted.

CHAPTER 2

REVIEW OF CONVENTIONAL TRANSPORT MODELS

2.1 INTRODUCTION

Transportation planning as currently practiced is extremely cumbersome, and very expensive. It is inflexible, and it is static rather than dynamic. That is, it is based upon measurements and estimated relationships from a single point in time, with an assumption that these relationships and estimates will not change over time except as may be specified by extraneous changes in total population, in wealth, and in similar characteristics.

Transportation planning processes involve the collection and analysis of large volumes of data and running of complex and costly computer models. This process is unwieldly, inflexible and slow and it is not certain that the level of detail and accuracy is well matched to the planning phase concerned (OECD Report 1974).

The four-step transport models as presented in Chapter 1, and shown graphically in Figure 2.1 derive their general name from the presence of the above four distinctive steps. The key question is whether the increased level of detail, complexity and cost is justified by a corresponding increase in the accuracy and validity of the models relative to what could be achieved by a more simplified approach.

In this chapter each model is critically reviewed in order to provide a background against which a new approach can be assessed.

2.2 TRIP GENERATION DEFINITION

According to the American manual on O-D Surveys a trip means a single journey with a certain purpose between two points made by a specified means of transport by a person aged at least 5. Journeys by motor cycle, bicycle or by foot do not count as trips according to this definition.

In principle any stop is considered the end of one trip and the start of another trip. Stops which have "secondary" purposes and which do not determine the choice of route e.g. depositing mail, buying petrol etc.) are disregarded (Overgaard, 1966).

Trip generation is a general term usually applied to both origin end (O) and destination end of a trip (D). Consequently generation has to be classified into trip production (origin end) and trip attraction (destination end) (Wooten and Pick, 1967).

Most British studies divided the trip into two groups :

1. Trips which have one terminal point at home ("home based").

2. Trips which have no terminal point at home ("non-home based").

The first group is generated at the residence while the trips in the second group are considered generated at the origin. Home based trips are generally between 85 percent and 90 percent of all trips, this percentage is fairly constant.

In this study, trip generation is defined as the average number of one-way journeys generated by a household per week. The return journey is a complementary one which occurs within 24 hours of the day.

2.3 TRIP GENERATION COMPONENTS

Figure 2.2 shows how traffic on a new improved road may develop. The total traffic consists of the following components :

1. Present traffic: This is composed of traffic on the old roads which can be found by survey. The present traffic characteristics are usually needed for calibrating the models constructed to describe the travel pattern in the study area.

2. Normal growth : This is due to increasing population and income, and consequent increasing in car usage.

3. Diverted traffic : Improvement of one highway will

often result in the immediate attraction or diversion to it of some of the traffic formerly using parallel or alternative routes. On the other hand, if the road is a new one the whole of its traffic upon completion will have been diverted from other links. This traffic already exists so it is not part of the trip generation components; it is an amount required only at the last stage of planning, i.e., the "assignment stage".

4. Generated traffic : When there is a reduction in the cost of travelling between two points as a result of road improvement, certain journeys which were possibly not worthwhile before the improvement, become worthwhile afterwards. Thus traffic between the two points will increase (Dawson, 1968). This component accounts for up to 30 percent of present traffic.

5. Development traffic : is another type of generated traffic caused by providing a new and convenient level of accessibility for land not previously served adequately by highways. Building and new development are then likely to occur. Moreover, intensified commercial, industrial and residential use can be expected (Matson et al, 1955).

2.4 CONVENTIONAL TRIP GENERATION MODELS

2.4.1 Introduction

"Trip end forecasting" is based on the principle that "land use generates traffic". The level of traffic generation, and in particular the mode of travel, depend on a large number of factors which can be conveniently divided into the following groups : (Douglas and Lewis, 1970).

1. Socio-economic variables. Socio-economic variables largely measure the desire and potential of any household to make a trip. The variables normally considered include car ownership, household income, household size, wage earners per household and occupational status.

2. Location variables. Location variables reflect the surrounding environment and should ideally measure the spatial separation of households from each of the amenities which

they desire, e.g., schools, shops and workplaces.

Conventional methods of modelling trips are "Regression Analysis" and " Category Analysis". Both models are discussed below.

2.4.2 Regression analysis

Regression analysis in a general sense simply assumes that some variable 'Y' responds to changes in other 'X' variables. The Y-variable is the quantity under study (here, number of trips) and is known as the "dependent" variable. The X-variables are those which exhibit a causal effect on the the values of Y, and are known as "independent " variables, e.g. (car ownership, household income, etc.).

The most commonly used method has been that of "least squares" regression. For computational purpose the response surface has generally been assumed to be linear. The model can be expressed by :

$$Y = a_o + a_1X_1 + \dots + a_nX_n \tag{2.1}$$

where

Y is the dependent variable (number of trips

$X_1 \dots X_n$ socio-economic variables

a_o is the intercept term

$a_1 \dots a_n$ parameters (regression coefficients)

The use of least-square regression analysis involves a number of assumptions relating to the distribution of the "distrubance term" (the difference between observed Y and that estimated by the model), the independence and accuracy of the explanatory variables, and the shape of response surface. The various statistical tests associated with the least-square model may become invalid if the basic assumptions are not fulfilled.

The intercept term (a_0) and the regression coefficients a_1, a_2 .. a_n) are calculated from observed data by using the principle of least-square, i.e., the sum of the squares of residuals or deviations from the estimated line is minimised.

After fitting the best equation, the model is applied to find Y of a future year using X values which are independently estimated for the future year. Their corresponding coefficients are assumed to remain constant throughout the period.

Different levels of aggregation are usually checked as a unit of observation. In formulating zonal regression models, there is an apparent choice between the use of "aggregate" and "rate" variables. "Aggregate" variables express total zonal values such as trip/zone and person/zone, while "rate variables" express mean zonal values, such as trips/household/zone and person/household/zone. On the other hand disaggregate models which make no reference to zone boundaries considers households as basic trip making units. It should be noted, however, that the ultimate aim is to produce an estimate of total zonal trips. Consequently any disaggregate model must be capable of expansion to the zonal level. The level of disaggregation can be based on mode of travel and trip purposes, particularly when data is available for such classification.

Widespread computer availability allows flexibility in the development and testing of the regression models. A stepwise procedure is used for selecting different combination of independent variables. The output from a typical stepwise regression program is shown in Table 2.a.

It must be emphasised that the regression method can be used to calculate both trip generation and trip attraction.

The typical equations (Table 2.a) can be tested statistically. The statistics usually considered are the coefficient of simple correlation (R) which is a measure of association of variables. R^2 is the proportion of variability explained by the equation.

Other tests are "t" tests to see whether a coefficient value differs significantly from zero or not; the "F" test is used to test the significance of relationship between the dependent variable (Y) and the independent variables $X_1, X_2 \ldots X_n$; the "confidence interval" for the regression line is another way of showing one usefulness of the model for forecasting. A summary of procedure for both linear simple and multiple regression analysis presented in Appendices 1 and 2.

Table 2.a.

person trip/zone	$= 3\ X_1$
person trip/household/zone	$= 3.2\ X_2$
person trip/household	$= .9 + 1.5\ X_3 + X_4$
Vehicle trip/zone	$= 3.5\ X_5 + 1.1\ X_6$
vehicle trip/household/zone	$= 1.3\ X_7 + .8\ X_8$
vehicle trip/household	$= 1.1 + 1.5\ X_9 + .9\ X_{10}$
X_1	= person over 5 years/zone
X_2	= person over 5 years/household/zone
X_3	= cars/household
X_4	= worker/household
X_5	= cars/zone
X_6	= worker/zone
X_7	= cars/household/zone
X_8	= worker/household/zone
X_9	= cars/household
X_{10}	= wage earner/household

2.4.3 Category analysis

This method is based on determining the average number of trips (dependent variable) for defined categories of households. Unlike the regression method, category analysis does not require the formulation of any kind of equation directly. It requires the allocation of households to different categories; those categories are however arbitrary. In British transportation studies, households were allocated to 108 categories as in the following table :

Table 2.b

X_1	X_2	X_3
Cars/ household	Household structure	Household income/ per year
0	0 employed residents and 1 unemployed adult	Less than £500
1	0 employed residents and 2+ unemployed adults	£500 to £1000
2+	1 employed resident and 1- unemployed adult	£100 to £1500
	1 employed resident and 2+ unemployed adult	£1500 to £2000
	2+ employed residents and 1- unemployed adult	£2000 to £2500
	2+ employed resident and 2+ unemployed adults	£2500 or more

The combination of these three variables (X_1, X_2, X_3) make 3X6X6 = 108 categories.

Furthermore, trips generated per day by a household of a given category include trips of several types, so that the total number of trips is broken down by the mode of travel and purpose of the trip.

Three modes and six purposes are isolated as follows_ :

Modes :

1. Driver of cars
2. Public transport passenger
3. Car passenger

Purposes :

1. Work
2. Business

3. Education
4. Shopping
5. Social
6. Non home based

Purposes 1 to 5 have their origin or destination at home and are defined as home-based; this distinguishes them from purpose 6.

Each of the 108 categories of household has associated with it a trip rate for each of the 6X3 = 18 modes and purpose combinations. From the base year data, an average rate can be found for each category. Knowing the number of each household category in each zone for target year, the task of predicting future zonal trips is confined to a simple procedure obtained by multiplying the rate of trips of a certain category by the number of households in that category. All categories can then be summed to yield the total number of trips for the zone under consideration.

The assumption in this method that these trip rates are stable over time, so long as factors external to the household remain the same. It is assumed that the trip-making activity of a household will not change unless it aquires another car, another member, or greater income, and that when it does it will emulate those households already in the category it moves into (Wootton and Pick, 1967).

The problem is to predict the number of households, in each category in each zone, for a future year. For this purpose, different probability distributions are used, mainly the following :

The distribution of households by income.

The average and standard deviation of income for the study area traffic zone is assumed to be known, and the households are classified into income groups by assuming that the income distribution is represented by a continuous p bability density function $\phi(X)$, the number of households having income X such that $a < x \leqslant b$ is given by

$$N \int_b^a \phi(x) . dx \tag{2.1a}$$

where N is the number of household in the zone, the function $\phi(x)$ is defined so that its mean and standard deviation are equal to the known values. A Gamma distribution is used so that :

$$\phi(x) = \frac{\alpha^{n+1}}{n!} . x^n . e^{-x} \tag{2.1b}$$

$$\alpha = \frac{\bar{x}}{\sigma^2} \tag{2.1c}$$

$$n = \alpha\bar{x} - 1 \tag{2.1d}$$

This distribution was found to fit the base year data of West Midland Transport Study (Wootton and Pick, 1967), for forward projection of income distribution α was recalculated according to

$$\bar{\alpha} = \alpha(1+g)^y \tag{2.1e}$$

where g is the annual growth rate of income relative to the cost of living. $\bar{\alpha}$ is the calculated value of α and y is the number of years for which the projection is required. This process results in the average income increasing by a factor of $(1+g)^y$ during the projection period, while leaving the ratio of average to standard deviation unchanged. However, if resultant synthesised household income distribution is different from observed values, it is necessary to apply a correction factor to each income group.

Household car ownership distribution.

The distribution of household by car ownership has been found to be related closely to the distribution of households by income. Hence "conditional probability" functions have been formulated which express the probabilities of owning n cars 'given' the household income (x) relative to the price of cars. Gamma functions as before might be fitted to the data, the form is :-

$$P(n/x) = a_n X. m_n.e^{-b_n x} \qquad 2.1f$$

where a_n, m_n and b_n are constants.

This conditional probability can be found for the average values of constants for each level of car ownership mainly 0, 1 and 2. For projection purposes it is assumed that the function p(n/x) is stable with respect to time and that the income distribution relative to the price of cars will change i.e., lowering the price of cars relative to income increases the probability of owning a car.

Family structure distribution.

Total family size and the number of employees in the family are used to define the family structure groups. Family size is synthesised by the "Poisson" distribution. The probability that a household has n members of whom (r) are employed is then given by :

$$P(n,r) = \frac{e^{-\alpha} \alpha^n \quad n!}{r!(n-r)!(n-1)!} P_n (1-P_n)^{n-r} \qquad 2.1g$$

where

P_n :is the probability that a member of an n member household is employed;

α :average family size -1 (Douglas and Lewis, 1971).

Using the above expression it is possible to predict for each zone the number of households falling into various family structure groups. The only input required is the average family size and average number of wage earners. Reiteration is then used to combine the separate distributions by income, car ownership and family structure in order to obtain the allocation of households to the 108 categories.

2.4.4 Comments on trip generation models.

Regression analysis suffers from the disadvantage that a linear relationship is usually assumed between the dependent and independent variables, that the independent variables are assumed to be uncorrelated with each other and continuous. When two or more independent variables are highly correlated "Multicollinearity" exists. The practical interpretation of multicollinearity is that two or more correlated variables are explaining largely the same effect and may therefore be considered alternative causes. For example, in the Table 2.c examination of a simple correlation matrix, produced from the data of Glamorgan land use/transport study, indicates that employees per household has a highly significant correlation (0.685) with household income. The income is also correlated with other variables. Consequently the individual effects of these variables on trip-making behaviour would be somewhat obscure if both were

Table 2.c

Simple correlation matrix.

	Trips	Employee	Person	Cars	Income
Trips	1	.529	.420	.476	.505
Employee		1	.542	.441	.685
Person			1	.294	.431
Cars				1	.630
Income					1

Source : Douglas and Lewis, 1971.

included in the regression equation. In fact, in many studies the main cause of trip making behaviour, i.e., the income level, is discarded in final equation for this reason.

Category analysis has freed the analyst from many of the assumptions and problems inherent in the regression analysis. This technique does, however, present problems of its own, particularly relating to statistical distribution theory and sample size.

Both methods involve many independent variables. This implies costly and time consuming study processes. Furthermore, these variables represent factors outside the character of the transport network and level of service. The structural deficiency of these methods is their failure to establish an inter-relationship between the number of trips made and the character and price of transportation service actually available. This type of forecast suggests, or at least implies, that the total amount of travel is in no way related to the existence of congestion. Clearly such an assumption is questionable if not incorrect (Wohl and Martin, 1967).

There is evidence that reduction in the time and money costs of a trip will increase the number of trips demanded daily (Wilson, 1974). Studies made on both old and new facilities show a substantial increase using both roads when the new facility is completed. These increases continue for several years but at diminishing rates (Matson, 1975).

The conventional trip generation methods largely ignored "generated traffic" which arises from a greater level of service and consequently greater use of vehicle.

In conclusion, the method of trip generation estimation will be more realistic if one considers the ease of travel which will produce more trips, and also focus on the real cause of travel behaviour i.e., the household income. In this study a great emphasis is put on formulating a new method of trip generation based on sound economic theory of demand and supply.

2.5 TRIP DISTRIBUTION MODELS.

2.5.1 Introduction.

Trip distribution techniques are used to estimate the number of trips made between pairs of zones once the total number of trips starting from, and ending in, each zone is known. In other words, each zone is taken one at a time, and a determination made of the zones to which its produced trips will be attracted.

Distribution is made on the basis of the attractiveness of potential destination zones and costs or "impedence" of travel. To fulfil this aim , models are used as described below.

In general it is assumed in trip distribution that there is an existing O-D table. That defines the number of trips between the sets of origin (i) and destination zones (j). There is also an existing network of links and nodes defining the time, distance or cost of travel between the zonal centres for all origin zones (i) and destination zones (j). Additionally, estimates have been made of future zonal trip productions and attractions, (O_i) and (A_j), for each zone, produced in trip generation stage. As estimate has also been made of the future network travel impedences and it is then required to find, on the basis of these measurements, the future equilibrium flows (T_{ij}) between the zones.

The basic method that is used by all the models commences with a calibration phase, in which the model is set up to replicate the current pattern of travel. The calibrated model is then used to extrapolate into the future by applying it to estimates of new O_i and A_j and the travel impedence for the design year. Two basic trip distribution models are commonly used : "growth-factor models" and "gravity models" as outlined below.

2.5.1 Growth-factor models.

The growth-factor models represent the simplest form of trip-distribution based on a simple expansion of existing interzonal trips by means of zonal growth factors. Growth-factor models are still used in current studies for the forecasting of those trips that have one or both ends outside the study area. This is because for such trips, there is a lack of the detailed characterisation of both origin and destination needed for more sophisticated models. (Stopher and Meyberg, 1977).

There are many types of growth-factor models, for example, the "uniform-factor model", the "average-factor model", the "fratar model" the "Detroit model" and the "Furness model". The growth-factor models assume that the future interzonal trip movements can be predicted by using some measurement of the anticipated growth of trip making within the area being studied. It is assumed that the inter-zonal trip transfers will be independent of changes in the network. The primary differences between each of these techniques lie in the complexity with which the growth factors are applied.

The Furness method presented here is a typical growth-factor model. It is, however, necessary to first of all introduce the appropriate notation.

List of symbols used in the statements :-

t_{ij} = number of trips from zone i to zone j

t_{ji} = number of trips from zone j to zone i

gT_i = number of trips generated by zone i

aT_i = number of trips attracted by zone i (i.e. $aT_i = t_{ji}$)

gT_i^* = estimated number of "trip ends" at origin zone at forecast year.

aT_i^* = estimated number of "trip ends" at destination zone at forecast year.

gF_i and aF_i growth factor at origin end and at detination end.

Step 1 : $gF_i = \dfrac{gT_i^*}{gT_i}$

Step 2 : $aF_i = \dfrac{aT_i^*}{aT_i}$

Step 3 : $t'_{ij} = t_{ij} \times gF_i$

Step 4 : $aF_i' = \dfrac{aT_i^*}{aT_i'} = \dfrac{aT_i^*}{\sum\limits_{j \neq i} t'_{ji}}$

Step 5 : $t''_{ji} = t'_{ji} \text{ X } aF_i'$

Step 6 : $gF_i' = \dfrac{gT_i^*}{gT_i''} = \dfrac{gT_i^*}{\sum\limits_{i \neq j} t''_{ij}}$

Repeat from step 3 till stable results obtained.

The statement given for Furness method deals with directional movements from one zone to another. The method may also be applied to non-directional movements. The accuracy required of these calculations in practice should not be more than 5%. The method achieves a smaller improvement in accuracy with each successive iteration (Aitken, 1965).

2.5.3 Gravity models.

The gravity model is in fact the best known model of spatial interaction which is defined as the flow of activity between different zones. For almost 100 years researchers have used analogies to Newtonian gravity to explain the movement of groups of people. This concept can be used to describe person trips of vehicle trips especially in urban areas.

In mathematical terms the model is based on the hypothesis that the interaction between an origin zone i and a destination zone j is :

(i) directly proprtional to the demand generated (or produced) at the origin zone i;

(ii) directly proportional to the number or size of the opportunity (or attractions) in the destination zone, j;

(iii) proportional to some function of the separation, distance, time or cost of travelling. The function being one which decreases with increased cost or distance.

Based on the above hypothesis, there is a family of models rather than one model.

According to assumptions made above, the general form of the gravity model can be stated as :

$$T_{ij} = KD_j O_i f(c_{ij}) \qquad (2.1)$$

T_{ij} : is the interaction between zone i and zone j, (number of trips),

O_i : is the activity in the origin (total number of trips produced by zone i),

D_j : is the activity in the destination (total number of trips attracted to zone j),

$f(c_{ij})$: is some function of generalised travel cost or impedence between i and j,

K : is a constant of proportionality.

A well known form for the function of generalised travel cost has been Tanner's function.

$$f(c_{ij}) = \frac{e^{-\lambda c_{ij}}}{c_{ij}^{n}} \tag{2.2}$$

where λ and n represent parameters or coefficients of calibration, to be found from base year data and assumed to remain constant for future years.

The model presented in equation (2.1) represents the unconstrained situation for there are no constraints on the origin or destination of trips. However, the model is usually subject to an overall accounting constraint of the form.

$$\Sigma_i \; \Sigma_j \, T_{ij} = T \tag{2.3}$$

(see Table 2.e)
where T is the total number of trips in the area.

The gravity model has to satisfy constaints, either at one end, origin or destination (single constraint), or at both production and attraction ends (doubly constrained). These constraints can be stated as follows :

$$\sum_j T_{ij} = O_i \tag{2.4}$$

$$\sum_i T_{ij} = D_j \tag{2.5}$$

and note that

$$\sum_i \sum_j T_{ij} = \sum_i O_i = \sum_j D_j = T$$

The appropriate model satisfying constaint equations (2.4) and (2.5) is written as :-

Table 2.e

TRIP MATRIX

Destination zones / Origin Zones	1	2	3	j	n	$\sum_j T_{ij}$
1	-	T_{12}	T_{13}	T_{ij}	T_{in}	O_1
2	T_{21}	-	T_{23}	T_{2j}	T_{2n}	O_2
3	T_{31}	T_{32}	-	T_{3j}	T_{3n}	O_3
i	T_{i1}	T_{i2}	T_{i3}	T_{ij}	T_{in}	O_i
n	T_{n1}	T_{n2}	T_{n3}	T_{nj}	-	O_n
$\sum_i T_{ij}$	D_1	D_2	D_3	D_j	D_n	$\sum_i \sum_j T_{ij} = T$

Note : It is necessary in any study to provide a Trip Cost Matrix corresponding to the above Trip Matrix.

$$T_{ij} = A_i B_j O_i D_j f(c_{ij}) \qquad (2.6)$$

In this case the term A_i and B_j, which are called "balancing" or "normalising" factors, replace the constant K, in (2.1) A_i and B_j can be found by summing (2.6) over j and i respectively and these terms evaluated as :

$$A_i = \frac{1}{\sum_j B_j D_j f(c_{ij})} \qquad (2.7)$$

$$B_j = \frac{1}{\sum_i A_i O_i f(c_{ij})} \qquad (2.8)$$

for doubly constrained situation the production-constrained model is subject to constrained equation (2.4) and is written as :

$$T_{ij} = A_i O_i D_j f(c_{ij}) \qquad (2.9)$$

$$A_i = \frac{1}{\sum_j D_j f(c_{ij})}$$

As there are no constraints on the destination in (2.9), then in general the predicted and actual amounts of trip in j are not equal, that is :

$$\sum_j T_{ij} \neq D_j$$

In a similar way, the attraction-constrained model is only subject to constraint equation (2.5), and the model is written as :

$$T_{ij} = B_j O_i D_j f(c_{ij}) \qquad (2.10)$$

$$B_j = \frac{1}{\sum_i O_i f(c_{ij})} \qquad (2.11)$$

"The equation describing the frequencies of different trip distributions can be interpreted as an entropy of the system, and Wilson's method is referred to as the method of "entropy-maximising". Entropy is maximised subject to accounting constraints such as those in (2.4) and (2.5) and also subject to a constraint on the cost of travel C. In the case of production-attraction constrained model, this constraint is of the form, (Batty, 1976).

$$T_{ij}c_{ij} = C \qquad (2.12)$$

Although the original application of this approach was in the field of transport, Wilson has extended the method for residential location behaviour and housing. The cost constraint as in formula (2.12) assumes that there is a total cost budget for travel.

2.5.4 Comments on gravity models.

"All forms of the gravity model make the assumption that size of origin, size of destination and distance between these places are independent variables. Parameter values obtained should consequently have meaning and a general factor, which we may call friction of distance, should be available for interpretation. However, it is fairly obvious that flows will depend on the spatial distribution of jobs and homes and one wonders how the gravity model takes this into account" (Sayer, 1977).

Regarding the dynamic of the society, and the nature of space-economy, and change in map pattern of almost all activities in urban areas in long-term, one cannot expect the parameters of the model to hold constant during the process of urban change. Because of lack of time series data a firm conclusion cannot be stated about stability of the parameters over a period of time.

The gravity model does not take into account the behaviour of the "analysis unit" i.e., the household. The phenomenon of higher income people to make longer trips both for work and other purposes is a real life fact. If this is taken into consideration the trip distribution model should be applied by household income group.

2.6 MODAL CHOICE MODELS.

2.6.1 Introduction.

The modelling stage termed "modal choice" or modal "split" is concerned primarily with an attempt to allocate person trips to the various alternative modes available. It is usually concerned in practice with dividing trips between cars and public transport (buses, etc.). The basic interpretation of modal split is the assumptions that travellers make rational choice between the available modes, based on :

(a) characteristics of those modes

(b) characteristics of the traveller himself.

It is assumed that this evaluation is performed within the constraints imposed by the purpose and destination of their trip and their attitudes towards alternative transportation system characteristics.

There are basically two types of modal choice models, the type being determined by the point in the modelling process where they are considered to operate. These two types are presented in the following sections.

2.6.2 Trip-end models.

A "Trip-end model precedes trip distribution, and has as its function the prediction of the split of total trips generated by each zone among the available modes. The trip-distribution phase, which follows the trip-end model-split model, involves the construction of separate distribution models for each mode" (Stopher and Meyburg, 1977).

Trip end models usually estimate total public transport share of trips to all destinations from each origin zone. For this purpose the regression analysis is mostly used. In general, these kind of models are able to reproduce the survey data to an adequate level of accuracy. However, these models still leave a considerable amount to be desired in their ability to produce acceptable forecasts. This is largely a result of the fact that the models are not based on sound reasoning of the actual processes that determine choice of transport mode. The independent variables used were not directly related to the level of service provided by public transport. Consequently results from most of the trip-end models were unsatisfactory.

2.6.3 Trip-interchange modal choice model.

The other principal type of modal choice model is termed trip interchange model, because it seeks to split each trip-interchange volume between the available modes.

The choice or "split" between two modes is seen in this model as a function of four variables which describe both the transportation alternatives between each pair of zones and the socio-economic characteristics of the people who avail themselves of the alternatives (Dickey, 1975). These variables are :

i. relative travel time (TTR)
ii. relative travel cost (CR)
iii. economic status of the tripmaker (EC)
iv. relative travel service (L)

TTR represents the ratio of the door-to-door travel time by public transport to that by car.
CR represents the ratio of cost of the trip by public transport to that by car.
EC represents median income per worker in the zone of trip production.
L represents travel time ratio, other than "in-vehicle-time"

Having interpreted these variables in a definite manner, regression analysis might be utilised to relate the two variables of public transport share of trips and relative travel time (TTR). These were then constituted within each discrete stratification of CR, L and EC, and graphically presented in form of diversion curves (see Figure 2.3).

2.6.4 Comments on modal choice models.

The division of trips between the modes of transport available can be done before, or after, the distribution stage. In the former case the effect of transportation system efficiency on mode choice is lost and in the latter case movements between zone pairs cannot normally be affected by mode characteristics (OECD, 1974). A potentially fruitful approach may be based on economic background and historical behaviour of traveller in mode choice and consequently predicting the percentage share of public transport. In this consideration, relevance will have to be given to the level of service provided by each mode.

2.7 TRAFFIC ASSIGNMENT.

2.7.1 Introduction.

Traffic assignment constitutes the final stage in the travel forecasting process. This step involves the allocation of the distributed volumes of trips, by mode, to individual network links. It represents the choice of routes for a fixed journey between a pair of origin and destination points (or zones), to minimise certain criterion. This criterion may be distance, time, cost, convenience, or some other quantity - or indeed some quality - which is difficult to quantify. It is also possible to use as the criterion, "generalised cost", which depends on a certain combination of each of the individual variables.

Results of assignment calculations provide data for reviewing traffic flow, network efficiency and evaluation of the location of present and proposed transportion facilities together with economic feasibility of proposed changes in the network, etc.

The assignment of each vehicle journey to a route through the road network is a process which can be performed in many different ways. Three techniques are described : (1) all-or-nothing, (2) multipath and (3) capacity restrained assignment.

2.7.2 All-or-nothing assignment.

The basic principle of all-or-nothing assignment is that all drivers will follow the shortest route from origin to destination and no drivers will follow any other route. When two or more equally short routes exist for a journey, then all traffic making in that journey is divided equally between the routes.

The principle of all-or-nothing, introduced by Wardrop, 1952, and its popularity in the fifties, was due to its simplicity in concept and application. However, this technique often leads to unrealistic over and under loading on some links, so the concepts of multipath and capacity-restraint are evolved.

2.7.3 Multipath assignment.

The multi-path technique of traffic assignment has been developed from the "all-or-nothing" method to allow for the effects of driver perception, and for almost equally short routes. The method consists of a sequence of "n" all-or-nothing calculations (iterations), each constructing its trees on the network with a (different) unique set of journey units. Each load is a proportion of 1/n of the total traffic to its shortest path, traffic flows on each link, and are formed by the accumulation of journeys passing along the links each time they are part of a tree.

Journey unit values given in the original road network description for each pair of adjacent links and are taken as being the mean values of distribution of journey units. For each all-or-nothing calculation in the sequence, a particular journey unit value is selected by random sampling from each distribution. This sampling process produces some values greater than the mean and some less with a tendency to give a unique set of journey units for each iteration.

The most commonly used distribution is either "normal", with a spread of values defined by its standard deviation, or "rectangular" with a spread defined by its range. Actual value of the standard deviation or range may be constant for all distribution set, or it may be stated as a constant percentage of each distribution mean value. The assignment of traffic to a road system by multi-path technique implies that each section of road has an infinite capacity. To improve the realism of the calculation, the capacity-restraint method is introduced.

2.7.4 Capacity-restrained assignment.

Different approaches are used to relate the amount of flow on each link with expected speed at that volume through "speed-flow" relationship, using an iterative method to adjust link time for the next iteration.

The method used in the University of Strathclyde is as follows :

If "n" iteration is specified, then $\frac{1}{n}$ of the traffic from each origin is assigned in each iteration. To apply the speed-flow relationship correction for the next iteration, the flow actually assigned to a link is "projected forward" to the end of the calculation. The object is usually to reach a stable result for all links in the network while using the smallest number of iterations possible.

One of speed flow relationship is formulated by the Bureau of Public Road (Assignment Manual, 1964).

$$TN = T_o \left[(1+0.15(V/C)^4\right] \qquad 2.13$$

in which

TN = the link travel time at the assignment volume

T_o = base travel time at zero volume, and

T_A = $T_o + (T_N - T)/4$

Where T_A is the adjusted travel time for the next iteration (only one quarter of the adjusted difference is applied to minimise oscillations in loading through successive iterations.

In Britain, Department of the Environment, introduced a speed flow relationship for use in transportation studies as follows :

$$V = \frac{Vc}{1 + \frac{Vc}{8L}(E-1)} \qquad 2.14$$

where

V = speed at demand flow, Q, which is greater than Qc the limiting capacity pcu/h/lane (km/hr)

Vc = speed at limiting capacity Qc (km/hr)

L = linke length (km)

E = $\frac{Q}{Qc}$ where Q is the demand flow (pcu/h/L)

Different classifications are made for rural, suburban and urban roads, and the resulting relationships can be presented graphically (see Figure 2.4 for urban area).

2.7.5 Comments on assignment techniques.

In general, all the techniques discussed in this section have been based on assignment to a minimum path through a network. The assignments are founded upon the hypothesis that the basis of route choice is a consideration of travel time only.

The simpler all-or-nothing assignments generally show problems of instability and lack of realism in that a very small difference between two alternative routes produces a mass switching to the shortest route. Although the other methods, multipath and capacity restraint, produce certain refinements in the assignments procedure, they also introduce some artificiality into the process. Their structure of simulation makes the procedure of calibration less valid than is the case in other models.

A new method suggested in this study for assignment technique provides a better understanding of the characteristic unit of route choice.

2.8 SUMMARY.

Large-scale computerised models form the glamourous end of demand forecasting and have accordingly attracted a great deal of attention. However, these models rely on behavioural hypotheses which are often much cruder than the apparent sohpistication of the main model. The calibration process, no matter how carefully carried out, rests on very simple assumptions such as the propensity to travel, modal choice, etc., and are related to a small set of easily measured factors. Some assessments of the reliability of these assumptions can be achieved by examining their stability through historic time, (Bayliss, 1977). The sophistication of model technique is questionable until the behavioral basis is strengthened. This requires very careful in-depth analysis of travel behaviour of different types of people, in different circumstances and their response to change in transport service quality as well as their own income.

Moreover, this in-depth research reaches the point where land use/transport models, single mode demand models and measurements of elasticities of demand come together. Its success therefore contributes not only to the better performance of different families of models but to their linkage and therefore towards a generalisation of the theory of transport demand.

A research group of the Organisation for Economic Cooperation and DEvelopment (OECD) prepared a report in 1974 on the possibilities for improvement and simplification of urban traffic models. The classical type of detailed transportation study takes too much time and money. It involves the collection and analysis of large volumes of data and the running of complex and costly computer models. This process is unwieldly, inflexible, slow, and it is not certain that the level of detail and accuracy is well matched to the planning phases concerned. The OECD stated that <u>simple</u> and <u>reliable</u> traffic models are urgently needed(Leibbrand, 1977).

CHAPTER 3

THE ECONOMICS OF TRAVEL, 1
DEMAND FOR TRAVEL

3.1 INTRODUCTION.

Basically any demand for travel from the need to fulfil consumers satisfaction. Trips are usually intermediate goods, which are jointly demanded with other economic goods. The trip then forms an integral part of some larger activity such as shopping, work etc. (the usual trip-purpose classification presented earlier in Chapter 2).

In the economic sense, demand is the quantity of a commodity or service which consumers wish, and are able to buy at a given price in a given period. Demand in economics thus goes beyond the every day notion of 'desire' or 'need' and unless the desire is made effective by ability and willingness to pay it is not 'demand'.

"The amount of a commodity that a consumer will be prepared to buy in a given period depends upon the price charged, the quality of the commodity, the service supplied with it, the price of related (substitute or complementary) commodities, his preferences between alternative commodoties, his income and his expectation (of future income and prices)". (Seldon and Pennance, 1975). To relate quantity demanded to so many variables at once it not practicable. The economist therefore attempts to isolate what he considers (either intuitively or from observation of events in the market) to be the most important variable and to relate the quantity of demand to any change in it, assuming all other things constant. In this way demand is generally expressed in relation to price. Observation of the behaviour of buyers in the market then yields the following basic generalisation, or the law of demand" "That is, the greater the amount to be sold, the smaller must be the price at which it is offered in order that it may find purchasers; or, in other words, the amount demanded increases with a fall in price, and diminishes with a rise in price" (Marshall, 1920). But demand can also be expressed as a function of income, service, quality, etc.

The movements of people within an urban area can be regarded as an economic good. The consumption of travel activities necessarily requires an allocation of scarce time and money resources. Although transport studies have recognised the economic nature of travel, they have in general, neglected the analytic techniques of economics. "The principle of economics, which provide explanations for other economic phenomena, should also apply to consumer behaviour in urban travel", (Walter and Shuldiner, 1967).

According to the law of demand, every fall however slight in the price of travel (for car, pence/Km) will, all other things being equal, increase the total travel distance of a household, and consequently the number of trips will increase. Obviously this phenomenon must be reflected in trip generation models.

It is instructive, and helpful, to express the law of demand in a graph. If price is measured vertically (on Y axis) and quantity horizontally (on X axis), then if the price is assumed to change continuously by small amounts, the law of demand given above would yield a smooth "demand curve", falling from left to right indicating that the lower the price the larger the demand. Diagram 3.a

3.2 ECONOMIC ANALYSIS OF TRAVELLERS' BEHAVIOUR.

The individual, in order to engage in some activities, is forced to spend some of his time in travel to work, to shop etc., and unless he walks, he must lay out money cost as well as time. The combination of time and money costs of travel is usually termed the "generalised cost" of travel.

"The time and the money, or generalised cost, which has to be spent travelling to engage in an activity or purchase of commodity, forms part of the price of the activity or commodity, just as much as the direct money outlay involved when the destination is reached and the activity enjoyed or commodity bought. This implies that the price of the activities the individual may wish to engage in, or commodities he may wish to buy, has two components :- first, that of access to them and second, the price at the destination", (Harrison, 1974).

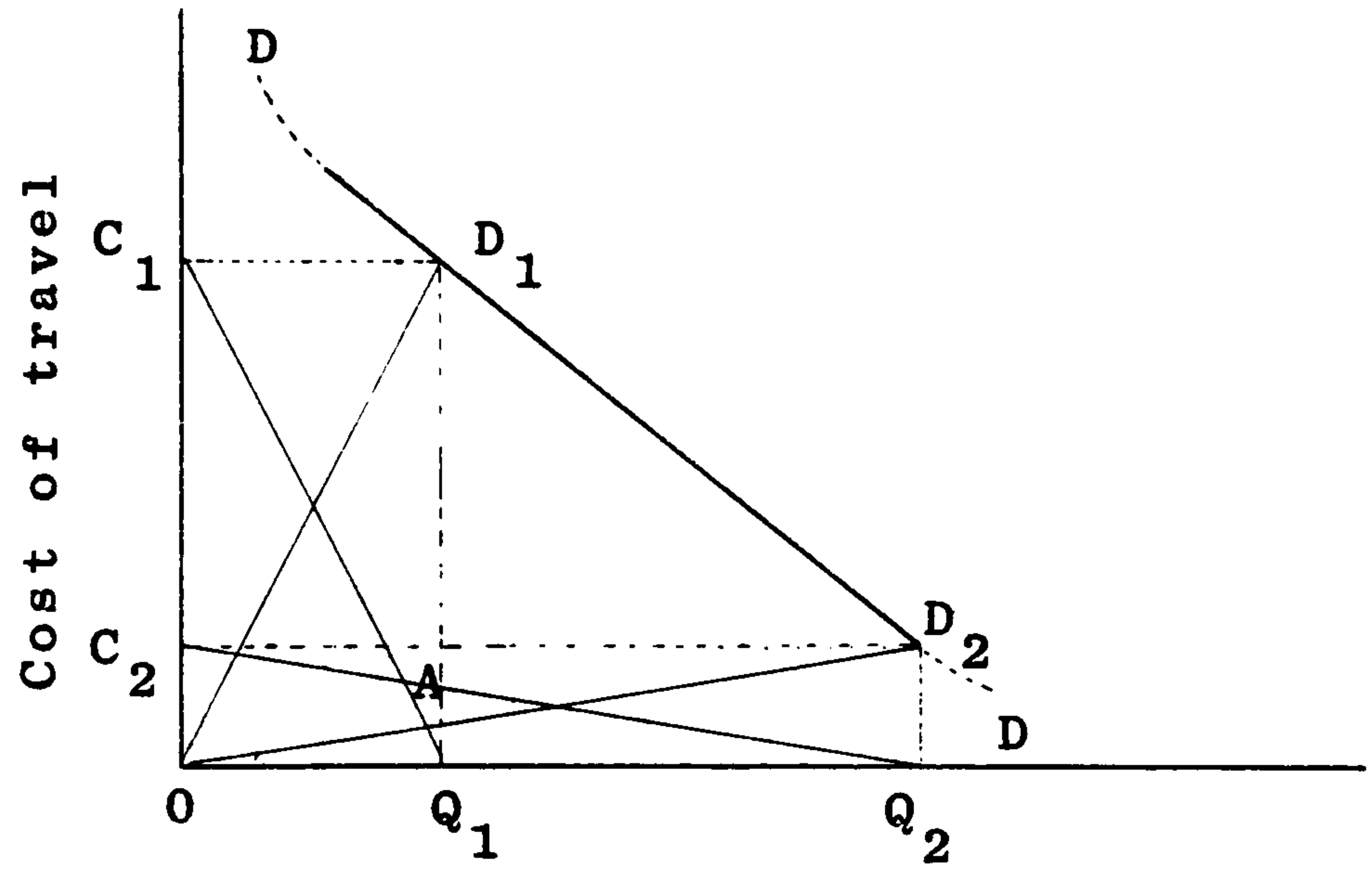
Generalised cost of travel can be reduced by investment in a facility such as a road which reduces journey times as well as money costs of travel. For the traveller two basic consequencies follow:

(1) Because the generalised cost of his existing journeys are reduced, the income of the consumer is directly increased either by an increase in the money he has available to spend on other goods or services (if money costs have been reduced) or indirectly by an increase in the time he has available (if journey has been speeded up). This can be used to generate more income if additional employment opportunities are open to him. The time saved can alternatively be spent on activities which yield "utility" (utility in economics is the power of a commodity or service to give satisfaction by meeting a want) directly to him.

(2) The relative prices of the various commodities or activities to which he allocates his time and money are altered, because the components of their price to him consists of the generalised cost of travel which has changed. In general he may be expected to shift his behaviour in favour of those activities the price of which, in terms of generalised cost of access to them, has fallen most. That is, he will tend to change his travel pattern in favour of activities which are at further distances from his location, from activities he formally carried out at or near home. The frequency, destination and the length of the trip he makes will be increased as a result.

3.3 THE MEASUREMENT OF BENEFITS.

In diagram 3a the demand curve DD drawn for convenience as a straight line, shows the quantity of travel demanded with price.



Quantity of travel

Demand curve

Diagram 3.a

At high prices very little transport would be demanded, and most activities would be carried out at home or within a very restricted radius which would often need only a walking trip (walking trips according to the definition put forward in transportation planning process are not considered as "trips"). As cost falls, demand for travel generally increases and journeys become longer and more frequent, reflecting the various adjustment of the traveller's behaviour .

A measure of the effect brought about by a road improvement can be defined by considering how a change in level of generalised cost from C_1 to C_2. This leads to an increase in the quantity of travel demand from Q_1 to Q_2.

A classical study of "consumers' surplus" is generally associated with the name of Alfred Marshall (Marshall, 1920) who defined the measure of a consumers' surplus as "the excess of money a consumer is willing to pay over the amount he does in fact pay". In this example, the area $C_1D_1AC_2$ represents the consumers' surplus. In Cost - Benefit analysis this area is usually regarded as a direct benefit due to reduction of cost from C_1 to C_2,. It represents a fall in the generalised cost of travel currently being carried out on those trips made before the cost change. The second component area $D_1A D_2$ corresponds to the second type of response to a change in generalised cost, the various shifts of behaviour of those activities which involve more travel, longer trips, more frequent trips or new trips (generated trips). The amount of benefit gained per vehicle kilometer travelled is not the same for this source of benefit as it is for the first. The amount varies, just to the right of the point D_1, in Diagram 3a, the extra unit distance of travel induced by the reduction in generalised cost lead to a benefit, but as a point D_2 approached, the benefit diminishes until at point D_2 it disappears entirely. The average benefit thus can be seen to be half the cost change.

The quantity of travel demand can be considered in terms of number of trips or total distance travelled for the consumer while generalised cost can be expressed in terms of pence/km.

3.4 ELASTICITY OF DEMAND.

3.4.1 Introduction.

The rate at which the quantity demanded changes in response to changes in any of the determining factors is described in terms of a series of elasticity concepts. Alfred Marshall, 1920, introduced the concept of elasticity of demand into economic theory. He said that "the elasticity (or responsiveness) of demand in a market is great or small according to the amount demanded increases much or little for a given fall in price, and diminishes much or little for a given rise in price".

3.4.2 Price Elasticity.

The price elasticity of demand (e_p) may be expressed according to the above definition as :

$$e_p = \frac{\text{proportionate change in amount demanded}}{\text{proportionate change in price}}$$

$$= \frac{\text{change in amount demanded}}{\text{amount demanded}} \div \frac{\text{change in price}}{\text{price}}$$

in Diagram 3.a

$$e_p = \frac{Q_1 - Q_2}{Q_1} \div \frac{C_1 - C_2}{C_1} \qquad (3.1)$$

This formula in fact gives the point elasticity of demand on the demand curve, which measures the effect on the quantity demanded of an infinitesimally small change in price, if p = price and q = quantity demanded, the general shape of the formula is :

$$\text{elasticity of demand} = \frac{dq}{q} \div \frac{dp}{p} \qquad (3.2)$$

for very small changes in price, with elasticity over a small (strictly infinitely small) range of the curve. The formula for measuring point elasticity of demand gives reasonable answers only if the changes in price and quantity are not too large. However, it is sometimes required to measure elasticity of demand over a substantial range of a demand curve, because a fairly large change in price has occurred. "A second formula for elasticity of demand is therefore used, which allows us to measure what is known as "arc" elasticity of demand. It measures elasticity of demand over a range, or an arc, of a demand curve". (Stonier and Hague, 1975), like the range of D_1D_2 in Diagram 3.a. The second formula is :

$$\text{arc elasticity of demand (e)} = \frac{Q_1 - Q_2}{C_1 - C_2} \times \frac{C_1 + C_2}{Q_1 + Q_2} \qquad (3.3)$$

This formula actually gives the average of the old and new prices and the average of old and new quantities. It will be noticed that elasticity of demand should be represented by a nagative number because $Q_1 - Q_2$ is negative.

3.4.3 Significance of Elasticity Measures.

In formula 3.3

$$e = \frac{Q_1 - Q_2}{C_1 - C_2} \times \frac{C_1 + C_2}{Q_1 + Q_2} \qquad (3.3)$$

Assume e = -1.

then

$$-1[(C_1-C_2)(Q_1+Q_2)] = (Q_1-Q_2)(C_1+C_2)$$

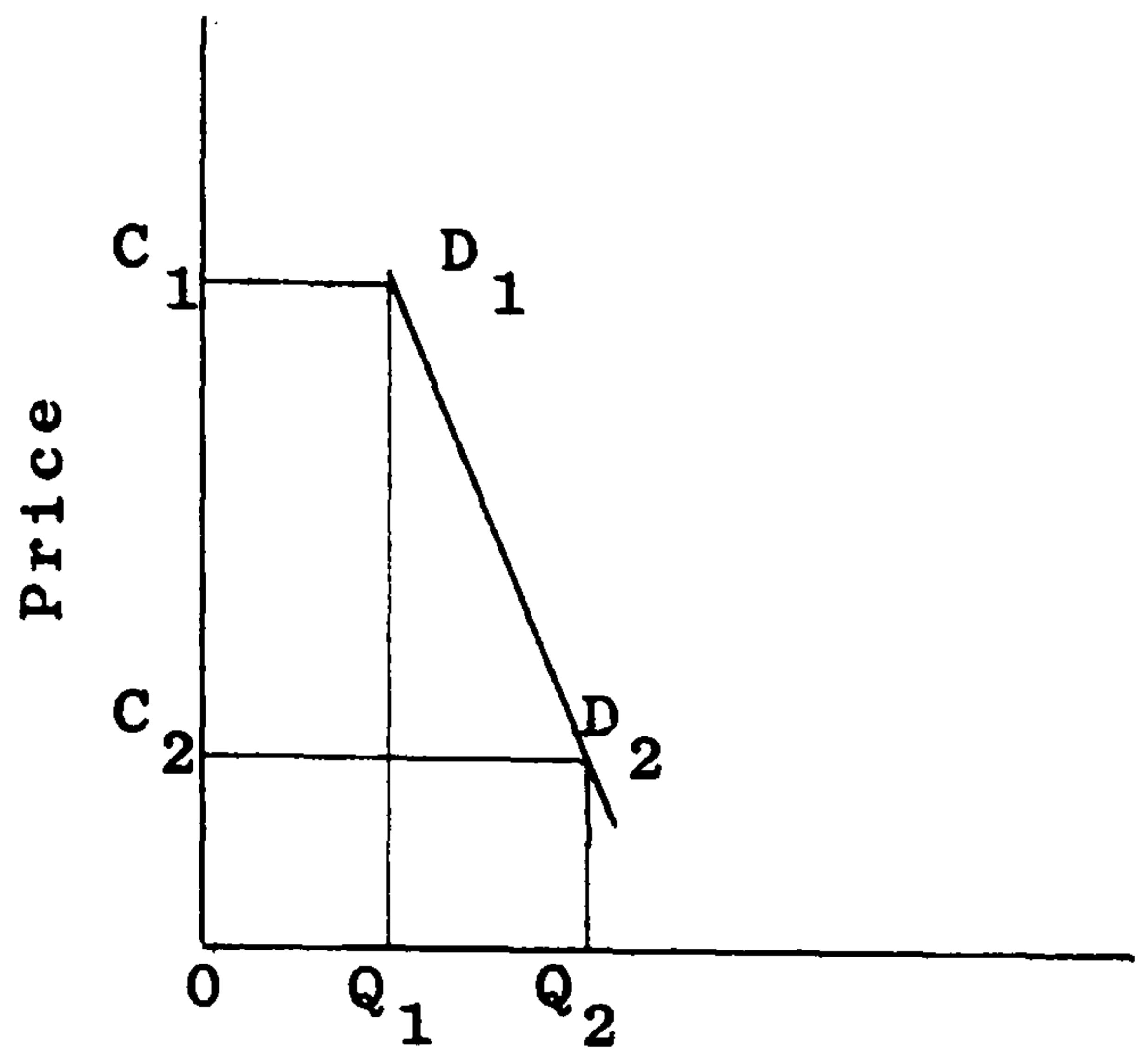
the formula can be reduced to :

$$Q_1C_1 = Q_2C_2 \qquad (3.4)$$

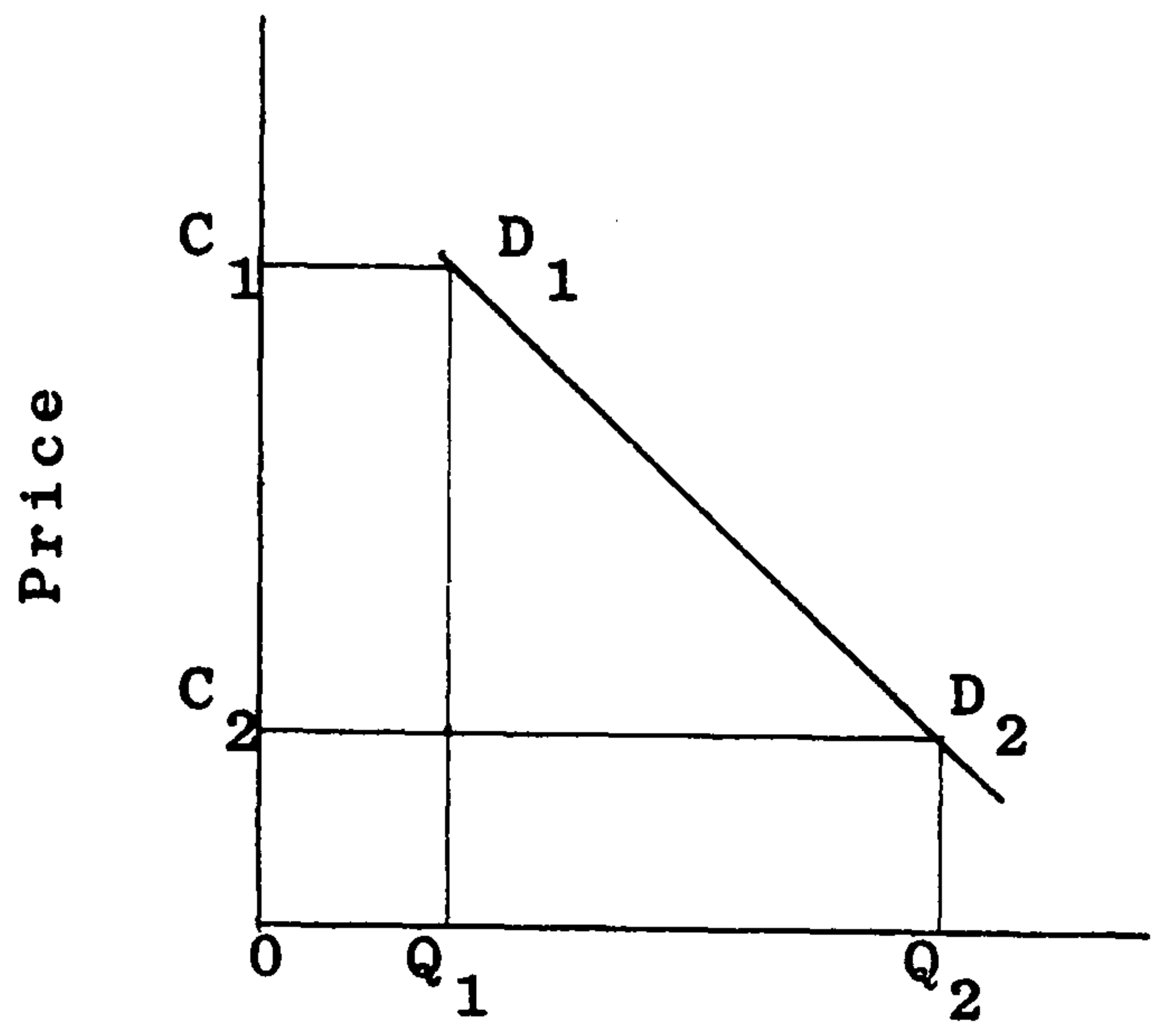
This means that the rectangles $C_1OQ_1D_1$ and $C_2OQ_2D_2$ inscribed under the demand curve are both of exactly the same area, as shown in Diagram 3'.a. Looking at the economic significance of these rectangles, it is clear that the area of such a recti-angle shows total expenditure, or total outlay, on the comm-odity at the price in question. In other words, it means that the percentage change in quantity demanded is just equal to the percentage change in price which gives rise to it. Otherwise elasticity would not be unity. Consequently, the total expenditure before equals total expenditure after.

In formula 3.4 there are only two other poss-ibilities;

1. $$Q_1C_1 > Q_2C_2 \qquad (3.5)$$



Case 1



Case 2

Demand curve

Diagram 3.b

In Diagram 3.b, Case 1 represents this condition given by formula 3.5. The total outlay <u>before</u> is more than total outlay <u>after</u>. The fall in price from C_1 to C_2 led to a small increase in quantity demanded, or the proportionate change in quantity demanded is less than proportionate change in fall in price. This implies that elasticity of demand is less than unity. In economic terms the demand is "inelastic".

2. $$Q_1C_1 < Q_2C_2 \qquad (3.6)$$

Case 2 represents this condition given by formula 3.6. The total outlay <u>before</u> is less than total outlay <u>after</u>. The fall in price from C_1 to C_2 led to a large increase in quantity demanded. In other words, proportionate change in quantity demanded is larger than the proportionate change in fall in price. This implies that numerical elasticity of demand is more than one. In economic terms, the demand is "elastic"

To sum up the relationship :

"Whenever numerical elasticity of demand for a product is greater than one, a reduction in its price will increase total expenditure (outlay) on that product. Whenever numerical elasticity of demand for a product is less than one, a reduction in its price will reduce total outlay on it. And, whenever numerical elasticity of demand for a product is exactly equal to one, a reduction in its price will leave total outlay completely unchanged. It follows at once that similar relationships will hold for increase in price. If the price of a product is increased, then total expenditure on it will fall if elasticity of demand is greater than one, but will rise if elasticity is less than one. Again, total outlay will remain unchanged if elasticity of demand is just one (Stonier and Hague, 1975).

3.4.4 Income Elasticity of Demand.

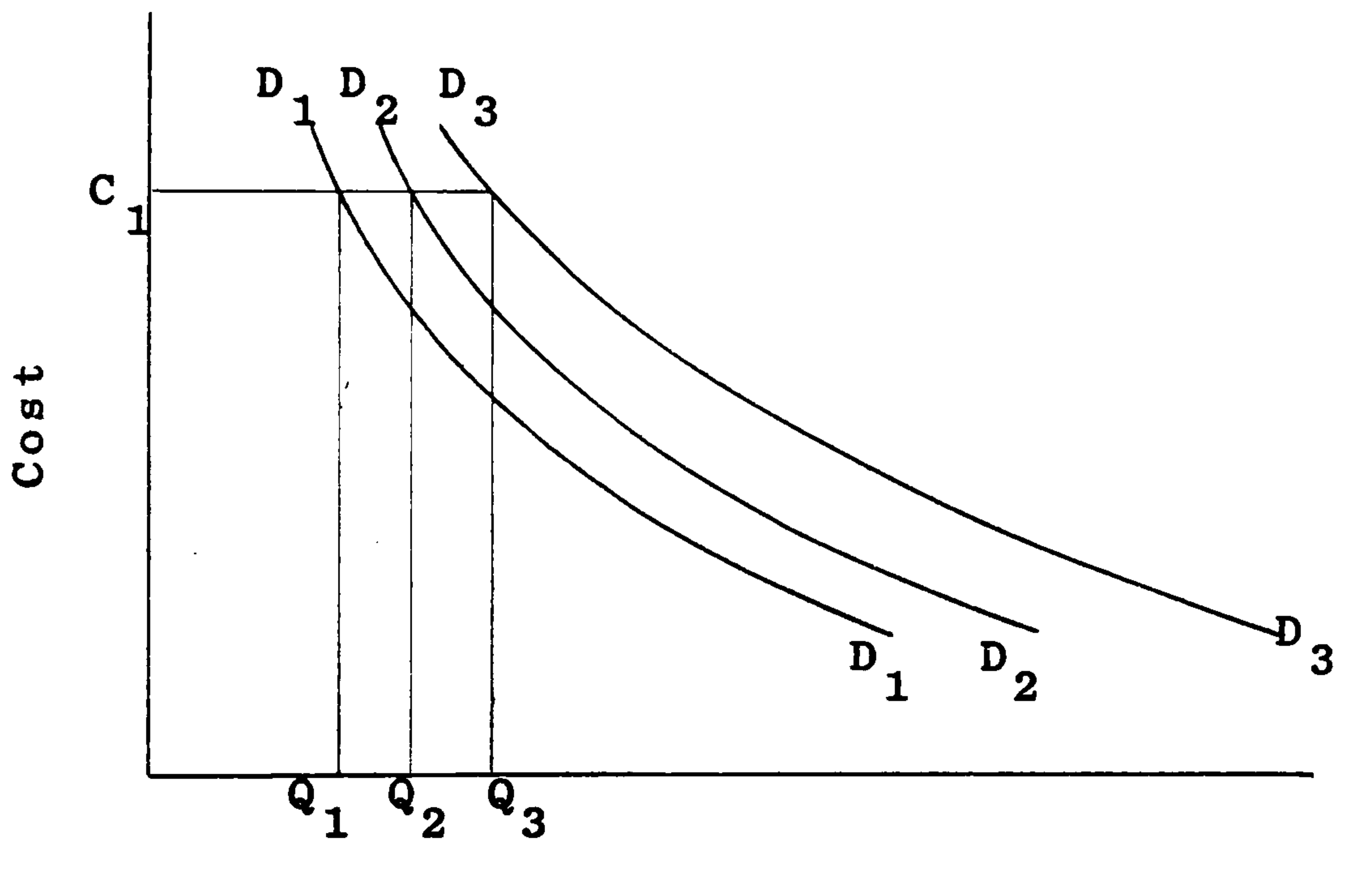
Income elasticity of demand may be defined analogously to the price elasticity as :

$$e_i = \frac{dq}{q} \div \frac{dy}{y} \tag{3.7}$$

where y is income and q is quantity demanded per period of time (Gwilliam and Mackie, 1975). The latter also stated that the income elasticity of demand for person movement is relatively high. This is partly because transport services themselves, and particularly the more expensive forms of transport, are viewed as a luxury and the consumption of which, by definition, increases more than in direct proportion to increase in income. However, it is partly because the demand for person movement is derived from the demands for other luxuries such as residential locations far removed from work places, recreational visits to distant parts and so on.

3.5 DEMAND AND INCOME.

Generally, personal money incomes take the form of, and are measured by, wages, salaries, interest, profits, dividends and rent. For any household, income represents the total earnings of all its members. If income rises a consumer will tend to buy more of a commodity than before. In a graph, this relation would be represented by a shift of the whole demanded curve to the right. Diagram 3.c represents three demand curves, for low, medium and high income levels. A commodity demanded at any given price, by each income group, is shown by Q_1, Q_2 and Q_3 respectively.



Demand curve for income groups.

Diagram 3.c

An apparent contradiction is "inferior goods", which is defined as "the consumer consumes less when he is becoming richer". However, transport services themselves, particularly the more expensive forms of transport as mentioned earlier, are viewed as a luxury.

Income significantly affects the total amount of transport consumed at any given service level. "The higher the income level, the greater the number of trips made" (Gwilliam and Mackie, 1975). The latter also stated that the effect of income on trip generation can be viewed as consisting of two components :

1. The average number of trips per household per day increases with income increases both for car-owning and for non car-owning households (see Figure 3.1.a)

2. For any given level, the number of trips per car-owning is greater than that of a non car-owning household, as shown in Figure 3.1a. But, as Figure 3.1b shows, the proportion of car-owning households, with the higher trip generation rate, also increases with income. Accordingly, in this study the household as a unit of trip generation is classified into a number of income groups (Section 5.2.1).

3.7 VALUE OF TIME (VOT).

3.7.1 Introduction.

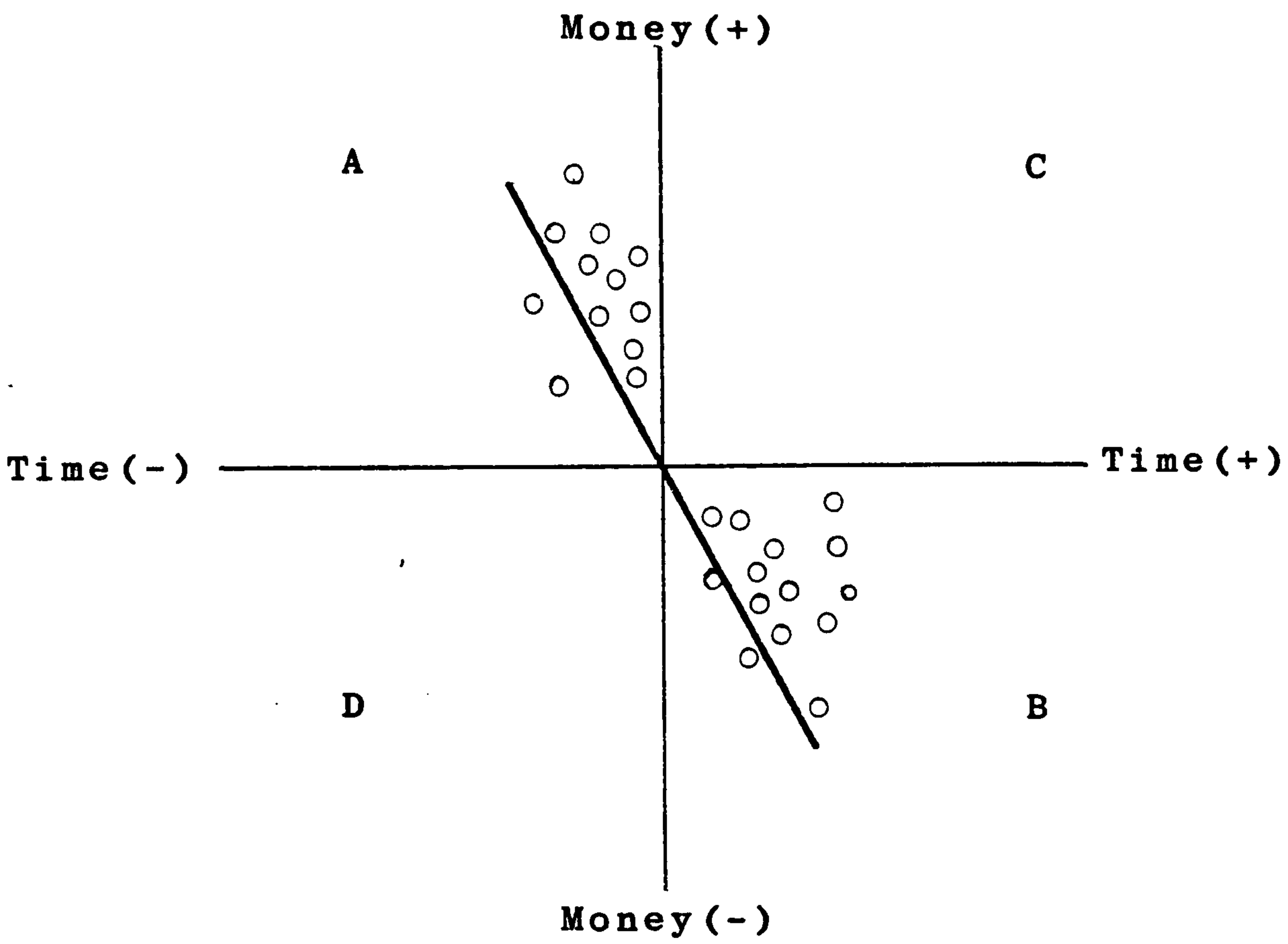
Time as a resource, is part of generalised cost of travel. To express generalised cost in a single index of cost, it is necessary for weighting to be given to time, or value of time, expressed in money terms. This section will be devoted to describing methods used in analysing the value of time and its use in transportation study.

3.7.2 Methods used in Evaluation of Time.

Many mode choices have a value of time implicit in them. One example that has been much studied is the choice between a slow cheap mode and a faster expensive mode. If a person in such circumstances chooses to pay x pence to save y minutes, then he is revealing an implicit valuation of his time of at least x/y pence per minute.

Most British studies have tried to explain the choice of travellers by equating time to money value. Usually, because of the problem of data checks, attempts have been confined to commuter's behaviour. This situation offers a number of advantages for estimation purposes. This is beacuse travellers are repeating the journey regularly and may therefore be fairly well informed concerning the alternatives. Genuine time/money trade-off situations frequently occur.

The technique used by Beesly (1965) in the analysis of the journey to work was by plotting on a graph the cost in money and time for each traveller showing the advantange or disadvantage of the chosen mode as in Diagram 3.d .



Save (+)
Pay extra (-)

Diagram 3.d

The travellers for whom the quickest mode is also the cheapest appear in quadrant (C) of the graph. For others, however, the quickest will be more expensive than the alternative. If they choose the cheaper, they will fall in quadrant (A).

An inspection for the best estimate of the value of time is easily undertaken on the graph. The slope of a straight line through the origin in quadrant A and B gives a "trade-off" rate of value of time. To be explained as rational, individuals need to be to the right of the line in both quadrant A and B.

Other studies of the value of non-working time shows that the value of time saving is related to income "falling between 15% and 50% of the average wage rate for the group" (Gwilliam and Mackie, 1975). It is generally agreed that the level of income will affect the choice of travel mode, the income variable has been handled in modal choice either by substratification or as variables.

3.7.3 (VOT) in Cost-benefit Analysis.

Cost-benefit analysis can be defined as an aid to decision making in the public sector; it attempts to make economic assessment of projects for which the market mechanism may not provide an optimum allocation of resources because of difficulties of deciding who the beneficiaries are and to what extent they benefit. The cost benefit analyst attempts to enumerate and evaluate benefits to those who may accrue such benefit and apportion costs to those who are deemed should pay. An agreed criterion is then used to make an economic judgement on individual projects or to rank projects according to their economic worth.

COBA is a method frequently employed by The Department of Environment (DOE) in the U.K., for economic evaluation and appraisal of highway schemes. They state that:- "The returns to the community which are measured to set against the capital costs are simply the cost savings to the road users, which are divided into three components, viz., time saving, savings in the costs of vehicle operation and savings in accidents. By comparing the overall characteristics of the new road with what it has superceded, the relative distances and travel speeds (hence vehicle operating costs and time saving) are obtained, together with the expected accident saving, over a whole year. Of these three components of the total benefit, the most important generally is the time saved by travellers. For the typical scheme this constitutes something like 60% of the total benefit" (COBA, 1973).

Consequently, upon the application of Cost Benefit Analysis, as enunciated by (DOE) 1973, a more recent analysis into the amount of time ~~saving~~ indicated that: "All time savings are taken to be of value and are divided between working and non-working time. On average, 80% of the quantified benefits from a typical trunk road scheme are derived from time saving. If working time is saved, it is assumed that opportunity arises for extra productive activity which is of value to society as a whole. If leisure time is saved the benefits accrue to the individual, in as far as he finds this extra time of value to himself, it is counted as a social benefit in the analysis", (Leitch, 1977).

Working time is valued at its cost to the employer. This equates the employer's cost with the value of the extra output he gains from the employee. Thus savings of working time are assumed to be used by the employer in extra output. So a certain percentage of vehicle occupants travelling in working time must be estimated.

Whilst the value of working time is based on the gross wage rate of employees, no direct market values exist for non-working time savings. These encompass a wide range of activities from travel to work, shopping, leisure etc. The values adopted are therefore based on observation of peoples behaviour, on the view that in their day to day decisions they implicity reveal a valuation of their non-working time as described in Section 3.7.2.

In a sensitivity analysis of COBA carried out in the Leitch report the results of increasing and decreasing working time values by 20% are shown. The impact on scheme evaluations is fairly uniform and is significant. It follows from this that the values in use should be as accurate as possible and that the search for a correct figure has a practical importance.

Table 3.a shows the values of working time used by DOE for 1976 as revealed in the Leitch Report. These values are assumed to grow over time in line with increases in Gross Domestic Product (GDP) per head.

Table 3.b is the value of non-working time as percentage of wage rate, presented by Watson, 1974 for different studies.

Table 3.a

Values of Working Time

(Pence per hour : 1976 prices)

Working time	Value
All workers	333
Car drivers	379
Car passengers	332
Bus passengers	196
Rail passengers	407
Underground passengers	360
Bus drivers	191
Bus conductors	182
HGV occupants (1)	178
LGV occupants (1)	158

(1) Excludes HGV and LGV drivers who are classified under "all workers" Source, Report of the Advisory Committee on Trunk Road Assessment (Leitch Report, 1977).

Table 3.b

Value of non-working time as % of wage rate.

Study	(VOT)as % of wage rate	Method of Analysis
Beesley	31-37 lower income 42-50 higher income	Time-cost trade-off behaviour.
Stopher	42	Logit analysis
Quarmby	21-25	Discriminant analysis
L.G.O.R.U.	53.5	-
E.G.A.M.S.S.	67.5	Logit analysis

After Watson, 1974.

The value of non-working time quoted by Harrison and Quarmby (1970) in some countries were as follows :

American Study by Lisco 40-50% of average hourly income

French Study 75% of wage rate

values from other studies presented by Hills (1976) are shown in Appendices -3- and -4- . However, it is clear from Table 3.b and Appendix -4- that either a universal value of time does not exist, or the methods used in evaluation are not suitable.

3.7.4 Time in Network Description.

The term "behavioural cost" is an expression describing the totality of "cost" or disutility incurred by a traveller in making a zone-to-zone trip by a particular mode of travel. "It is simply that cost which best explains the traveller's behaviour within the framework of the model processes in use" (McIntosh and Quarmby, 1970). The object therefore is to define a cost function and to suggest parameter values for use in studies. The form of cost function suggested by later authors is :

$$b_1 = B_1X_1 + B_2X_2 + \dots + B_nX_n \tag{3.8}$$

where b_1 is the behavioural cost of travel along a link "1" of a network by a particular travel mode. X_1, X_2 etc. are values of factors which are important in determining the overall travel disutility as it affects behaviour. B_1, B_2 etc. are the relative weights of these factors. The normal network manipulation and tree building programmes can then be used to find "cheapest" routes (using behavioural cost), instead of fastest routes as with time. Trees are "skimmed" to produce an inter-zonal behavioural cost matrix b_{ij}, instead of an inter-zonal travel time matrix. The behavioural cost matrix is then available for use in trip distribution modal split and assignment procedures.

Results of empirical works, recommended that the factors which should be included in a behavioural cost function are :- the in-vehicle travel time, walking time, waiting and transfer time, and the financial cost of travel.

The behavioural cost function for a network link is thus:

$$b_1 = B_1(\text{in-vehicle time}) + B_2(\text{walking time}) +$$

$$B_3(\text{waiting and transfer time}) + B_4(\text{travel cost}) \quad (3.9)$$

It can also be seen that B_1/B_4 is the value in travel cost unit of in-vehicle time, B_2/B_4 the value of walking time and so on. For any particular study, therefore, the task is to estimate the relative values of the parameter, B, and to decide what units to express them in. If b is expressed thus in monetary units, the cost function is in fact representing a generalised cost of travel.

3.7.5 Daily Travel Time.

Thrift, 1977, stated the following :- "Time and space are resources. We must realise that just as we use space as a resource, allocating particular portions to particular uses, so we use time as a resource allocating particular intervals to particular uses". (Thrift, 1977).

The classical time-budget approach is based on the notion that human activities take time and this activity can be measured in physical time units. And since time is a limited resource it can be budgeted and allocated etc. The time taken to perform tasks is empirically observed in various social and environmental settings, usually by asking a selected sample of people to fill in diaries for some length of time. It is then possible to make all kinds of observations and calculations on how activities are and can be performed.

In Figure 3.2 the daily path of each member of five households for different activities, work, recreation etc. is shown, while Figure 3.3 represents a typical example of an individual path moving among four places with time spent on stationary versus mobile activities in a 24 hour period. The figure thus shows the relationship between time-space path and time-budget.

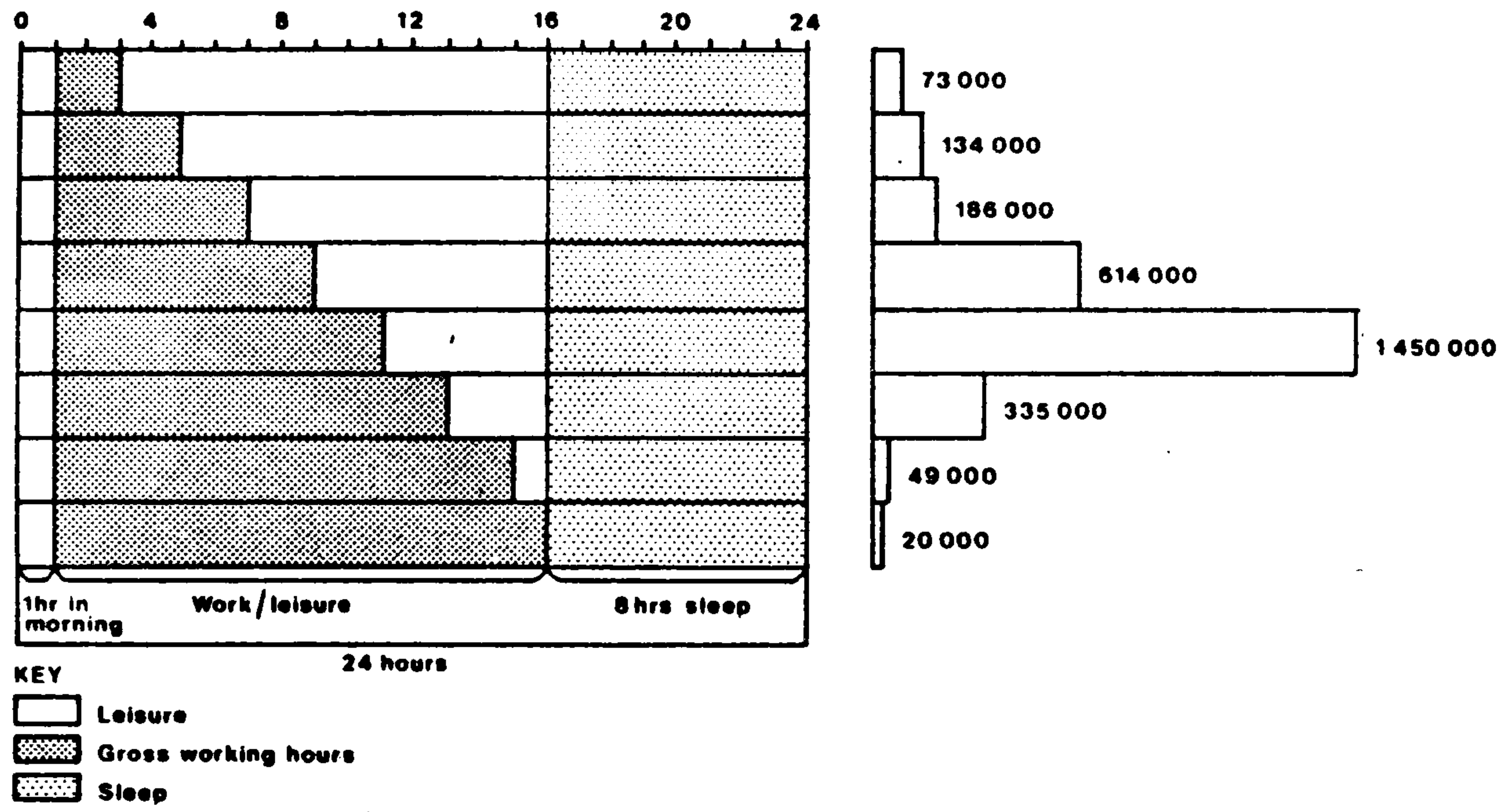
Analysis of National Travel Survey data by Goodwin, 1977, and of the National Personal Transport Study data (U.S.A.) by Zohavi, 1976, suggests that, on average, people spend about an hour per day travelling by all modes as illustrated in Figure 3.4, which refers to the U.K. data. This amount represents approximately 6% of the time available for the individual for all activities. This suggests that there is a time budget for travel, so that as journeys become quicker people travel longer distances by car or public transport.

3.8 SCARCITY OF RESOURCES.

Money and time are resources, realising that just as money used, allocating particular portions to particular uses so the time as a resource allocating particular intervals to particular uses.

The simple act of moving from some point A to another point B in space will take a certain amount of money and time (depending on the mode of travel). Work is the main source of the individual's income, "the capability constraints limit the activities of the individual through both his own biological make-up (for instance, the need to sleep) and also the capacity of the tools he can command", (Hagerstand, 1970). Other constraints on work activity are "coupling constraints". These arise because it is necessary that individuals, tools and materials are bound together at given places at given times, i.e., during working hours, and the contraints of authority which limits and controls the access. The influence of such constraints on individual activity is presented in Diagram 3.e.

While the time supply is reasonably obvious, i.e., 24 hours per day for each individual, the income supply can only be detected by analysing the statistics of income for groups of individuals at some level of aggregation. The amount of time spent on travelling, while engaged in other activities, can be assessed by asking for a selected sample of people to complete questionnaire forms with an indication of time consumed in travel; (walking, waiting and in-vehicle time). Money spent on travel can easily be calculated from statistics of family expenditure survey which usually includes transport and vehicle expenditure.



Relation between leisure, gross working hours and sleep for a Swedish wage-earner in 1968. - After Lundahl

Source : Thrift, 1977

Diagram 3.e

3.9 SUMMARY AND CONCLUSIONS.

Travel can be considered as one of a type of intermediate goods, which are jointly demanded with other goods. The trip forms an integrated part of some large activity such as shopping, work, etc.

In an economic sense, to make a trip is to buy a trip. Hence the principle of economics, as far as demand and supply is concerned (which provides explanations for other economic phenomena) should also apply to consumer behaviour in travel. According to the "law of demand" every fall in price of travel increases the total distance and consequently the number of trips will increase.

However, travel consumes not only money but time as well, improvement of transport facilities obviously will lead to a fall in both time and money cost of travel, and because these two inputs (time and money) are regarded as scarce resources, both of them must be considered in any traveller's behaviour. While the users' monetary cost of travel can be defined, the monetary value of time as a concept is more controversial and complicated.

Hills, (1976) postulated that "variations (in value of time) arise from the use of weighted and unweighted elapsed times and modified and unmodified wage rates, as well as basic differences in experimental technique. Much research remains to be done". Therefore, there is a need to find a simple concept to evaluate the saved time in a transportation study, and an attempt to do this is outlined in Chapter 6.

Income significantly affects the amount of travel consumed at any given service level. The higher the income the greater the number of trips made. In the following chapters, the household income and expenditure on travel will be analysed, with factors affecting the rate of trips, with particular consideration of the effect of petrol price changes.

CHAPTER 4

THE ECONOMICS OF TRAVEL, 2.

VEHICLE SPEEDS AND OPERATING COST

4.1 INTRODUCTION.

Vehicular speed is an important consideration in highway transport. The rate of vehicle movement has significant economic, safety, time and service (comfort and convenience) implications. Because of its major role in transportation planning, the method of speed measurement and interpretation must be clearly specified in any study. Unfortunately the means of measurement and the method of interpretation is not usually specified in many studies.

Measuring vehicular speed at a specific location of the highway is called "spot speeds". Speed characteristics obtained from spot speed studies have many applications; e.g., assessing the speed on a section of highway, in fact means giving a (time) value to that link of the network. The mean journey time attached to each link is the most important parameter in many stages of any transportation study.

Vehicle operating costs are found to be a function of speed. In this chapter such a relationship will be discussed and a detailed concept of speed and speed measurement will be presented.

4.2. DEFINITIONS : (Highway Capacity Manual, 1965).

(1) Speed - the rate of movement of vehicular traffic or of specified components of traffic, expressed in kilometers per hour.

(2) Spot speed - the speed of vehicle as it passes a specified point on a roadway.

(3) Time mean speed - the average of the individual spot speeds of all vehicles, or a specified class of vehicles at a specific point on a given roadway during a specified period of time.

(4) Space mean speed - the average of the speeds of vehicles within a given space or section of roadway at a given instant.

(5) Overall travel speed - the total distance traversed divided by the toal time required, including all traffic delays.

(6) Running speed - the speed over a specified section of highway, this being the distance divided by running time. The average for all traffic, or a component thereof is the summation of distances divided by the summation of running times.

(7) Volume - the number of vehicles that pass over a given section of a lane or roadway during a time period of one hour or more. Volume can also be expressed in terms of daily traffic or annual traffic, as well as on an hourly basis.

(8) Capacity - the meaximum number of vehicles which pass over a given section of a lane or roadway in one direction (or in both directions for a two-lane or three-lane highway) during a given time period under the prevailing roadway and traffic conditions.

4.3 TIME MEAN SPEED AND SPACE MEAN SPEED.

4.3.1 Time Mean Speed (V_t)

This can be a fixed time unit used for measurement or in interpreting the results, and it is the sum of distances on a highway traversed by a set of vehicles divided by the total (overall vehicles) of the given intervals of time needed by each vehicle to traverse the corresponding distance. Stated symolically this definition becomes :

$$V_t = \frac{\sum_{i}^{N} D_i}{NT} \quad \text{(fixed time)} \qquad (4.1)$$

where

T = Unit time of measurement or interpretation of time as a fixed unit time.

D_i = Distance travelled by vehicle i in fixed interval T.

N = Total number of observed vehicles.

$$\bar{D} = \frac{\sum_{i}^{N} D_i}{N} \qquad (4.2.a)$$

where

$\bar{D}$ = average distance per vehicle

substituting 4.2a into 4.1 :

$$\boxed{V_t = \frac{\bar{D}}{T} \quad \text{(average distance per unit time)}} \qquad (4.2)$$

For vehicle speed in groups, denoting (f) as the frequency or number of vehicles with the same speed : then,

$$N = \sum_{i}^{n} f_i \qquad (4.2.b)$$

where n is the number of groups, and equation 4.1 becomes :

$$\bar{V}_t = \frac{\sum_{i}^{n} f_i D_i}{t \sum_{i}^{n} f_i} \qquad (4.3)$$

but $D_i = t\, V_i$ (time constant) (4.3.a)

Substitute 4.3.a into 4.3 :

$$V_t = \frac{t \sum_{i}^{n} f_i V_i}{t \sum_{i}^{n} f_i} = \frac{\sum_{i=1}^{n} f_i V_i}{\sum_{i=1}^{n} f_i} \qquad (4.4)$$

equations 4.1, 4.2, 4.3 and 4.4 all give the same results, and can be applied to the data available.

4.3.2 Space Mean Speed (V_s)

"This involves fixed distance instead of fixed time so can be defined as the total of given distances on a highway travelled by a set of vehicles divided by the sum of the times all vehicles take to traverse that distance" (Dickey, 1975). Stated symbolically this definition becomes:

$$V_s = \frac{ND}{\sum_i^n t_i f_i} \quad \text{(fixed distance)} \tag{4.5}$$

where,

D = a fixed distance on a highway

t_i = time, vehicles in group i takes to traverse D.

In equation 4.5, divide both denominations, and numerator by N

$$V_s = \frac{D}{\frac{\sum_i^n t_i f_i}{N}} \tag{4.6}$$

$$N = \sum_i^n f_i \tag{4.6.a}$$

$$\bar{t} = \frac{\sum_i^n t_i f_i}{\sum_i^n f_i} \tag{4.6.b}$$

$$\therefore \boxed{V_s = \frac{D}{\bar{t}} \quad \text{(fixed distance per average time)}} \tag{4.7}$$

where $\bar{t}$ is average or mean time for all vehicles to cover a fixed distance D.

Equation 4.5.

$$V_s = \frac{ND}{\sum_i^n t_i f_i} \tag{4.5}$$

put

$$N = \sum_i^n f_i \tag{4.2.b}$$

$$t_i = \frac{D}{V_i} \quad \text{(distance constant)} \tag{4.7.b}$$

then,

$$V_s = \frac{D \sum_i^n f_i}{D \sum_i^n \frac{f_i}{V_i}} = \frac{\sum_i^n f_i}{\sum_i^n \frac{f_i}{V_i}} \tag{4.8}$$

Therefore space mean speed in reality is a harmonic mean as in equation 4.8, and the term $\frac{f_i}{V_i}$ represents the density, i.e.

number of vehicles per unit distance. On the other hand, time speed is an arithmetic mean as in equation 4.4.

The following hypothetical example makes the idea more clear :

Assume a stretch of highway is 1 km long; a observer measures the time needed for each vehicle to travel this distance by one of the methods listed in Section 4.5., the data and calculations are presented in Table 4.1., the point of interest is that, no matter what method is used in the measurements, (e.g., fixed distance in this example) to measure V_s, but as the analysis and method of interpretation shows in Table 4.1., V_t could be calculated as well.

This can be computed in the following manner : referring to Table 4.1.

Table 4.a

fixed distance 1 km for (V_s)	fixed time 1 min. for (V_t)
10 vehicles, each need 1 min time	10 vehicles, each cover 1 km distance
15 vehicles, each need 1.2 min time	15 vehicles, each cover $\frac{1}{1.2}$ km distance
20 vehicles, each need 1.5 min time	20 vehicles, each cover $\frac{1}{1.5}$ km distance
5 vehicle, each need 2 min time	5 vehicles, each cover $\frac{1}{2}$ km distance

This indicates that although the original aim was to measure a mean speed over a fixed distance of 1 km of the highway, it is possible to work out the distances which will be travelled by each vehicle in a fixed time period of 1 minute.

The point which must be stressed is that it is not only the method of measurement which must be included in reports on transportation study but also the method of analysis.

4.3.3 Relation between V_t and V_s.

General formula for variance can be written as follows :

$$\sigma^2 = \frac{\Sigma(x-\bar{x})^2}{n} \qquad (4.9)$$

$$\doteq \frac{\sum_i f_i \; X^2}{\sum_i f_i} - \left(\frac{\Sigma f_i \; X}{\Sigma f_i} \right)^2 \qquad (4.9.a)$$

where X is the variable under consideration

variance for $V_t = \sigma_t{}^2$

$$\sigma_t{}^2 = \frac{\sum_i f_i \; V_{ti}{}^2}{\sum_i f_i} - \left(\frac{\Sigma f_i \; V_{ti}}{\Sigma f_i} \right)^2$$

variance of $V_s = \sigma_s{}^2$

$$\sigma_s{}^2 - \frac{\sum_i \frac{f_i}{V_{si}} V_{si}{}^2}{\Sigma \frac{f_i}{V_{si}}} - \left(\frac{\Sigma \frac{f_i}{V_{si}} V_{si}}{\Sigma \frac{f_i}{V_i}} \right)^2 \qquad (4.11)$$

Note that f_i in space mean speed replaced by $\frac{f_i}{V_{si}}$ because of dealing with fixed distance. Equation 4.11 can be reduced to :

$$\sigma_s{}^2 = \frac{f_i \; V_{si}}{\frac{f_i}{V_{si}}} - \left(\frac{f_i}{\sum \frac{f_i}{V_{si}}} \right)^2 \qquad (4.11.a)$$

dividing both sides of equation 4.11.a by

$\frac{\Sigma f_i}{\Sigma \frac{f_i}{V_{si}}}$ yields the following

$$\frac{\sigma s^2}{\frac{\Sigma f_i}{\Sigma \frac{f_i}{V_{si}}}} = \frac{\Sigma f_i \; V_{si}}{\Sigma \frac{f_i}{V_{si}}} \times \frac{\Sigma \frac{f_i}{V_{si}}}{\Sigma f_i} - \frac{\Sigma f_i}{\Sigma \frac{f_i}{V_{si}}} \qquad (4.11.b)$$

but

but

$$V_t = \frac{\Sigma f_i V_i}{\Sigma f_i} \tag{4.4}$$

and

$$V_s = \frac{\Sigma f_i}{\Sigma \frac{f_i}{V_i}} \tag{4.8}$$

$$\therefore \quad \frac{\sigma_s^2}{V_s} = V_t - V_s \tag{4.11.c}$$

$$\therefore \quad V_t = V_s + \frac{\sigma_s^2}{V_s} \tag{4.12}$$

The relation given in equation 4.12 is originally obtained by Wardrop (1952) using a different procedure. This relation indicates that time mean speed is always greater than space mean speed unless the variance of space mean speed equals zero.

To check the relation on the data given in Table 4.1 when

$$V_t = 46, \ \sigma_s^2 = 83.05 \text{ and } V_s = 44.12$$

$$V_t = 44.12 + \frac{33.05}{44.12} = 46 \text{ kph, which is the} \tag{4.12}$$

same as computed in the table.

The existence of V_t and V_s indicates that their distributions are different, one in time (V_t) and one in space (V_s) (see Figure 4.1).

To find which mean speeds V_t or V_s can yield the original information, i.e., total time and distance covered, referring to Table 4.1.

$$V_t = 46 \quad \text{kph}$$

$$V_s = 44.12 \text{ kph}$$

fixed distance = 1 km

total time spent by all vehicles = $\Sigma f_i t_i$ = 68 mins.

Assuming mean speed = 46 kph (i.e., V_t)

50 vehicles as in in example needs :

$$\text{Total time} = 50 \frac{1}{46} 60 = 65.2 \text{ min.}$$

Using V_s = 44.12

$$\text{Total time} = 50 \frac{1}{44.12} 60 = 68 \text{ min.}$$

which is the same amount of time consumed by all vhicles.

From this it is clear that space mean speed V_s will reproduce the total amount of time and not time mean speed (V_t), and the distance is the same, i.e., 1 km for each vehicle in both cases.

4.4 THEORETICAL SPEED-FLOW RELATIONSHIP.

The theoretical speed-flow relationship is depicted in Figure 4.2 in general, speed decreases as the flow increases until the capacity flow, q_m is reached. In the congested portion of the curve, both flow and speed decrease.

Speed-Density Relationship.

Density, or concentration is defined as the number of vehicles per unit distance of the road. The speed-density relationship is presented in Figure 4.2. In general speed decreases as density increases.

Flow-Density Relationship.

In general, density increases as flow increases until the capacity of the roadway is reached. From this point on flow decreases as density increases until "jam density" is reached and flow equals zero. Figure 4.2.

A dimensional analysis of the variables suggests the following relationship : (Wattleworth, 1976).

$$q \text{ (vehicle/hour)} = v\text{(km/hour) } k \text{ (veh./km)} \qquad (4.13)$$

where

q = mean rate of flow

v = space mean speed

k = mean density

For practical purposes, however, a simple relation as discussed in Chapter 2, is presented in Figure 2.4.

4.5 MEASUREMENT OF SPEED.

The measurement of sample of vehicular speeds at a specific location is called a spot speed study. Spot speed studies are conducted to determine the speed distribution of all vehicles passing a particular location under the condition prevailing at the time of study (Kell, 1965). The data obtained usually contains information about the traffic flow, which is also needed in transportation studies.

Two major techniques are used to obtain speed data. One method consists of measuring the time required by a vehicle to traverse a measured distance. The other method utilises a radio wave reflected from the moving vehicle. The following methods are used in speed studies :

(a) Moving observer method (Wardrop,Charlesworth (1954)

(b) Registration number method (licence-matching method)

(c) Radar speed meter (TRRL, Research on Road Traffiç, 1975)

(d) Enoscope (- do -)

(e) Aerial photographs.

(f) Pneumatic tubes (Salter, 1974).

(g) Loop detectors.

4.6 VEHICLE OPERATING COSTS.

4.6.1 Introduction.

Vehicle cost estimates are used for a variety of different purposes by both central and local government, industry and research institutions. These users require such statistics for a variety of purposes, e.g., reimbursing employee's travelling expenses, economic assessment of transport projects, indices, market forecasts, etc.

These different objectives are of a very specific nature, and so cost estimates made with one of these objectives in mind may be inappropriate if used for a different objective.

The cost of operating a vehicle consists of running costs and fixed costs. Running costs are those which are a function of vehicle use and include fuel, oil, tyres and maintenance. Fixed costs are those costs which are not a function of vehicle use and include such items as insurance, and road tax.

However, the inclusion of any item into operating cost depends mainly on the objective of the analysis, e.g., whether or not fixed costs, petrol excise duty is included as a component of consumer's cost. In this study, the analysis of vehicle operating cost includes only running costs including fuel tax, for reasons which will be outlined later in the following chapters.

Three major categories of cost estimates are readily identifiable :

(a) Empirical expenditure estimates.

(b) Fixed assumptions, cost estimates.

(c) Speed related cost estimates.

Empirical expenditure estimates can take a number of forms. The most usual is a household survey, recording what a household spends on motoring broken down into various categories of capital and running costs. The latter are usually mileage related. The data collected in Family Expenditure Survey (FES) records the amount spent by each household on cars, broken down into detailed categories. Unfortunately no details of mileage is recorded.

Theoretical (fixed assumptions) cost estimates have a different conceptual base. For some price indices and when estimating the long term expenditure in costs, there is a need for a set of estimates with rigid behavioural assumptions from which an index of costs may be constructed.

Theoretical cost estimate indices will thus show how vehicle running costs are changing and the empirical surveys will show how people are reacting to such costs.

The Automobile Association (AA) publish two estimates on motoring costs which are prepared by separate departments within the Association. Since spring 1974 the AA's magazine 'Drive' has published an 'Index of Motoring Costs' based on a continuous national survey of some 1,000 motorists per month. This examines all costs except depreciation. However, more known is the Technical Service Department's 'Schedule of Estimated Running Costs'. This has been issued annually for many years. The Royal Automobile Club (RAC) also produce a similar 'Schedule of Estimated Vehicle Running Costs'. Both of these schedules are theoretical (fixed assumptions) cost estimates. However, it is argued that the fixed assumptions in these schedules means that they bear very little relation to actual expenditure on motoring (Potter, 1978), and consequently the AA Schedule over-estimates the cost per mile. The speed related cost estimated can be based on an empirical survey combined with data collected from a vehicle test, especially the relation of fuel consumption with vehicle speed. The Road Research Laboratory (RRL) issued car operating cost formula which has been widely used in transport research and will also be used in this study.

4.6.2 Fuel Consumption.

Fuel consumption per unit of distance by a vehicle in speed < 60 kph (which is the case in urban traffic flow) could be expressed approximately as a linear function of the reciprocal of the average trip speed, that is :

$$\phi = k_1 + \frac{k_2}{\bar{V}} \quad (\bar{v} < 60 \text{ km/hr}) \qquad (4.14)$$

where

ϕ : is fuel consumption per unit of distance

$\bar{v}$: is the average speed, defined as the trip distance divided by the total trip time including stop time.

k_1 and k_2 are vehicle dependent parameters (Evans and Herman, 1976) The parameters k_1 can be associated with the fuel consumed per unit distance to overcome rolling resistance and is consequently approximately proportional to the vehicle mass, i.e.,

$$k_1 = \alpha m$$

where

α : is a constant of proportionality

m : is the vehicle mass

the parameter k_2 may be associated with various time dependent frictional losses, and it is approximately proportional to the "idle" fuel flow rate. This formula indicates that to save fuel and energy requires reduction in the mass of the vehicle and an increase in the average speed.

4.6.3 Air Resistance.

Air resistance will obviously increase fuel consumption. Air resistance is composed of the direct effect of air in the pathway of vehicles, the frictional force of air passing over the surface of vehicles (including the under surface), and the partial vacuum behind the vehicle. Formula 4.15) give the air resistance force acting on a car.

$$R_a = 0.0011 \, AV^2 \quad \text{(Claffey, 1976)} \qquad (4.15)$$

where

R_a = air resistance in kilograms

A = frontal cross-section area in meters

V = speed in kilometers per hour.

4.6.4 Maintenance, Oil, Tyre and Depreciation Costs.

Maintenance Cost.

Maintenance cost includes periodical service re-required and other non-periodical items such as brakes, exhaust systems etc.

Oil consumption.

Oil consumption results from oil contamination by use and oil losses through leakage consumption.

Tyre Wear.

Tyre wear results from rolling resistance, the frictional slip between tyre surface and the road.

Depreciation.

The magnitude of motor vehicle depreciation costs can be defined as the quotient resulting from dividing the difference between original cost and scrap value by life time mileage, it depends largely on non-highway factors (new and used car market values and user travel desires).

However, there are "standing charges" such as road tax, insurance etc. which are not affected by the use, hence these factors are not reflected by vehicle operating costs (See Appendix-5 -).

4.7 OPERATING COST FORMULA.

4.7.1 Vehicle Operating Cost Formula.

The total operating costs presented by (Charlesworth and Paisley, 1952) was in the form :

$$C_o = a_o + a_1 t + a_2 t + a_3 t \qquad (4.16)$$

where

C_o = total operating costs per mile

a_o = costs per mile independent of journey time,

$a_1 t$, $a_2 t$ and $a_3 t$, represent costs of fuel, tyres and wear and tear respectively which vary with journey time.

t = journey time/unit distance.

Combining the results of various available data with assumptions about average vehicle engine capacity, a formula presented by the above was :

$$C = a + \frac{b}{v} \qquad (4.17)$$

where

C = total cost per unit distance (labour, vehicle-time and operating cost)

v = average speed

a and b are parameters, which can be found from available data for certain years by vehicle types.

The DOE has found that the function which best fits the data can be expressed :-

$$C = a + \frac{b}{v} + cv^2 \qquad (4.18)$$

where

C = operating cost per unit distance pence/km

v = average speed km/hr.

a,b and c = parameters calculated for each vehicle type. in other words, separate values are calculated for car, light goods vehicle, heavy goods vehicle and buses. However, value of time (pence/hr) can be added to the parameters (b) to calculate the generalised cost of travel (pence/km).

4.7.2 Car Operating Cost Formula.

Table 4.b gives the 1973 values of each of these parameters for cars with 1400 cc - this represents the average size of cars licensed in 1973.

Table 4.b

Item	Weight per kilometre		
	a	b	c
Fuel gross	0.41	21.4	0.000053
Oil	0.05	-	-
Tyres	0.08	-	-
Maintenance	0.45	4.1	0.000010
Depreciation etc	0.30	1.0	-
Operating cost	1.29	26.5	0.000063
Time	-	81.0	-
Generalised cost	1.29	107.5	0.000063

Note : a, b and c as expressed in formula 4.18.

Car occupant's time was valued at 81 pence per hour assuming that 16 percent of car travel was in working time and 32 percent in commuting time (Dawson and Vass, 1974), the formula for 1973 can be written in terms of operating cost as :

$$C = 1.29 + \frac{26.5}{\nu} + 0.000063\ \nu^2 \qquad (4.19)$$

and in terms of generalised cost as :

$$C = 1.29 + \frac{107.5}{\nu} + 0.000063\ \nu^2 \qquad (4.20)$$

where the terms are as defined above.

4.7.3 Fuel in Operating Cost Formula.

Referring to Table 4.b, the role of fuel consumption in the formula 4.19 expressed as percentages of fuel consumption contributes to parameters a, b and c as follows :

a = 32%

b = 81%

c = 84%

The analysis of operating cost at different speeds, and contribution of fuel cost as percentage of total operating cost shown in Table 4.c shows that the cost of fuel represents almost 50 percent of total operating cost. The fuel cost was 50 pence per gallon in 1973, and increased sharply afterwards, indicating that the percentage of fuel cost to toal running cost may be even higher. Consequently other items, oil, tyres, maintenance andeven depreciation are all subject to relative increase. The wage increase which followed after 1973 made vehicle labour and materials costs more expensive, and the net effect was that the cost of fuel as percentage of total cost remained constant at about 50 percent.

Table 4.c

Speed km/hr	Total cost pence/km	Fuel cost				Cost of fuel / Total cost %
		a	b	c	Cost/km	
20	2.615	.41	1.053	.021	1.485	56
40	2.04	.41	.521	.084	1.02	50
60	1.95	.41	.351	.190	.95	49
80	2.018	.41	.263	.338	1.011	50
100	2.413	.41	.210	.529	1.15	48

Note : the breakdown of cost formula by vehicle type is presented in Appendix -6 - for year 1973.

4.8 SUMMARY AND CONCLUSIONS.

Vehicular speed is an important consideration in transportation study. The rate of vehicle movement has significant economic, safety, time and service (comfort and convenience) implications.

Two mean speeds generally can be obtained from measurement of vehicle speeds. Firstly, time mean speed (V_t) which is defined as "average distance per unit time" Secondly, space mean speed which is defined as "fixed distance per average time".

It has been found that space mean speed is more consistent and can reproduce both original amounts of time and distance.

Vehicle running cost has been used as a function of vehicle speed. The fuel costs are found to represent almost 50 percent of total running cost at different speeds with the remaining 50 percent accounted for by material and labour. This relationship is assumed to remain stable even for higher fuel prices; for simplicity in modelling, the fuel price index is taken as being the single best measure of travel cost.

The formula given in TRRL report concerning vehicle operating cost can be used for determining cost per unit distance, mainly for private transport. However, average cost per unit distance for public transport can be found from statistical returns from public transport operator and farestructures.

Having established the cost per unit distance by modes as outlined here, the next chapter will deal with the amount of money paid by a household expressed as a cost for travel by each mode.

CHAPTER 5

THE ECONOMICS OF TRAVEL, 3

HOUSEHOLD INCOME AND EXPENDITURE ON TRAVEL

5.1 FAMILY EXPENDITURE AND INCOME.

5.1.1 Introduction.

Household expenditure usually includes such items as housing, fuel, light and power, food, drinks and tobacco, clothing, durable household goods, transport and vehicles etc. In this chapter the analysis of household expenditure on transport and vehicles will be investigated. The source of data for such analysis are the Annual Reports of the Family Expenditure Survey (FES).

The FES originates from a recommendation of the Cost of Living Advisory Committee (now The Retail Price Index Advisory Committee) in an interim report published in 1951. A large scale household expenditure enquiry was undertaken in 1975 (FES 1975). However, full reports of these have been published annually from the 1962 survey onwards. FES reports provide an important economic and social data. Information from the survey indicates how the expenditure patterns of many different kinds of household vary. It also throws light on the relationship between household income and amount of expenditure on different goods and services.

Although in this study emphasis is put on the relationship between household income and expenditure on travel, expenditure on each mode of travel is related to the attitude of travellers, which seems to be coloured by the quality of service provided by the different modes.

5.1.2 Definitions.

The definition as enunciated in FES reports are as follows :

Household.

A household comprises one person living alone or a group of people living at the same address and having meals prepared together and with common housekeeping.

Expenditure.

Any definition of expenditure is to some extent arbitrary, and the inclusion or exclusion of certain types of payment is a matter of convenience or convention, depending on the purpose for which the information is to be used. In FES reports, total expenditure represents expenditure on goods and services. Total expenditure, defined in this way excludes those recorded payments which are really savings or investments (e.g. national insurance contributions, mortgage, income tax payment etc.).

Income.

The concept of income is, as far as possible, that of gross weekly cash income at the time of interview, i.e., before the deduction of income tax, national insurance contributions and other deductions at source. Although information about most types of income is obtained on a current basis, some data, principally incomes from investment and from self-employment, is estimated over a twleve-month period.

5.1.3 Main Features of Family Expenditure Survey (FES) Annual Reports.

All types of private households in the United Kingdom are covered by the survey. In 1975 for example 11,000 addresses in the U.K. were selected. Households at the selected addresses were visited in turn and occupants asked to co-operate by providing interviewrs with information about the household, relating to incomes, certain payments which recur fairly regularly. In order to obtain a representative picture they were asked to make an expenditure record of such items for a period of 14 days.

The sample is designed so that each household has an equal chance of selection, and also so that the sample is spread evenly throughout the year. "Comparison of the results of the surveys over successive years, however, justifies confidence in their general reliability, and an examination of the characteristics of expenditure and income pattern of various groups of household shows 'a high degree of internal consistency'", (FES, 1975). Like all estimates based on samples, the results of the survey are subject to chance variations. A numerical measure of the possible margin of error, due to the limited size of the sample, is provided by "standard error". A true mean value is almost certain to lie within two standard errors on each side of the estimated mean values. The standard error on the item of transport and vehicle was 2% in FES 1975 reports.

Figure 5.1 shows variation of expenditure patterns related to incomes for the year 1975, with average household's expenditure on each individual item. Figure 5.2 shows variation of expenditure pattern over a period of time. It must be emphasised that of the two main items in household expenditure, housing, transport and vehicles are the only items which show an increasing trend over time. Transport and vehicle costs consume the highest share of income after food in average households budget.

It can be observed that household expenditure as presented in FES reports represent users cost as far as transportation is concerned.

5.2 HOUSEHOLD INCOME.

5.2.1 Household Income Groups.

Grouping of household into a number of income groups is found to be necessary because the amount of transport consumed by each group is different, as has been outlined in Chapter 3.

Household can be classified by income into different categories depending on the type of data available and purpose of analysis. However, there are two recognised methods used in transportation studies :

1. To choose arbitrarily a lower and upper boundary of each income group, with a corresponding number of households in each group.

2. To choose arbitrarily a fixed percentage of households in each income group and find their average income.

As an example of the first type, discrete income classes were used by Wootton and Pick (1967) in trip generation (Category Analysis - see Chapter 2). In the second approach used in Transport Policy (1976). The analysis of distribution of expenditure on transport by households, is by categorising households into five income groups; there are some 20% of households in each income group.

In this study, however, the latter method is used, and the income considered is the gross income i.e., before taxation.

5.2.2 Household Income Trends.

The data available from FES reports permits analysis of household income groups from 1962 onwards. However, for this study, a ten year period was chosen (1965-1975) and only four annual reports are analysed, i.e. FES reports of 1965, 1968, 1972 and 1975. It is thought that those four points in time will give sufficient information relating to both income and expenditure on travel. Furthermore, for some intermediate years checked, it is found that the results are compatible and consistency exists for the whole of the ten year period.

Tables 5.1.a, b, c and d are an abstract from FES for the years 1965, 1968, 1972 and 1975, and they are represented graphically on a semi-log scale in Figure 5.3 with (Y) as ordinate and X_1 as abscissa. From this figure, the average household income is computed, as well as average income by income groups for the years under consideration.

Despite the effect of inflation, the distribution of household incomes remain constant over the years. As income forecasting is a major contribution to the transportation planning process, this method of representation (Figure 5.3) is of considerable benefit.

Tables 5.2.a, b, c and d, extracted from Figure 5.3 stratify households into five income groups with 20% of households in each income group.

The following table shows average hosehold income and total expenditure on all items including transport and vehicle based on average weekly data..

Table 5.a

Year	Income (£)	Total expenditure (£)
1965	24.56	21.22
1968	29.88	24.93
1972	42.82	35.06
1975	72.46	54.58

Source : FES reports, 1965, 1968, 1972 and 1975,

5.2.3 Income and Socio-economic Characteristics.

I Income and car ownership.

Great promise was expected in earlier studies in using car ownership variables for traffic predictions, thus much major work was directed into forecasting car ownership.

While it became obvious in this study that car ownership is a characteristic of households as a group, related directly to the income of that group, nevertheless it is misleading to use car ownership as a measure of mobility. Furthermore, household groups with higher percentage of car ownership spend more money on travel by bus and train than households with lower percent of car ownership.

Table 5.b

Annual income (£)	Percent owning car households
500	10
1500	60
3500	80

Source : (Gwilliam and Mackie, 1975) - see also Figure 3.1

The above figures were originally abstracted from "Movements in London". Other studies by Hillman, Henderson and Whalley (1973, 1976), concluded that household car ownership was an "inadequate measure of mobility". A survey in the outer London (an area of high car ownership) produced the same conclusion (Ball and Percival, 1978).

This picture is also consistent with American cities. The following table is an abstract from the Pittsburg Area TRansportation Study (1960).

Table 5.c

Annual income ($1000)	Car/household
0-2	0.25
2-4	0.50
4-6	0.85
6-8	1.0
8-10	1.2
10-12	1.3
12-14	1.5
14 +	1.7
Average	0.9

(After Wohl and Martin, 1967)

The figures indicate that the same trend is universal, i.e., car ownership increases when income increases, and there are a substantial number of households without a car, from average figure (0.9) : Even if average equals 1.0 or more there will be households without car.

II Household composition and number of wage earners.

The following table shows the correlation which exists between these variables and income.

Table 5.d

Income Per week (£)	Person Per household	Wage earner/household
15-20	1.105	0.107
45-50	2.702	1.136
100-120	3.434	2.096

Source : FES, 1975.

The above figures show clearly that all factors which were previously regarded as important to trip generation, are in fact a function of household income. Moreover an examination of the simple correlation matrix produced by Douglas and Lewiss (1971), see Table 5.e, indicates that employees per household, persons per household andcars per household, have a highly significant correlation with household income.

Table 5.e

	Trips	Emps.	Persons	Cars	Income
Trips	1	.529	.420	.476	.505
Emps.		1	.542	.441	.685
Persons			1	.294	.431
Cars				1	.630
Income					1

Simple correlation matrix. After Douglas and Lewiss 1971.

5.3 HOUSEHOLD EXPENDITURE TRENDS ON TRANSPORT.

5.3.1 Item Classification.

In the FES, six items can be considered to cover all transport and vehicle expenditure. These items are :

Table 5.f

Item No.	
77	Net purchase of motor vehicles, spares and accessories.
78	Maintenance and running of motor vehicles.
79	Purchase and maintenance of other vehicles and boats.
80	Railway fares.
81	Bus and coach fares.
82	Other travel and transport

(Note : for components of these items see App.-7-)

These six items can be combined into five classes, comprising the main features of expenditure on transport. As referred to in this study, these are as follows :

Table 5.g

Class	Item	Reference
1	77,78,79,80,81,82	Total transport and vehicle
2	77,78,80,81	Transport
3	78,80,81	Total travel
4	78	Travel by car (private transport)
5	80,81	Travel by bus and rail (public transport)

The anlysis of the items and classes are presented in Tables 5.1.a, b, c and d and 5.2.a, b, c and d, for the year 1965, 1968, 1972 and 1975.

5.3.2 Expenditure on Total Transport and Vehicle.

This class includes all items as presented in FES reports under the name of "Transport and Vehicle". The total household expenditure on transport and vehicle as shown in Table 5.h, and presented graphically in Figure 5.4.b is as follows :

Table 5.h

Year	Money spent on transport and vehicle (M)£	(M) as % of total expenditure %	(M) as % of income %
1965	2.63	12.40	10.71
1968	3.27	13.12	10.95
1972	4.96	14.17	11.59
1975	7.53	13.80	10.40

Source : FES report.

Household expenditure on transport and vehicle

In Figure 5.4.b, Curve 1 is total household expenditure on all items of transport and vehicle as percentage of total household expenditure. The slightly increasing trend is a logical result of the last decade, resulting from the improvement and building of new roads.

Since Curve 2 is based on household income, this curve obviously falls below Curve 1, because gross income (before taxation) is more than a total (household) expenditure.

The difference between income and expenditure is supposed to represent income tax and saving. However, as commented in FES reports, the net saving cannot be measured directly from the two amounts of income and expenditure.

These two curves (1 & 2) are expressed in (£) per week. The trend here is more obvious - apart from the inflation effect - total money outlay is increasing for the period shown by the figures.

5.3.3 Expenditure on Transport.

This category as classified earlier in Section 5.3.1 includes four main items; 77,78,80 and 81 as indicated in Tables 5.f and 5.g.

Figure 5.5 shows the average household expenditure on the main four items of transport. On average about 10% of household expenditure (as percent of income) is spent on transport. If this is expressed in terms of total expenditure rather than the income, the figure will be about 13%.

Categorising household expenditure on transport by income group is shown in Figure 5.6 and the first 20% (lowest income group) trend is seen to be falling between 1968-1975. Other income groups are mostly rising in their trends, with some exceptions, especially the higher 20% income of households (group 5). This is because they spend relatively more money on travel by air compared with other income groups. Group 4 and 5 is also characterised by usage of the firms car, the cost of which is borne by the employer, and not included in household's expenditure survey figures.

5.3.4 Expenditure on Purchase of Motor Vehicle (Item 77).

The average household expenditure on car purchase for the period under study, expressed as % of household income was as follows :-

Table 5.i

Year	%
1965	3.86
1978	4.06
1972	4.57
1975	3.45

There is no significant conclusion to be attached to these figures apart from the fact that average household expenditure for this item is about 4% of the total income. This is equivalent to a large amount on a national basis, and thus has an important impact on the car industry.

This study is not considering car ownership and non-car ownership, because as discussed earlier in Chapter 3, car ownership is a function of household income (see Figure 3.1.b). The relevant relationship used in this study is that of expenditure with car travel. So the whole analysis is based on all households irrespective of whether or not they own a car.

5.4 TRAVEL BY CAR (PRIVATE TRANSPORT).

5.4.1 Expenditure on Maintenance and Running of Motor Vehicle (Item 78).

This item is the most important part of the household's expenditure, and as can be seen from (Figure 5.4) the slightly increasing trend is clear; the average figures for the period under consideration expressed as percent of household income is as follows :

Table 5.j

Year	% of Expenditure on travel by car
1965	3.89
1968	4.48
1972	4.57
1975	4.87

Item (78) maintenance and running of motor vehicles is also represented in Figure 5.3 for the same period (Y-from Table 5.1 - as ordinate and X_2 as abscissa) for the sake of comparison.

The similarity and consistency in trend between the two sets of curves, income, and expenditure on running a car for those years which are selected randomly, can be of a great help to modelling and forecasting of expenditure on travel by car. A forecast for the year 1985 of Item 78 is made on the same diagram, using the concept that increase in wages is a reflection of energy prices. In item 78 - running of a car - 50% is taken up by fuel cost and 50% by labour cost, which is indirectly a function of fuel price as outlined in Chapter 4.

In Figure 5.4.b, curve 4, shows expenditure on maintenance and running motor vehicle as a percentage of total household expenditure.

Curve 5 is the same but as percentage of household income. This curve can do a great deal in modelling car trip generation. Because of its consistency over that decade, the forecast task is to find what percent of the household's income is spent on this item for the target year. Curve 6 is a combination of these two cur s in (£).

The trend of household expenditure on running a car as percentage by income group is shown in Figure 5.4.a. The lowest income group, throughout this period (1965-1975) showed a constant decline with a falling in spending on travel by car. On the other hand other groups, mainly 2, 3 and 4 are better off and the increasing trend is clear as far as expenditure on travel by car is concerned.

Group 5 did not necessarily lie above other income groups. It almost fell below group 4 for the whole period, and from 1971 fell below group 3, and from 1973 fell below group 2.

The reason for this may be explained as :

(a) The share of group 5 in travel by car is always the highest of all the groups, in terms on money spent. Even if the above curve falls under the other groups when expressed as percent of income, the percent share of group 5 (the top 20%) is always the highest share (see Figure 5.9.b).

(b) This group is travelling more by air and first class trains, or using firm's car.

5.5 TRAVEL BY PUBLIC TRANSPORT.

5.5.1 Expenditure on Travel by Train (Item 80).

One main feature of the expenditure of the average household on rail fare is that almost a constant percent of average household income is spent on this item. These figures were as follows for the year under study:

Table 5.k

Year	% of Expenditure on rail fare
1965	.546
1968	.468
1972	.513
1975	.483

Unfortunately, not all items are so consistent and fixed as this item, as far as the average household is concerned. However, the disaggregation into five income groups still shows different trends in that period (see Figure 5.7).

But these fluctuations are around 0.1% for some income groups and it was an almost negligible amount for others.

5.5.2 Expenditure on Travel by Bus (Item 81).

The trend of the average household on travel by bus as a percent of household income for the period shown is as follows :

Table 5.1

Year	% of Expenditure on bus fare
1965	1.6122
1968	1.325
1972	1.167
1975	0.855

From these figures it appears the expenditure on travel by bus, as far as the user was concerned, declined continuously throughout this period.

As well as disaggregation into income groups, it is not surprising that the decline in each income group is clear (Figure 5.8). Moreover as was expected, the lower income groups spent more - as percentage of household income - on travel by bus than those of higher income groups, in contrast to what we have seen on travel by car and rail. However, this still does not mean that the lower household income groups are spending more money on travel by bus (Figure 5.9c).

5.6 PERCENTAGE USER'S SHARE ON EXPENDITURE ON TRAVEL.

Without exception, the money spent by a household in a higher income group - for any item, is more than that of a lower group, Figure 5.9.a, b, c and d.

This can be expressed as "Propensity" or percentage share of expenditure on travel which is also an indication of the level of trip making by a household.

Fluctuation results for the year 1965 was mainly due to smaller samples compared with other years under study (Table 5.1) where the total household number for that year was 3392 households, while for the years 1968, 1972 and 1975 were 7184, 7017 and 7203 respectively. For this reason 1965 data is not shown graphically in some figures. Apart from that year percentage share for household by income group was almost stable. <u>This is also an indication of income impact on travel behaviour and the realtively small fluctuation in trend of household income group to travel by one mode, will be absorbed by the other mode, resulting in fluctuation in opposite direction.</u>

This can be regarded as the basis of modal choice, i.e., the switching of a traveller from one mode to another (or demand for that mode) will be according to how much he is prepared to allocate from his money budget for travel by each mode. This mainly depends on the level of service associated with supplying the mode. Figure 5.9.d shows the perecentage share of each household income group on travel by all modes jointly (car, bus and rail). This figure shows the trend of household income groups for that period. Group 5 (the highest 20%) is declining in propensity, mainly as mentioned earlier, due to more travel by air and use of a firm's car.

Groups 2, 3 and 4 are showing some increasing trends in propesity to total travel for this period.

Group 1 (the lowest 20%) is declining in trend, but unlike group 5 they have no chance to travel by air or use a firm's car so widely. This indicates that the lowest 20% income groups are the most travel deprived. Moreover, most of the unemployed and pensioners are in this group. Any kind of subsidy to public transport must include this group of people before any other. This may be a guide for decision making as far as social justice is concerned.

However, all household income groups, showed a great deal of consistency throughout the period. Table 5.n, on travel by all modes, car, bus and rail. The little difference for the same household income group in their share of total travel is mainly due to the effect of other price indices compared to their income indices, as well as the possibility of using firm's car by different amount for the same income group throughout the period.

Table 5.n

Income group	1965	1968	1972	1975
1	3.87	4.71	4.1	3.44
2	12.27	11.75	11.94	13.95
3	17.36	17.59	19.02	20.00
4	25.00	27.18	25.74	27.33
5	40.78	38.75	39.18	35.24
Total	100	100	100	100

Household income group share on travel by all modes, car, bus and rail.

5.7 ANALYSIS OF TOTAL TRAVEL.

The important aspect of trends in expenditure on total travel can be seen in the combination of the expenditure on all modes, see Table 5.3, and following table.

Table 5.m
Household expenditure on travel as percentage of income.

Year	Car	Rail	Bus	Total
1965	3.89	.546	1.612	6.05
1968	4.48	.468	1.325	6.27
1972	4.57	.513	1.167	6.25
1975	4.87	.483	.855	6.21

These figures can be shown diagrammatically as in Figure 5.10. The total expenditure on travel (private and public transport) represents a fixed amount of a household's expenditure expressed as percent of household income.

Therefore, any decline in this trend in public transport expenditure will be accompanied by rising trend in travel by private transport.

On the other hand, if better service is provided by public transport, the increasing trend of expenditure on travel by public transport is more likely to produce a decline in private transport.

However, (Figure 5.10) shows clearly that the total expenditure on travel is constant throughout this period, and the increase in trend - by different amounts - in expenditure on travel by car, is accompanied by the same amount of decline on travel by public transport.

These trends of expenditure on travel match the trends of passenger - distance travelled on all roads (see Figure 1.3). The consistency also exists on the amount of expenditure on travel (private and public transport) by income groups (Figure 11) and Table 5.p. Although there is some fluctuation for the same household income group throughout the period of 1965 - 1975, but the difference between any two consecutive periods is less than 1%.

The overall picture is that expenditure on travel for all households on average (including car and non-car ownership) is a fixed percentage of income, and that the allocation of certain portions of this amount to any mode depends on the level of service provided by that mode.

Table 5.p

Income group	1965	1968	1972	1975
1	3.69	4.61	4.23	3.87
2	5.62	5.79	6.15	7.08
3	6.19	6.21	6.59	6.91
4	6.20	7.27	6.86	6.38
5	6.44	6.10	6.10	5.55

Household expenditure on travel by all modes, car, bus and rail as percentage of income group.

5.8 TRAVEL CHARACTERISTICS.

5.8.1 Introduction.

The primary source of information used in this study concerning travel characteristics is the National TRavel Survey 1972/1973 (NTS). "The NTS 1972/73 is the latest in a series of comprehensive enquiries about people's travelling habits", (NTS 1972/73).

This survey was commissioned by the Department of the Environment between April 1972 and March 1973 and published in 1976 in three volumes.

The first volume, entitled "Cross Sectional analysis of passenger travel in Great Britain", was intended to provide a broad picture of travel patterns and to describe relationships between households, e.g., their personal characteristics and different aspects of travel, passenger mileage, vehicle ownership and parking etc.

The second volume was entitled "Number of journeys per week by different types of households, individuals and vehicles", its objective was to illustrate travel frequencies for different purposes, on different modes and by different types of individual, household and vehicle.

The third volume compared the results of the 1965 and 1972/73 surveys. The data was collected from 7113 households by means of travel diaries lasting one week, with the finishing dates for the recording periods being spread evenly throughout the year. The journey in NTS is defined as 'any travel for a single main purpose'.

5.8.2 Trip Purpose.

The classification of trip purpose as in (NTS 1972/73) is as follows :-

1. To and from work.
2. In course of work.
3. Shopping and personal business.
4. Entertainment, sport, eating and drinking.
5. Personal - social travel.
6. Other personal travel (holiday, pleasure etc.)

This classification can be regarded as adequate, because it includes all significant trips which account for a considerable amount of total travel.

5.8.3 Average Trip Length.

The following table on trip length distribution for all purposes shows clearly that there is not any significant difference in trip distance distribution between the two surveys, 1966 and 1972/73. This indicates that on average, trip length distances stay quite stable over time, for the main modes of travel, car, bus and train.

Table 5.q

Trip length distribution

Length	Percentage					
	car and van		local bus		British Rail	
	1966	1972	1966	1972	1966	1972
Under 3 miles	35	39	53	50	4	4
3 and under 10 miles	43	40	42	44	28	28
10 and under 15 miles	9	8	3	4	18	20
15 and under 30 miles	9	7	2	2	32	27
30 and under 100 miles	4	4			14	17
100 miles and over	1	1			3	5
All distances	100	100	100	100	100	100

Source : NTS 1972/73, Table 2, page 2
(A comparison of 1966 and 1972/73 survey).

Average trip length by purpose can be found if data is available. Table 5.r is an abstract from "An analysis of travel patterns using the 1972/73 National Travel Survey", (Rigby, 1977). The analysis includes only one day out of the seven days of the survey. The following results are obtained :

Table 5.r

Average trip length (km)

Mode	Purpose		
	Work	Shopping	Social
Car	10.43	7.74	11.02
Bus	7.97	6.05	9.54
Rail	22.07	16.35	16.85

This table shows only a sample calculation of trip length distance by mode and purpose (and the same procedure can be applied for all other purposes). Table 5.4 is the trip length distribution by mode and purpose. Knowing total distance by mode covered by a household per week for each purpose (see Figure 5.12). The number of trips can be found simply by dividing mileage by average trip length for corresponding mode and appropriate purpose. If it is thought that different household income groups have different trip length distribution for the same journey purpose, then the adequate categorisation might include analysis for each household income group separately.

5.9 FINDINGS AND CONCLUSIONS.

Household expenditure on travel shows some fluctuation by household income groups (Figure 5.11), but still the difference - apart from lowest income group - is on average less than 1% for a certain year, expressed as percentage of household income. Group 4 in 1968 is the single exception. Furthermore, the fluctuation of the expenditure by the same household income groups is less than 1% for any two consecutive periods under consideration. These minor fluctuations could reasonably be expected, because the relative wage and price indices do not always increase simultaneously. In addition, there is the possibility of using firm's cars by different amounts by household income groups in different periods.

The other fact reflected in household trends by income group is that group 1 (the lowest 20%) declines in travel making. The main reason for this, as mentioned earlier, is that this group can barely afford the basic essentials e.g., food, clothing, houseing etc. Consequently this group is left with little money for travel. They are obliged to make more walking trips, despite the fact that this group includes more pensioners (50% of household income group 1 is old age pensioners, Transport Policy 1976). This is also clear from their percentage share of travel (Figure 5.9.d); while they show a decline in spending on travel by all modes, their 'percentage share' is almost constant throughout the period, indicating that they are only making trips of an essential nature, while groups 2 and 3 are still seeking "saturation" as far as travel is concerned. Their trend of expenditure (as percentage of income), and their percentage share of total travel is still increasing, indicating that these two groups can afford to pay more for travel.

By contrast, household income groups 4 and 5, the highest income groups, have been "saturated" (Figure 5.11), and they show a decline in their trend as well as propensity to travel indictaing they are either using a firm's car frequently, or using air transport for business purposes as well as some leisure activities.

These ideas can help to fix the expenditure of households by income group on travel, which is needed in trip generation models in the following chapters. This also has a relevance for other aspects of travel expenses, particularly parking and toll charges. For example, introducing higher parking charges in CBD area will mean less traffic to the town centre - if there is only a fixed amount of money available to spend on travel - or "user may prefer to switch to an out-of-town location rather than change to bus", (Harrison, 1974) to maintain the same level of trip making.

The trend of household income as revealed in this study (Figure 5.3) shows that one can forecast for a target year - say year 1985 - with reasonable accuracy, simply because the curves for different years are almost parallel, and only the lowest 20% is fluctuating, which is in practice of a little propensity in travel (Figure 5.9.d). Having fixed household income, Figure 5.10 showed clearly that household expenditure (on average) on travel (private and public transport) is a fixed amount of household's income (6.2% is a money budget of travel).

The consistency of trends on each single item of travel, car, train and bus, can be viewed as follows : Expenditure on train remained almost constant (0.5%) of household's income. The decline in bus expenditure from 1.6% to 0.85% over the period 1965 to 1975 was absorbed by increasing trend in expenditure on travel by car (an increase from 3.89% to 4.87% over the same period). This leaves the total expenditure on travel constant (Table 5.m).

Using this concept, the percentage of household income spent on each item can be assessed. Furthermore, it has been possible to eliminate the effect of inflation on wage rates and incomes. As an example for such forecast, income and expenditure on maintenance and running of car is shown on Figure 5.3, assuming that on average 5% of household's income will be spent on this item by the year 1985.

However, for more detailed study, these percentages of household income must be done on the basis of household income groups. The consistency which is found in this study in propensity (i.e., percentage share) of each household income group can be used as a guide for determining the percentage of household income on any mode of travel (Figure 5.9).

Summing up the discussion the following picture emerges :

It became clear from the analysis of household expenditure on travel by all modes available, car, bus and rail, that a fixed amount of a household's income (6.2%) is allocated for tripmaking. (see Table 5.m and Figure 5.10). This amount can be called household's "money travel budget". From this fixed amount each mode takes its share according to the level of service provided by that particular mode as well as traveller's attitude towards the mode of travel.

The trend was clear; travel by car rises throughout the period under study (1965-1975). This rising trend of travel by car is accompanied by a commensurate decline in travel by bus, while leaving the trend on rail travel fairly constant (Table 5.j, k and l).

Having fixed the amount of household expenditure on travel by each mode, the method of translating this amount into total distance which can be travelled, is evaluated by simply dividing the household expenditure (by mode of travel) by cost per unit distance for that particular mode, as presented in Chapter 4.

On the other hand, (from NTS 1972/73), the trip length distribution in 1965 and 1972/73 remains almost stable, indicating that average trip length remains almost unchanged for different modes. This concept can also be applied in urban areas, which exhibits more specific characteristics than on a national scale.

Figure 5.12 shows percentage of total distance on average covered by a household for each purpose. There was no corresponding figures for 1965, but in spite of this it seems reasonable to assume that little change will occur in these percentages over time. Figure 5.13 is average car trip length based on NTS 1972/73.

Finally, total number of trips made by a household can be computed by dividing total distance travelled by each mode by average trip length.

As far as car-ownership is concerned by far the most important factor has always been found to be income. Other factors, especially the nature of the household's neighbourhood, which is represented by residential density, household structure - the number of old and young. The number of workers in the household etc. are all shown to be highly related to the household's income.

The concentrated researches in the past on car-ownership was in fact required for forecasting purposes of car use and it was therefore necessary to translate the forecasts of car-ownership into forecasts of use by determining the number of kilometres per unit time that the number of cars would undertake.

In this study, the stratification of all household by income group implicitly include different level of car-ownership, which is found to be the main character of the level of income - thus there is no need for model of car-ownership and other variables, if the main objective could be achived without it.

In the following chapters, the concepts presented here are formulated in mathematical terms.

CHAPTER 6

TRAVEL PREDICTION, 1

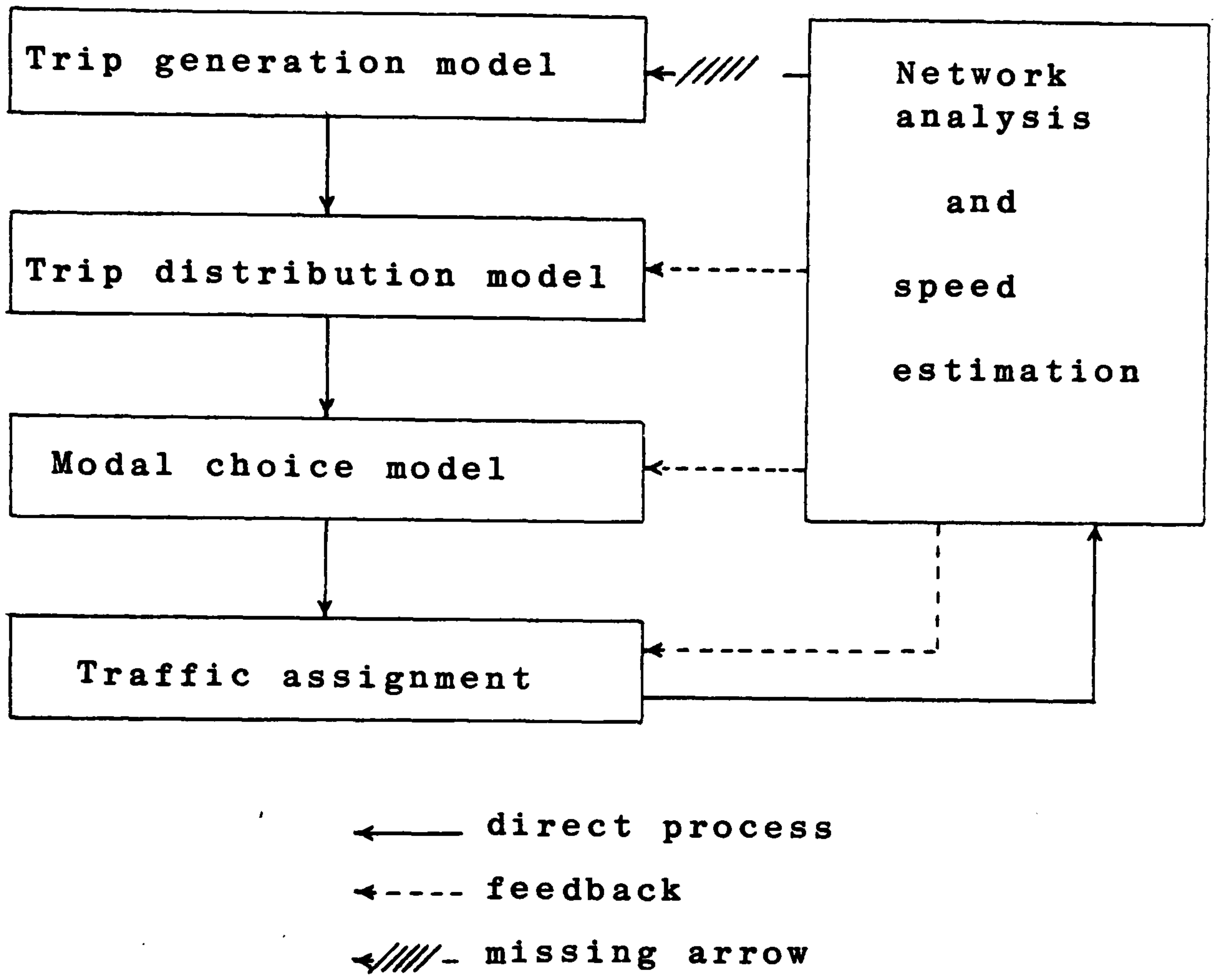
BUDGET MODELS

6.1 INTRODUCTION.

The minimisation of travel time or cost is generally an objective in transportation planning. However, transport models usually ignore the fact that when travel time or cost is reduced, the number of trips will rise. In other words, the provision of a new or improved transport facility may well result in a greater amount of travel activity than previously existed. Whol and Martin, 1967, commented that this situation - more travel - means more trips result, then presumably more community desires are being satisfied. This situation is closely analogous with the economic theory of demand and the associated concept of consumer surplus.

The major structural deficiency of traffic forecasting models is their failure to establish an interrelationship between the number of trips made, or travel volume, and the character and price of the transportation service actually available.

In the four-step conventional transport model (diagram 6.a) there is a feed-back from a network analysis box to only three steps, i.e., trip distribution, modal choice and traffic assignment. In other words, the change in the network definitely affects these steps. There is a missing feed-back arrow between network analysis and trip generation step.



Transport model

Diagram 6.a

Wilson, 1974, stated that "it would be theoretically correct to connect the network analysis box, (diagram 6.a) with an arrow to the trip-generation box. Since we would expect trip generation rate to vary with ease of travel (as presented by travel time). Unfortunately, no one has yet succeeded in building an effective elastic trip generation model of this kind".

The main objective of this study is to introduce a new and simpler approach, with relatively little effort needed for data collection. Based on economical theory of consumer's behaviour, it is possible to put back "the missing arrow" mentioned by Wilson (as discussed in Chapter 2).

The modified transport models can be represented as in Figure 6.1. Trip generation models have absorbed modal split models, and from the start of transport planning process, private travel - car trips, as well as public transport - person trips by bus - are predicted separately. Others, like external trips, which use the network and commercial vehicles are also treated separately, and total load on each link of the network is checked at assignment stage.

Trip distribution might give better results if separated on the same basis of disaggregation, i.e., by household income groups by purpose, on the assumption that different household income groups possess different average trip lengths, and average trip length for the same household income group differ by purpose.

6.2 GENERATED TRIPS.

It is commonly accepted that each new transport facility or each improved facility may cause induced or generated traffic to appear along the section of road directly or indirectly affected by the improvement, with other traffic being diverted, because the new level of attractiveness of such a particular route containing improved links.

This additional traffic is observed with the opening of the new facility, and has continued as a stable and slightly increasing component for at least the first four or five years as revealed by records covering this period (Shmidt and Campbell, 1956).

In time it becomes increasingly difficult to isolate and measure this component, and it possibly diminishes as the other components grow and crowd it out.

Generated traffic is composed of trips previously inhibited by inadequencies in quality and operational characteristics of the existing facilities. Little consideration has been given to the issue of "frustrated travel", i.e., those journeys which people would like to make but do not, because they are deterred by the shortcomings of transport facilities, including good roads (Stephen, 1972).

The trip generation model introduced here will take account of generated trips as well as trip generation.

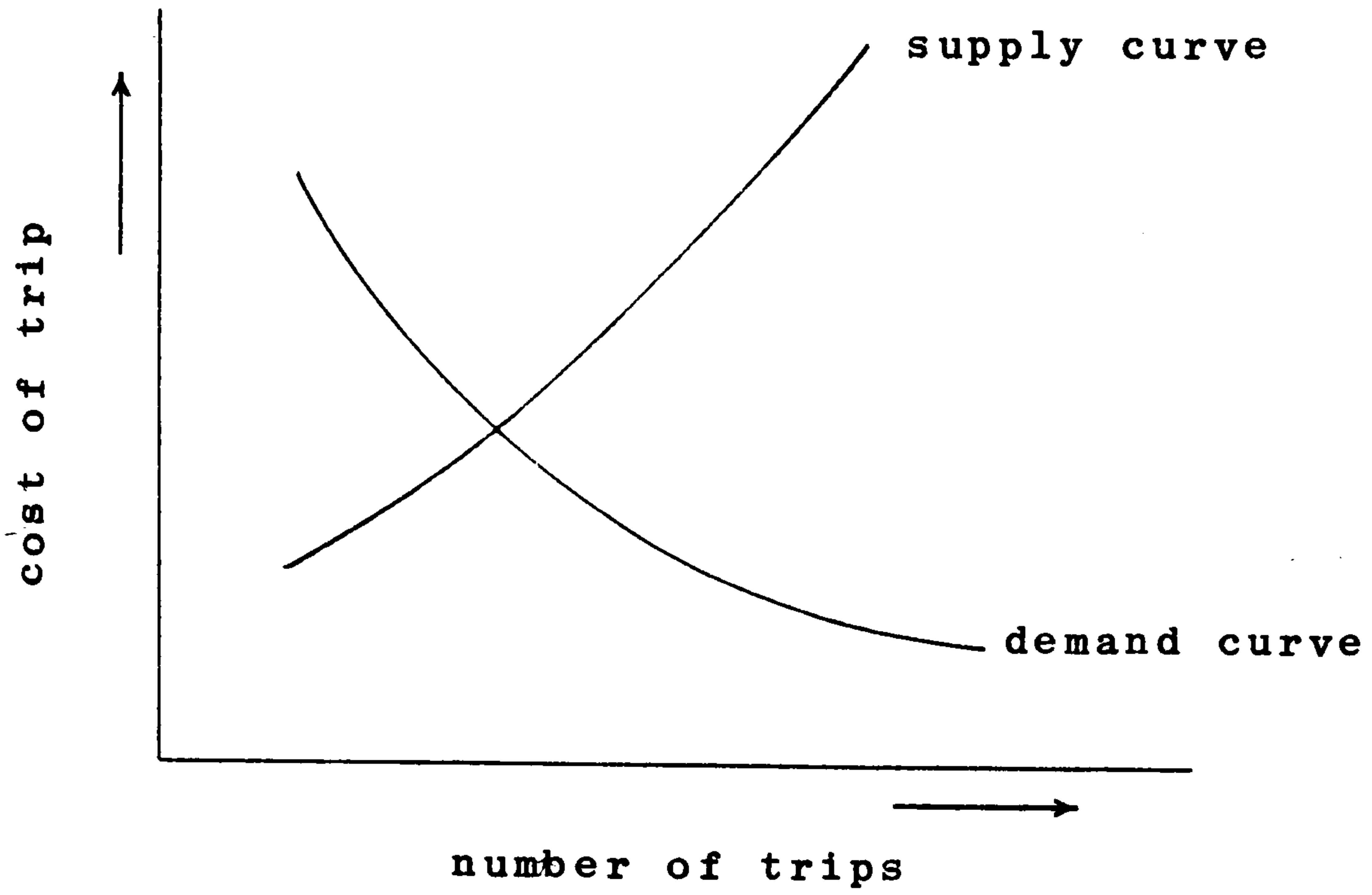
6.3 FACTORS AFFECTING TRIP GENERATION.

Having predicted the amount of money a household is prepared to pay for travel by a certain mode per unit time, as well as average trip length for each purpose (Chapter 5), the factors affecting number of trips for a particular mode are:

(i) the type of facility available and the level of service as far as road users are concerned. Level of service can be best defined by average speed and cost of travel,

(ii) the amount of change. This extent of change is the percentage of the route improved, between a pair of origin and destination. Thus the existence of two situations, before the change and after the change will be discussed.

Category (i) indicates the demand curve while category (ii) is the supply curve, Diagram 6.b.



Demand and supply curve

Diagram 6.b

6.4 BUDGET MODELS OF TRAVEL

Model for Generated Traffic.

Consider a part of a network which is used for journeys from origin A to destination B. The total length of journey from A to B is L units. Part of the route, a length L_1, is improved (where $L_1 \leqslant L$), then the part which is not improved can be denoted by L_2 (where $L_2 = L - L_1$), hence $L_1 = DL$, $L_2 = L - DL$ (Diagram 6.c).

The assumption about consumer's behaviour is that he is trying to save time from his time budget for travel after improvement. Also, he is attracted by the new situation to make more trips, and he is prepared to increase his amount of money outlay by some amount against his time saving if his income allows this.

If he makes n_b trip. Before per unit time, his allocated time budget will be:

$$t_b = n_b \frac{L}{V_b} \tag{6.1}$$

where

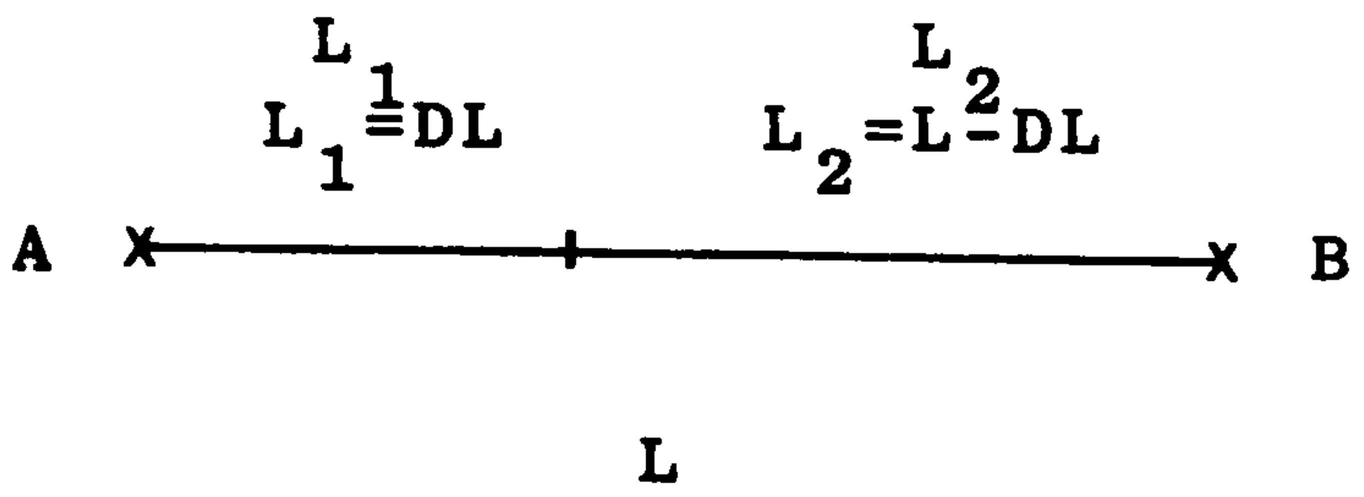
t_b : is time spent on a trip, before improvement

L : is the total length of the route between origin and destination

V_b : is the average speed on (L) before improvement

n_b : is number of trips before improvement per unit time

Diagram 6.c



After improvement of part of L which is L_1

$$t_a = n_a \left[\frac{L_1}{V_a} + \frac{L_2}{V_b}\right] \qquad (6.2)$$

where

t_a : is time spent on a trip after improvement

L_1 : is part of route L which is improved

V_a : is speed on L_1 after improvement

n_a : is number of trips after improvement per unit time

L_2 : $L-L_1$

To utilise fully the travel time budget:-

$$t_a = t_b \qquad (6.3)$$

Substituting 6.1 and 6.2 into 6.3

$$n_b \frac{L}{V_b} = n_a \left[\frac{L_1}{V_a} + \frac{L_2}{V_b}\right]$$

$$\therefore \quad \frac{n_a}{n_b} = \frac{\frac{L}{V_b}}{\left[\frac{L_1}{V_a} + \frac{L_2}{V_b}\right]}$$

set
$$R_t = \frac{n_a}{n_b} \tag{6.4}$$

$$\therefore \quad R_t = \frac{\dfrac{L}{V_b}}{\left[\dfrac{L_1}{V_a} + \dfrac{L_2}{V_b}\right]} \tag{6.5}$$

where

R_t : is the rate of trip change, for time budget.

Similarly, for money budget:-

$$M_b = n_b \,.\, B.\, L \tag{6.6}$$

where

M_b : is money spent before improvement

B : running cost per unit distance, before improvement

Other notations as before.

After change on L_1 took place

$$M_a = n_a \left[A.L_1 + B.L_2\right] \tag{6.7}$$

where

M_a : is money spent, after change

A : is running cost per unit distance after change

Other notations as before.

To utilise fully travel money budget:

$$M_a = M_b \tag{6.8}$$

Substituting 6.6 and 6.7 into 6.8

$$n_b\, BL = n_a \left[AL_1 + BL_2\right] \tag{6.9}$$

$$\frac{n_a}{n_b} = \frac{BL}{\left[AL_1 + BL_2\right]} \tag{6.10}$$

Set
$$R_m = \frac{n_a}{n_b} \tag{6.11}$$

$$R_m = \frac{BL}{AL_1 + BL_2} \tag{6.12}$$

Set $h = \frac{V_a}{V_b}$ (6.12a) $D = \frac{L_1}{L}$ and $L_2 = L-L_1 = L-DL$ (6.12b)

$$R_t = \frac{\frac{L}{V_b}}{\frac{L_1}{V_a} + \frac{L_2}{V_b}} = \frac{\frac{L}{V_b}}{\frac{L_1}{hV_b} + \frac{L_2}{V_b}} \tag{6.5}$$

$$R_t = \frac{hL}{hL_2+L_1} = \frac{hL}{h(L-L_1)+L_1} = \frac{hL}{hL-hL_1+L_1}$$

$$\therefore \quad R_t = \frac{h}{h+(1-h)D} \qquad \underline{\text{Time budget}} \tag{6.13}$$

for $D = 1$

$$R_t = h \tag{6.13a}$$

$$R_m = \frac{BL}{AL_1 + BL_2} = \frac{BL}{AL_1 + BL-BL_1} \tag{6.12}$$

$$R_m = \frac{BL}{BL + L_1(A-B)}$$

$$R_m = \frac{B}{B + (A-B)D} \qquad \underline{\text{Money budget}} \tag{6.14}$$

for $D = 1$

$$R_m = \frac{B}{A} \tag{6.14a}$$

Time budget formula as in 6.13. Rate of trip change is a function of speed ratio (h) and percentage of route improved. While for money budget (6.14), the rate is a function of cost (before) as well as percentage of route improved. It is also obvious that B and A are a function of speed, this means that money budget model takes account of both the quality and quantity of the change.

To ensure that the time budget will not be exceeded for any value of R (rate of change of trips per unit time), and to spend more money according to the criteria explained earlier, then value of R actually lies between R_t and R_m.

then

$$R = R_m + (R_t - R_m)P \qquad (6.15)$$

or

$$P = \frac{R - R_m}{R_t - R_m} \qquad (6.15a)$$

where

P : is the proportion of difference between R_t and R_m

for $P = +1$ elasticity of time (e_t) = -1.0

$R = R_t$ time after = time before (6.16)

(Time budget)

for $P = 0$ elasticity of money (e_m) = -1.0

$R = R_m$ money after = money before (6.17)

(Money budget)

$\therefore$ P values are between -1 and 1 or :

$$-1 < P < +1 \qquad (6.18)$$

Considering the scarcity of resources of both time and money, the value of (P) will be such that the consumers settle at a new equilibrium point as far as time and money are concerned, i.e., the percentage increase of his money outlay is equal to percentage increase of his time saving. Then we proceed as follows:

$$\phi_t = \frac{\text{Time saved}}{\text{Time before}} 100 = \frac{\text{Time before-Time after}}{\text{Time bfore}} 100 \qquad (6.19($$

$$\phi_t = \frac{\frac{L}{V_b} - R(\frac{DL}{hV_b} + \frac{L-DL}{V_b}}{\frac{L}{V_b}} \qquad (6.19a)$$

$$= 1 - R\frac{D}{h} + 1-D$$

$$= 1 - R\frac{D + h - Dh}{h}$$

$$\phi_t = \frac{h - RD - Rh + RDh}{h} = \qquad (6.20)$$

for $D = 1$

$$\phi_t = \frac{h - R}{h} \tag{6.21}$$

$$\phi_m = \frac{\text{extra money outlay}}{\text{money before}} 100 = \frac{\text{Money after-money before}}{\text{Money before}} 100 \tag{6.22}$$

$$= \frac{R[ADL + B(L-DL)]-BL}{LB} 100 \tag{6.22a}$$

$$\phi_m = \frac{RAD + RB - RBD - B}{B} 100 \tag{6.23}$$

for D = 1

$$\phi_m = \frac{RA - B}{B} 100 \tag{6.24}$$

if

$$\phi_t = \phi_m \tag{6.25}$$

$$\frac{h - RD - Rh + RDh}{h} = \frac{RAD + RB - RBD - B}{B} \tag{6.26}$$

$$R = \frac{2BH}{2Bh + (B - 2Bh + Ah)D} \tag{6.27}$$

for D = 1

$$R = \frac{2Bh}{B + Ah} \qquad (6.28$$

Formula 6.28 indicates that the rate of trip change depends on cost of trip before and after, as well as the ratio of speed.

Therefore,

$$P = \frac{R - R_m}{R_t - R_m} \tag{6.15a}$$

$$P = \frac{\frac{2Bh}{2Bh+(B-2Bh+Ah)D} - \frac{B}{B+(A-B)D}}{\frac{h}{h+(1-h)D} \qquad \frac{B}{B+(A-B)D}} \qquad (6.29$$

for D = 1

$$P = \frac{\frac{2Bh}{B + Ah} - \frac{B}{A}}{h - \frac{B}{A}} \qquad (6.30$$

All formulas for D = 1, i.e., all the route has been improved, however, these formulas are also applicable (for D = 1) when D<1, taking new values for h, along the whole route. The analysis for D 1 criteria is more meaningful in applying cost formula than using D = 1 and making correction for h values.

6.5 VALUE OF TIME (VOT).

In Diagram 6.d, K represents the resources needed for travel, "time budget" Before can be denoted by K_{bt} where b stands for "before" and t for "time" at speed V_b. Similarly K_{bm} represents money budget before where m stands for money.

According to formulas given earlier, there is the possibilities of consuming the resources in after situation-at speed (hV_b) as follows:

1. consuming time budget:

$$R = nR_t = nh \qquad \text{time before} = \text{time after} \qquad (6.13a)$$

$$\therefore \quad e_t = -1.0$$

$$\phi_t = 0.0$$

2. consuming money budget:

$$R = nR_m = n\frac{B}{A} \qquad \text{money before} = \text{money after} \qquad (6.14a)$$

$$\therefore \quad e_m = -1.0$$

$$\phi_m = 0.0$$

3. consuming a combination of time and money budgets:

$$R = n\,\frac{2B}{\frac{B}{h} + A} \qquad e = -1.0$$

$$\phi_t = \phi_m$$

Accepting the criteria that the traveller will behave as in case 3 above, i.e., the trip rate will be increased by an amount such that the percentage time saved from time budget (ϕ_t) is the same as percentage of extra money (ϕ_m), then the following emerge:

The value of time can be represented by notion that in after situation, the time and money budget is changed. The extra money paid is directly related to the amount of time saved.

In Diagram 6.d, the consumer originally made (n) trips and consumed K units of his resources, "before". To bring the consumer into a new point of equilibrium R_{GC}, and to ensure that the two budgets of time and money will not be violated (which is represented by case 1 and case 2 above). The constraint $\phi_t = \phi_m$ must be satisfied. This point R_{GC} as can be seen in the following sections is also the point of consuming generalised cost of resources.

The value of time on this basis can be found from the fact that the consumer paid K_3 (money units) to save K_4 (time units) as shown in Diagram 6.d.

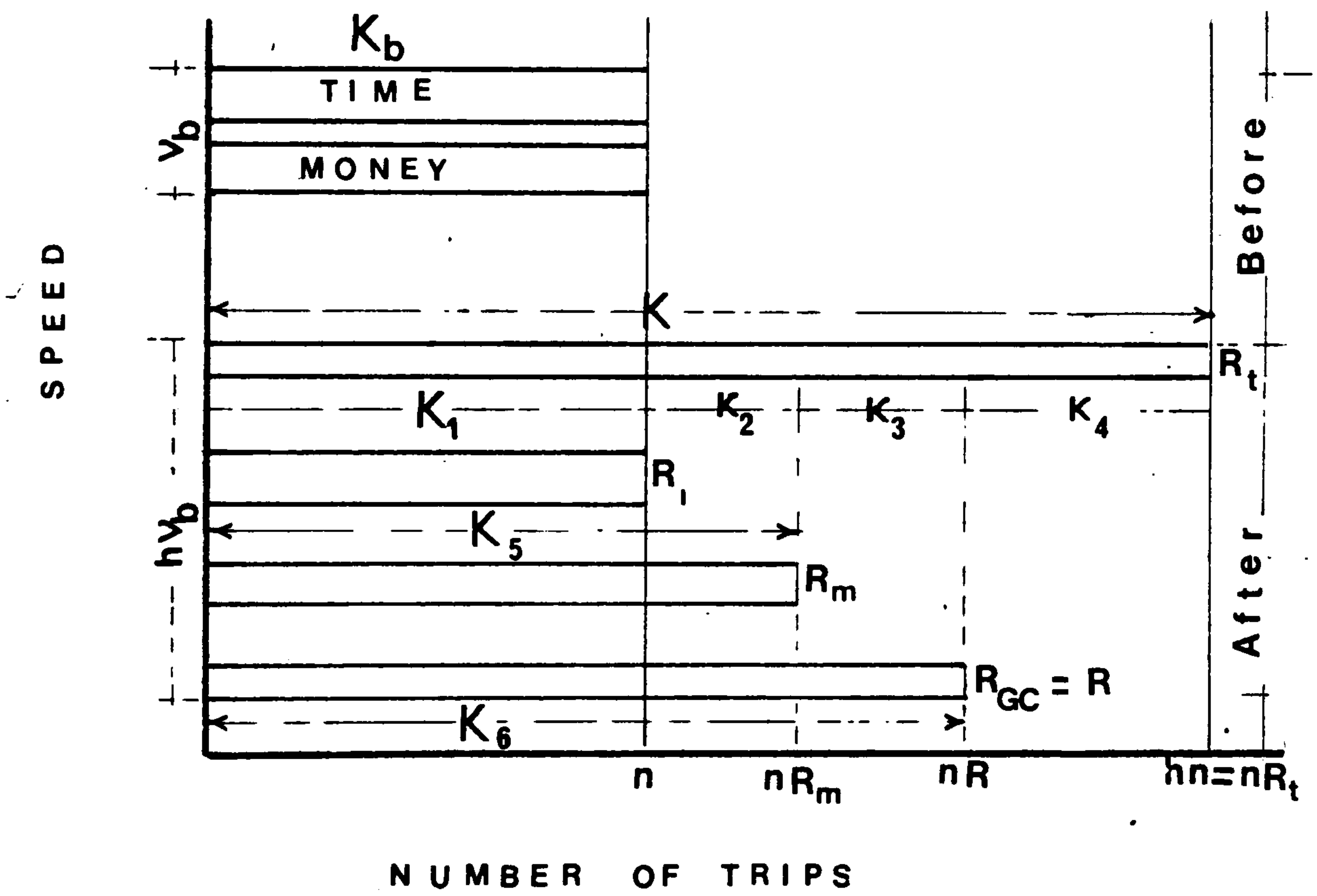


Diagram 6.d

$$\therefore \quad VOT = \frac{K_{3m}}{K_{4t}} \tag{6.31}$$

where

VOT = monetary value of time

K_{3m} = extra money paid

K_{4t} = time saved

$\therefore K_{3m}$ = money needed for (nR) trips - money budget.

$$= K_{6m} - K_{5m} \tag{6.32}$$

Similarly,

K_{4t} = time budget - time needed for (nR) trips.

$$= K_t - K_{6t} \tag{6.33}$$

$$\therefore VOT = \frac{K_{6m} - K_{5m}}{K_t - K_{6t}} \tag{6.31a}$$

Assuming a trip length of (L) and cost per unit distance B and A for before and after situations, and V_b and V_a speeds, where $V_a = hV_b$, where h is the amount of change in V_b, then :

K_{6m} = LAnR money needed after

K_{5m} = LBn money needed before

$K_t = \frac{L}{V_b} n$ time before

$K_{6t} = \frac{L}{V_a} nR$ time after

$$VOT = \frac{LARn - LBn}{\frac{Ln}{V_b} - \frac{LRn}{V_a}} \tag{6.34}$$

$$VOT = \frac{RA - B}{\frac{1}{V_b} - \frac{R}{hV_b}} \tag{6.35}$$

$$R = \frac{2Bh}{B + Ah} \tag{6.28}$$

$$\therefore \quad VOT = \frac{\frac{2Bh}{B+Ah} A - B}{\frac{1}{V_b} - \frac{2Bh}{B+Ah} \frac{1}{hV_b}} \tag{6.36}$$

$$= BV_b \frac{\frac{2hA}{B+Ah} - 1}{1 - \frac{2B}{B+Ah}}$$

But

$$\frac{2HA}{B+Ah} - 1 = \frac{2hA-B-Ah}{B+Ah} = \frac{hA-B}{hA+B}$$

and

$$1 - \frac{2B}{B+hA} = \frac{B+hA-2B}{B+hA} = \frac{hA-B}{hA+B}$$

$$\therefore \boxed{VOT = BV_b} \qquad (6.37)$$

<u>i.e., value of time saved equals to cost per unit distance (before - at speed V_b) multiplied by average vehicle speed (before) for each of the occupants.</u>

6.6 GENERALISED COST MODEL.

Usually the vehicle operating cost formula used in economic assessment includes value of time as described in Section 3.7.3 using the formula 6.37 for VOT we proceed as follows:

Generalised cost(GC) = Money cost + monetary value of time

$$\text{Money cost} = a + \frac{b}{V_b} + cV_b^2 = B \qquad \text{Before} \qquad (4.19)$$

$$\text{Time cost} = \text{time X (VOT)}$$

$$= \frac{1}{V_b} \times V_b \cdot B = B \qquad \text{Before} \qquad (6.38)$$

$$\therefore (GC)_b = B + B = 2B \qquad (6.39)$$

$$\text{Money cost} = a + \frac{b}{hV_b} + C(V_b h)^2 = A \qquad \text{After} \qquad (6.40)$$

$$\text{Time cost} = \frac{1}{hV_b} \times V_b \cdot B = \frac{B}{h} \qquad \text{After} \qquad (6.41)$$

$$\therefore (GC)_a = \frac{B}{h} + A \qquad (6.42)$$

where

$(GC)_b$: Generalised cost before

$(GC)_a$: Generalised cost after

$$\frac{1}{R} = \left[\frac{GC_b}{GC_a}\right]^e \qquad \text{from (3.3)} \qquad (6.43)$$

or

$$R = \left| \frac{GC_b}{GC_a} \right|^{-e} \qquad (6.44)$$

$$= \left| \frac{2B}{\frac{B}{h} + A} \right|^{-e} \quad \text{substitute 39 and 42 into 44} \qquad (6.44)$$

Assuming elasticity of generalised cost is (-1.0), i.e., the amount of outlay in terms of money and monetary cost of time is constant (after = before).

$$R = \frac{2B}{\frac{B}{h} + A} = \frac{2Bh}{B + hA} \qquad (6.46)$$

which is the same formula as in (22)

Therefore, percentage increase in money outlay is equal percentage time saved, i.e., $\phi_m = \phi_t$.

Formula 6.46 can be modified to include average trip distance, and car occupancy.

$(GC)_b$ = [Car occupancy x (Time before x VOT) + Cost before] $\bar{L}_b$

$$= [Y \times \frac{1}{V_b} \cdot V_b \; B + B] \; \bar{L}_b$$

$$= [B(1 + Y)] \; \bar{L}_b \qquad (6.47)$$

$$(GC_a) = [Y \times \frac{1}{hV_b} \; V_b \; B + A] \; \bar{L}_a$$

$$= [\frac{YB}{h} + A] \; \bar{L}_a \qquad (6.48)$$

where

Y : is car occupancy

$\bar{L}_b$ and $\bar{L}_a$: are average trip distance before and after respectively.

$$R = \frac{[B(1 + Y)]\bar{L}_b}{[\frac{YB}{h} + A]\bar{L}_a} \qquad (6.49)$$

in formula 6.49 if average trip distance remains constant, then $\bar{L}_b = \bar{L}_a$.

$$R = \frac{B(1 + Y)}{\frac{YB}{h} + A} \tag{6.50}$$

$$= \frac{hB(1 + Y)}{BY + hA} \tag{6.51}$$

6.7 MODELS FOR TRIP GENERATION.

6.7.1 Introduction.

The main finding in Chapter 5 is that "Households on average are prepared to pay a fixed percentage of their income for travel by all modes. From this fixed percentage, a certain percentage of income is allocated for travel by each mode, depending on the level of service provided by that particular mode".

The trend of the period (1965-1975) in fact reflects this situation. Considering the trend of household expenditure on travel by car and bus, Table 6.a.

Year	Expenditure on running of car as % of household income	Expenditure on travel by bus as % of household income
1965	3.89	1.612
1968	4.48	1.325
1972	4.57	1.106
1975	4.87	0.855

See Table 5.3

The increase in car travel resulted in the provision of better roads. Hence the consumer experienced higher speed of travel,(i.e., less time needed for the same trip after than before) appreciating the value of time saved. The consumer paid more in after situation (years 1968, 1972 and 1975) than before (year 1965) in monetary terms.

On contrary, the level of service was decling in bus travel with the real cost per trip in 1972 being more than that of 1965, but with no improvement in level of service as far as time is concerned. The net effect was less expenditure by household on travel by bus.

According to this concept, a general share model can be formulated on the assumption that the percentage of household income needed for travel by each mode can be predicted according to the past trends in travel behaviour, considering also expected changes in level of service combined with travel characteristics of the area under study.

6.7.2 General Share Model (GSM).

The General Share Model (GSM) can be formulated according to the fact that a household allocate a certain percentage of his income to travel by each mode, part of which in turn will be allocated for certain purposes.

Assuming,

k modes	k = 1, 2 .... h	(car, bus, train, etc.)
ℓ purposes	ℓ = 1, 2 .... r	(work,shopping, etc.)
i income groups	i = 1, 2 .... q	(i=1,for lowest household income)
O zones	O = 1, 2..... n	(O=1, for zone 1)

From household income and expenditure analysis in Chapter 5, the following relationship can be formulated. (Number of trips per household for all purposes per unit time by mode k) x (Average trip cost) = Household expenditure on travel by mode k per unit time.

$$\therefore \quad t_k \bar{C}_k = E_K \tag{6.52}$$

$$\therefore \quad t_k = \frac{E_K}{\bar{C}_k} \tag{6.52a}$$

on the same basis, disaggregation by trip purpose for each mode, the formula becomes:

$$t_{k\ell} = \frac{E_K P_{k\ell}}{\bar{C}_{k\ell}} \tag{6.52b}$$

where :

P_{ℓ} : is percentage of E, spent on travel for purpose ℓ

$\bar{C}_{\ell}$: is average trip cost for purpose ℓ

Disaggregation by income group, formula 6.52b becomes :

$$t_{iK\ell} = \frac{E_{iK} \cdot P_{i\ell K}}{\bar{C}_{i\ell K}} \qquad (6.52c)$$

where :

$t_{i\ell K}$ = Number of trips, by household income group i, by mode K for purpose ℓ.

E_{iK} = Expenditure on travel by mode K, for household income group i, all purposes.

$P_{i\ell K}$ = percentage money allocated for purpose ℓ, by household income group i.

$\bar{C}_{i\ell K}$ = trip cost by mode K for purpose ℓ, by household income group i.

These terms can be computed as follows :

$$E_K = MN_K \qquad (6.53)$$

$$E_{iK} = M_i N_{iK} \qquad (6.53a)$$

where :

M : average household income

N_K : percentage of M allocated for travel by mode K

M_i : household income, in group i

N_{iK} : percentage of household income spent on travel by mode K, all purposes.

$$P_{i\ell K} = S_{i\ell K}\, F \qquad (6.54)$$

where :

$S_{i\ell K}$: percentage (from total distance for all purposes) of purpose ℓ

$$S_{i\ell K} = \frac{D_{i\ell K}}{\sum_{\ell=1}^{r} D_{i\ell K}} \qquad (6.55)$$

$$F = \frac{C_{i\ell K}}{C_a} \; \frac{\sum_{\ell} S_{i\ell K}}{\sum_{\ell} S_{i\ell K} \dfrac{C_{i\ell K}}{C_a}} \qquad (6.55a)$$

where :

$D_{i\ell k}$: distance travelled for purpose ℓ

$C_{i\ell K}$: cost per unit distance for purpose ℓ, by mode K household income group i

C_a : average cost per unit distance for all purposes.

F : correction factor

$$C_a = \frac{\sum_1^r C_{i\ell K}}{r} \tag{6.56}$$

Average trip cost, by mode K, purpose , by household income group (i) is :

$$\bar{C}_{i\ell K} = \bar{X}_{i\ell K}\, C_{i\ell K} \tag{6.57}$$

where :

$\bar{X}_{i\ell K}$ = average trip distance by mode K for purpose ℓ, by household income group i (6.57a)

$C_{i\ell K}$ as defined above

The model as presented by formula 6.52c is simply computing the average number of trips per week for household income group i, by mode, by purpose. Total trips per week for household income group i is simply the summation over all purposes.

$$T_{iK} = \sum_{\ell=1}^{r} t_{iK\ell} = \sum_{\ell=1}^{r} \frac{E_{iK} P_{iK\ell}}{\bar{C}_{i\ell K}} \tag{6.58}$$

where :

T_{iK} = total trips per week made by household income group i by mode K, for all purposes.

Knowing number of households in each income group;

$$TT_{iK} = H_i \sum_{\ell=1}^{r} \frac{E_{iK} P_{iK\ell}}{\bar{C}_{iK\ell}} \tag{6.59}$$

where :

TT_{iK} : total number of trips by all households in income group i by mode K,

H_i : number of households in income group i.

To compute the total number of trips for all household income groups in zone O, by mode K :

$$TT_K = \sum_{i=1}^{q} H_i \sum_{\ell=1}^{r} \frac{E_{iK} P_{iK\ell}}{\bar{C}_{iK\ell}} \tag{6.60}$$

where :

TT_K : Total number of trips made by all households from zone O.

This total number of trips, which is originated in zone O, can be found for all zones in the study area, and the model applied separately to compute trips from each origin zone O for each mode. The input to trip distribution can be on the basis of total trips by mode K for purpose ℓ .

$$Q_{\ell K} = \sum_{i=1}^{q} H_i \frac{E_{iK} P_{iK\ell}}{\bar{C}_{iK\ell}} \qquad \sum_{\ell=1}^{r} Q\ell = Q \tag{6.61}$$

$\sum_{i=1}^{q} H_i = H_O$ total number of households in zone of origin. (6.61a)

where :

$Q_{\ell K}$ = total number of trips made by all households in zone O, for purpose ℓ, and mode K.

i.e., total work trips for all households in each zone made by car, distributed first, then shopping trips, and so on. This might give better results for any type of distribution models to be used. Because the measure of attraction can be more meaningful and constraints can be put to facilitate calibration of distribution model, such as average trip length for purpose ℓ in zone O is constant and its value is already available.

$$\bar{X}_\ell = C_1 \tag{6.62}$$

A further constraint which can be introduced is that the total cost of all trips by mode K for purpose ℓ is constant according to original assumption.

$$\sum_{i=1}^{q} t_{1K\ell} \cdot \bar{C}_{i\ell K} = C_2 \tag{6.62a}$$

the value of C_2 can be computed from:

$$C_2 = \sum_{i=1}^{q} E_{iK} \, P_{iK\ell} \tag{6.63}$$

This constraint is the same as used by Wilson, 1974, when he introduced the concept of entropy maximization and the concept that total cost of trips is constant. In this model, explicitly one can introduce such a constraint as an outcome of trip generation model. However, there is a family of General Shape Models (GSM) introduced into transportation studies, each has its own characteristics. In this model households are only distinguished on the basis of income. All other variables which previous studies regarded as important, such as car-ownership, are no longer needed. Furthermore, this model considers at the generation stage the different land uses at possible destinations. Previously, these factors were used as measures of attraction in distribution models. In other words, given a certain threshold of development, people have a necessity for travel and the fulfilment of their desire (for each trip purpose) is a matter of choosing one destination rather than another.

The concept of accessibility can also be introduced to this model by considering the travel characteristics at a zonal level, i.e., average trip length for work trips for a household living and workind in CBD area is different from one living in the outskirts and working in CBD area.

The application of GSM for car trips can be found in Chapter 8, while in Chapter 9 bus travel is dealt with.

6.8 SUMMARY AND CONCLUSIONS.

Amongst the list of recommendations on traffic forecasting by a committee on trunk roads assessment (Leitch, 1977), is "There should be further study of the relationship between kilometres travelled per car and the price of fuel (including tax), income and different journey purposes for different sections of the population".

The translation of this statement is dealt with, not on the basis of trunk roads, but on the basis of urban areas. The mathematical models formulated for traffic prediction are on two levels; first for short term change when generated (induced) traffic also contributes to a large amount of total traffic on the road system, the generalised cost model can be applied. However, for long-range forecasting, the general share model can be applied, which takes account of both trip generation as well as generated trips.

The value of time (VOT) found in this study, derived from basic economic notions of consumer's behaviour in utilising the two main scarce resources needed for travel (time and money) and also the concept of "trade off" between these two variables. However, the (VOT) found in this study is also relevant in cost-benefit analysis.

Comparing these types of cost models, as a trip generation model, with category analysis, the superiority of budget models can be realised by recognising that category analysis is only a special case (which is highly improbable) of budget model, i.e., category analysis assumed no change whatsoever in level of service in the target year. Moreover, it assumes no relative change in income and cost of travel indices at all.

Applying the budget model, even for "do-nothing" situations, the rate of travel still depends on relative changes in household income and cost of trip. On the other hand, if level of service changes, assuming all price and income indices remain constant, still budget models will predict change in the amount of travel. However, the general case is that all these variables are changing. This will be the focus of attention in the application of budget models in the next chapter.

CHAPTER 7

TRAVEL PREDICTION, 2

BUDGET MODELS APPLICATION FOR PRIVATE TRAVEL

GENERATED CAR TRIPS

7.1 INTRODUCTION.

"When there is a reduction in the cost of travelling between two points, possibly as a result of road improvements, certain journeys, which were not worthwhile before the improvement, became worthwhile afterwards; traffic between the two points will therefore increase. The new traffic is usually known as 'generated traffic' " (Dawson, 1968). Furthermore, it is possible to attempt some quantification of this generated traffic. "This new traffic normally increases through a couple of years to a figure of about 5-30% of the current traffic". (Overgaard, 1966).

This increase in trip rate might also result in providing better car performance. The desire to produce generally smaller capacity engines, which will give better fuel economy, will not inevitably produce energy conservation in the long term for fixed real petrol price. This is because the greater fuel economy on a miles-per-gallon basis (associated with use of smaller engined cars) may be cancelled out by <u>new</u> trips which may possibly result in the same <u>total</u> fuel consumption.

In the economic assessment of road improvements, a new motorway or new river crossing which leads to large reduction in journey times and cost may result in a considerable amount of generated traffic. It is argued that benefits to generated traffic are half the rate applicable to existing and diverted traffic, and on this basis some allowance was usually included in the calculation.

It is possible to suggest, however, that the criteria employed have been inadequate to sufficiently justify the predicted amount of generated traffic.
The work presented here on generated trips, and the differentiation of the behavioural unit "houshold" by income groups is completely new and provides for the first time a theoretical framework for further investigation. It also provides the basis for much comprehensive analysis of real household's travel behaviour and their response, as well as their attitude towards changes in the level of service.

The level of service, for car trips, in the suggested budget models are based only on quantitative physical parameters, which include speed, operating costs and especially fuel prices which are directly related to operating cost as mentioned earlier. However, a subjective appreciation of environmental factors has been omitted from the model.

The application of budget models, in this chapter, is to assess the trip rate changes caused by proving different levels of service.

7.2 RESOURCES NEEDED FOR CAR TRIPS.

In Diagram 7.1b, a traveller consumes K units of resources needed for travel, in terms of time and money, at speed V_b, which represents the "before" situation. Increasing the speed to a new level of hV_b which represents the "after" situation where $V_a = hV_b$, the consumer will spend different amounts of K in the after situation, depending on economic status and background, which act as constraints on him.

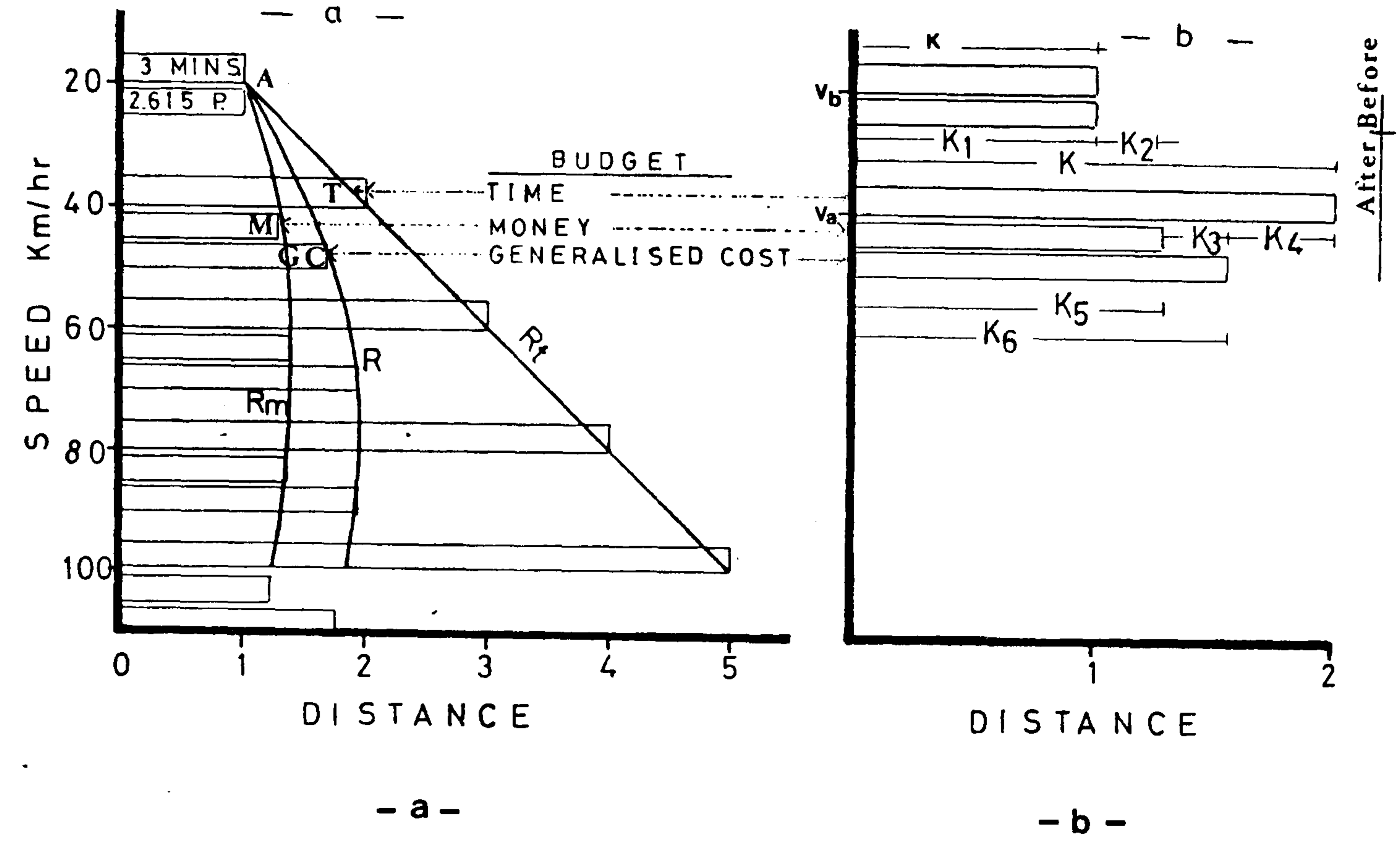


Diagram 7

7.2.1 Operating cost formula.

The vehicle operating cost formula given for 1973, is

$$C = 1.29 + \frac{26}{V} + .000063\ V^2 \qquad (4.19)$$

where

C : cost per unit distance, pence per kilometre

V : average speed, kph.

As an example of the application of 'budget models', assume the existence of a road between two points, with length L kilometers and in a unit of time (n) trips travel between these two points at an average speed V_b = 20 kph.

It was ascertained from analysis of models in Chapter 6 that dealing with (n) trips and fixed average trip length, is relatively the same as dealing with unit distance and analysing the rate of trip change R.

Two ranges of improvement are suggested for after situation :

1. High range

   speed from 20 kph to 40 60, 80, and 100 kph.

2. Low range

   speed from 20 kph to 22, 24, ... 40 kph.

The cost and time needed per unit distance is shown in Table 7.a for high level improvement.

Table 7.a

Speed kph	Cost pence/km	Time min./km	
20	2.615	3.0	B
40	2.041	1.5	A
60	1.950	1.0	A
80	2.018	0.75	A
100	2.180	0.60	A

Note : B : Before : A : After

7.2.2 Travel Time Constraint.

People who are constrained by travel time, consume K units of the resources in the after situation. For a change of speed from 20 to 40 kph, the following values for K in Diagram 7.b can be obtained :

$$K \begin{cases} = T = \dfrac{1}{V_b} = \dfrac{60}{20} = 3 \text{ mins. (Time budget)} \\ = R = \dfrac{V_b}{V_a} = h = \dfrac{40}{20} = 2 \text{ km} \\ = E = R.A = 2 \times 2.04 = 4.08 \text{ pence} \end{cases}$$

$e_t = -1.0$

where

T : is the time used before, (Time budget)

V_b : speed before

V_a : speed after

h : ratio of the two speeds

R : rate of trip change

E : expenditure after

A : cost per unit distance after (Table 7.a)

e_t : elasticity of travel time.

Time required originally (before) for a journey at speed 20 kph is 3 mins., which is the time budget for the traveller. This is represented by the upper bar in Diagram 7.b. The company time required to make a journey at speed 40 kph is 1.5 mins.

However, if the time surplus is to be consumed by travelling more, i.e. at speed 40 kph, traversing 2 km instead of 1 km at the original speed of 20 kph, this would represent 100% increase in the amount of travel. Similarly, for speeds 60, 80 and 100 kph fully utilising the time budget of 3 mins. would result in journeys of 3, 4 and 5 km respectively, corresponding to formula $R_t = h$ (6.13.a).

The distances which can be covered by the same time budget for different speeds is shown in Diagram 7.a. Joining the points of distance covered gives a straight line result which represents time budget constraint.

Referring back to the formulation of time budget model.

$$R = R_m + (R_t - R_m)P \qquad (6.15)$$

$$\text{for } P = 1 \quad \phi_t = 0$$

(time before = time after, elasticity of time $e_t = -1.0$) (6.16)

$\therefore R = R_t$

$R = R$ (100% of the route improved) (6.13.a)

$R_t = \dfrac{h}{h+(1-h)D}$ (for different amount of the route improvement) (6.13)

where $h = \dfrac{V_a}{V_b}$, (6.12.a)

$$\text{and } D = \frac{\text{length improved}}{\text{total length of the route}} = \frac{L_1}{L} \qquad (6.12.b)$$

Figure 7.1 is an application of the formula 6.13 assuming different lengths of the route to be improved to allow speeds of 40, 60, 80 and 100 kph, The resulting curves are a set of demand curves and with them are shown a set of supply curves. In all points, the amount of time consumed is the total 3 mins. time budget irrespective of the amount of travel and money paid.

The group of people behaving according to formula 6.13, i.e., using their total time budget for travelling after route improvement, most spend extra money to do so, as denoted by (M + To). Such a group has the highest rate of generated trips. They are mainly from the 20% highest income group and/or households using a firm's car (the cost of running paid by employer). There is no money constraint, only a constraint from their own time budget. Such a group can be regarded as "saturated" as far as travel is concerned, (Model 1 in Table 7.4) and this accounts for about 35% of total users expenditure on travel (Figure 5.9b).

Figure 7.2 shows that for this model time saved is zero, while extra money increases continuously until it reached 1.46 pence for speed change from 20 to 40 kph. This corresponds to a maximum value of R_t at this range of h, which is defined by

$$h = \frac{V_a}{V_b} = \frac{40}{20} = 2$$

$\therefore R_t = 2$

The rate of generated trips will be increased by 100% for time budget constraint, when speed changed from 20 to 40 kph between a pair of O-D;

and

$$\text{Extra money paid} = R_t A\text{-}B$$

$$= 2(2.041)\text{-}2.615) = 1.46 \text{ pence}$$

where

R_t : rate of trip change = 2 as found above

A : cost per unit distance after = 2.041 (Table 7.a)

B : cost per unit distance before = 2.615 (Table 7.a)

7.2.3 Income Constraint.

In Diagram 7.a some people behave according to the total income constraint. This group spends K_1 resources in after situation where :

$$K_1 \begin{cases} = t_a = \frac{1}{V_a} = \frac{1}{40}\, 60 = 1.5 \text{ mins.} \\ = R = 1 \qquad \text{(fixed travel rate)} \\ = E = RA = 1 \times 2.04 = 2.04 \end{cases}$$

where

t_a : is time after

and all other notations are as defined before.

There will be net savings of money and time, and the rate of generated trip is unity, i.e. no extra trips are wide.

The group of people constrained by their income denoted by (M-T -) (save money & time after route improvement), conventional trip generation models, implicitly, used this concept, because the effect of level of service has been ignored. This might occur only when the traveller feels that he is paying for travel more than he can afford, or the price indices for cost of travel are so high that he is looking for an opportunity to cut the cost of it. Hence there will be a new money budget, to bring him back to point of equilibrium as far as his total expenditure and income is concerned. This applies to households with a lower income, and mainly to the lowest 20% income group which can be regarded as "travel frustrated." More likely this group contains a high percentage of old, unemployed and pensioners (50% of OAP is included within the lowest income group, Transport Policy, 1976) (Model 2 in Table 7.4). The share of this group of households is only 4% of total users expenditure (Figure 5.9b) on car travel.

7.2.4 Travel Money Constraint.

The group of people who are constrained by the amount of money available for car travel consume K_5 units of the resources in the after situation, for a change of speed from 20 to 40 kph, the following values for K_5 in Diagram 7.b can be obtained :

$$K_5 \begin{cases} = B = 2.615 \text{ pence} \quad \text{(money budget)} \\ = R = \frac{B}{A} = \frac{2.615}{2.04} = 1.28 \text{ km} \\ = T_a = R t_a = 1.28 \times 1.5 = 1.92 \text{ mins.} \end{cases}$$

$$e_m = -1.0$$

where

B : cost at speed V_b, in Table 7.a

T_a : travel time after

t_a : travel time after per unit distance

e_m : money elasticity of travel

All other notations as defined before.

From Table 7.a, if one km cost (at speed 20 kph) is 2.615 pence (money budget), fully utilising this money budget, corresponding to formula 6.14a

$$R_m = \frac{B}{A} \tag{6.14a}$$

the procedure of plotting a curve is repeated for money budget constraint in the same way as for time, and is shown in Diagram 7.a for different speeds.

$$R = R_m + (R_t - R_m)P \tag{6.15}$$

$$\text{for } P = 0 \quad \phi_m = 0 \quad e_m = -1.0$$

(money before = money after)

$$R = R_m \tag{6.17}$$

$$R_m = \frac{B}{A} \text{ (100\% of the route improved)} \tag{6.14a}$$

for different portions of the route to be improved.

$$R_m = \frac{B}{B+(A-B)D} \tag{6.14}$$

Figure 7.3 is an application of formula 6.14. The same procedure is applied as for time budget, but for low range improvement (i.e., speed from 20 to 22, 24 .... 40 kph). The values of R (trip rate change) for different values of D (percentage of the improvement in the route) is shown in Figure 7.4, while Figure 7.2 shows that for P (the parameter in formula 6.15) equals zero, i.e., ϕ_m (percentage of extra money) equals zero there is always saving in time.

This model may be applied to people who will naturally take all opportunities to increase their amount of travel to the limit of their financial circumstances. If they were willing to pay a certain proportion of their income (before) towards satisfying their desire for travel, then the improvement brought about by a new level of service will encourage them to make more trips. This group can be households in income group 2, which is mostly transferred from group 1, and obviously seeking higher amount of travel, but they are deterred by their money budget constrains (Model 3 in Table 7.4).

Figure 7.2 shows that for this model extra money paid is zero, while time saved increases continuously until it reaches 65 seconds for speed change from 20 to 40 kph when the whole route is improved, i.e., D = 1 and at this point

$$R = \frac{B}{A} = \frac{2.615}{2.04} = 1.28$$

therefore each trip before becomes 1.28 trips after at the same cost, and

$$\text{Time saved} = K_t - R.t_a$$

$$= [3 -(1.28 \times 1.5)]60 = 65 \text{ seconds}$$

where

K_t : time spent before

R : rate of trip change

t_a : time per unit distance at speed V_a = 40 kph

7.2.5 Generalised Cost Constraint.

The group of people who are constrained by generalised cost budget consume K_6 in terms of time and money in Figure 7.a.

$$K_6 \begin{cases} = R \,.\, t_a & \text{mins.} \\ = R & \text{km} \\ = R \times A & \text{pence} \end{cases}$$

where

$$R = \frac{2\ Bh}{B+Ah} \quad \text{(Generalised cost budget)} \tag{6.46}$$

$$t_a = \frac{1}{V_a}$$

at speed 40 kph.

$$R = \frac{2 \times 2.615 \times 2}{2.615 + 2.041 \times 2} = 1.56$$

$t_a = 1.5$ mins.

$\therefore$

$K_6 = 1.56 \times 1.5 = 2.343$ mins.

$K_6 = 1.56$ km

$K_6 = 1.56 \times 2.04 = 3.187$ pence

$E = -1.0$

e is elasticity of generalised cost of travel.

$$R = R_m + (R_t - R_m)P \tag{6.15}$$

for generalised cost formula, at any level of improvement,

$$\phi_t = \phi_n \tag{6.25}$$

$$P = \frac{\frac{2Bh}{B+Ah} - \frac{B}{A}}{\bar{h} - \frac{B}{A}} \tag{6.30}$$

values for P to satisfy 6.25 found in Table 7.1 for maximum low range of improvement of 20 → 40 kph).

when

$$P = \frac{2}{5} \qquad\qquad e = -1.0$$

(generalised cost before = generalised cost after, generalised cost elasticity = -1.0

$$\phi_t = \phi_m = 22\%$$

on this basis Figure 7.5 represents a generalised cost demand curve, while Figure 7.6 represents the value of R for different values of D.

In Diagram 7.a, the curve R represents the rate of trip change for generalised cost model, which lies between the money constraint (R_m) and time constraint(R_t).

Figure 7.2 shows three curves, for low range speed increase (20 to 40 kph). The case of generalised cost, $P = \frac{2}{5}$ lies between the two extremes; P = 1, P = 0 which corresponds to time and money budget. In this situation the rate of generalised trip given by

$$R = \frac{2Bh}{B+Ah} \qquad (6.28)$$

for speed and cost at 20 to 40 kph.

$$R = \frac{2(2.615)2}{2.615+(2.041)2} = 1.56$$

$$\phi_m = \frac{\text{extra money paid}}{\text{money before}} = \frac{RA-B}{B} 100 = \qquad (6.24)$$

$$= \frac{1.56(2.041) - 2.615}{2.615} = \underline{22\%}$$

$$\phi_t = \frac{\text{time saved}}{\text{time before}} = \frac{h - R}{h} \qquad (6.21)$$

$$= \frac{2 - 1.56}{2} = \underline{22\%}$$

$\therefore\ \phi_t = \phi_m$ satisfies the constraint given by 6.25 consequently, the value of time saved equals to $V_b B$,

$$VOT = 2.615 \times 20 = \underline{52} \text{ pence/hr.} \qquad (6.37)$$

$$VOT = \frac{\text{extra money paid}}{\text{time saved}} = \frac{RA-B}{\frac{1}{V_b} - \frac{R}{V_b h}} = \frac{1.56(2.041)-2.615)}{\frac{1}{20} - \frac{1.56}{20 \times 2}} = \frac{52}{\text{pence/hr.}} \qquad (6.35)$$

It is clear from Figure 7.2 that the generalised cost, represents a compromise between the two extreme cases (case 1 and 2). Furthermore, any percentage increase in money outlay (ϕ_m) is always equalled by the %age of time saved (ϕ_t). The traveller, to behave as in case 3 implicitly values his time in monetary terms as given in formula 6.37, i.e., his value of time equals the cost per unit distance times speed as measured in the "before" situation.

Analysis of the high range of speed increas (20 to 40, 60, 80, and 100 kph) is shown on Figure 7.7. Y axis as ϕ_m and X axis as ϕ_t.

when

P = 1 . $\phi_t = 0$ Time budget

P = 0 . $\phi_m = 0$ Money budget

The 45^o line intersection with P-lines represent the generalised cost model, and it is clear from this figure that P has different values to satisfy $\phi_t = \phi_m$ for different speeds. Values for R, with corresponding P values shown on the figure are presented in Table 7.2 and 7.3.

Using this formula means that the position of the point of equilibrium K_3 is such that it makes $\phi_m = \phi_t$ i.e., the extra money paid as a percentage of money before is the same amount of time saved as percentage of the total time before. This applies to those households in group 3 and 4 which are able, or willing, to pay extra money on top of their original money budget without violating their time budget. They have also, in actual fact, saved an amount of time which is worth the extra money paid (Model 4 in Table 7.4)

One can now draw a clear picture of household behaviour in terms of travel by car, income group, and their responsiveness to the change in resources needed for travel, together with their attitudes towards utilisation of available sources,

As far as generated trips are concerned, different models can be applied to different household income groups.

Table 7.1 represents the effect of values of " on the general formula:

$$R = R_m + (R_t - T_m)P \tag{6.15}$$

For low range improvement. The values of R are shown using 1972 car operating cost formula. It is interesting to note that there is the possibility for the value of R to be below unity, i.e., the after situation will yield fewer trips than the before situation. This might occur due to the introduction of higher parking charges in city centres. For example, for $P = -\frac{3}{2}$, the value of R = 0.86, i.e., each 100 trips made before machine, only 86 trips were made afterwards. This represents a situation where the cost per trip before is less than the cost per trip after charge. Other values of P, resulting in different values of R are as follows:

Table 7.b

Budget	P	R
Income constraint	$-\frac{2}{5}$	1
Travel money constraint	0	1.28
Travel time constraint	1	2.0
Generalised cost constraint	$+\frac{2}{5}$	1.56

The values of R found by this procedure lead to a conclusion that each household income group has different P values. When an improvement takes place on a certain network, the mechanism for determining total generated trips inevitably calls for an estimation of the number of households using the network, classified by income group, with their corresponding position on the trip rate curve. For example, a household in income group 3 or 4, is assumed to behave according to the generalised cost model. If all the routes used by this household is improved from origin to destination (for low range, i.e., speed 20 to 40 kph) it will increase its trip rate by 56%. However, if only half of the route is improved to allow a speed of 40 kph, the trip rate wil be increased only by 20%, as shown in Figure 7.6. This fact must be reflected in any generated trip prediction to assess not only the type and amount of households using an improved route, but also the proportions which the improved route forms of all the origin to destination journeys.

7.3 COMMENTS ON VALUE OF TIME (VOT) FOUND IN THIS STUDY.

The value of time found in this study is represented by the formula 6.37 given by

$$(VOT) = B\ V_b \quad \text{pence/hour} \tag{6.37}$$

where

(VOT) : value of non-working time

B : cost per unit distance (before)

V_b : the speed (before)

The consistency and general agreement with conventional value of non-working time can be presented as follows, bearing in mind the term (before) is relative in this concept, i.e., what is regarded as (after) will become (before) for the next point in time, and this means that there is no fixed value of non-working time even for a single individual, The formula, although originally derived for car trips, will also deal with other modes like bus and train on the same basis.

In conventional cost/benefit analysis it is agreed that the value of non-working time grows 3% per annum. In the model presented here this assumption is replaced by a combination of

(a) average speed is increasing on all roads by 1.5 km/year, and

(b) the cost per unit distance is increasing with time.

Income.

It is also agreed that value of time for people of higher incomes is more than that for lower income groups. This phenomenon can be implicitly recognised if one considers both elements of the formula, cost per unit distance and average speed. Usually, people with higher incomes use larger cars with an engine capacity higher than 1400 cc which is used in operating cost formula, and will obviously lead to a higher running cost. Moreover, there is the ability of this type of car to run at higher speeds.

If this kind of approach is used, many difficulties can be overcome in making assumptions on values attached to time in conventional trip modelling methods.

Vans.

For light vans the value of time is usually higher than that for car occupants, and it is obvious that van operating costs are higher than average car costs (see Appendix-6-).

If cost per km for average car = 2.615 pence/km in 1973
then " " " " " van = 4.00 pence/km in 1973

The value of time as shown in the Appendix 6 is 81 pence/hour for cars and 120 pence/hour for vans, assuming both cars and vans have the same average speed, the ratio of the cost of van to that of car must then equal the ratio of van occupants to car occupants.

$$\frac{4.0}{2.615} = \frac{120}{81} \quad \text{which is almost the case}$$

Moreover, if the value of time of car occupants is 81 pence/hour, then

$$VOT = B\,V_b = 2.04 \times 40 = 81 \text{ pence/hour}$$

This means that the cost formula, implicitly assumed average car speeds for the year 1973 is 40 km/hour. The (VOT) on the same basis, for other modes, can be the cost per unit distance times the speed of the mode.

In terms of transportation planning, people in a lower speed region do not value their time as highly as those with a higher average speed.

If a person living in a zone (A) from which residents can travel with an average speed of 20 km/hour in 1970, is compared with another person in the same year living in another zone (B) from which the average speed of travel is 40 km/hour, then the value of time of person in zone A is

$$2.615 \times 20 = 52 \text{ pence/hour}$$

and the value of time of person in zone B is

$$2.04 \times 40 = 81 \text{ pence/hour}$$

This reflects the socio economic status of the individual in a zone, relating also to their choice of residence. That is, people living in the CBD area with its low average speed, value their time less, and have a different standard of living, to those living outside the CBD.

7.4 APPLICATION OF GENERALISED COST MODEL.

The formula given in 6.40 is a generalised cost formula, including the effects of car occupancy.

$$R = \frac{hB(1 + Y)}{BY + hA} \qquad (6.51)$$

The main assumption behind this model is that the money budget plus monetary value of time budget is the same before and after change, i.e. $e = -1.0$. The total outlay of money plus the monetary value of time for the traveller is constant. R in the formula can be regarded as the number of trips per unit time (person trips). Alternatively, it can be regarded as total distance covered by travellers per unit time.

7.4.1 Thomson's Work, 1967.

Thomson notes that from 1952 to 1964 the vehicle-distance of private traffic in urban areas, and in Great Britain as a whole, rose from 100 to 270 units, while in central London the corresponding change was from 100 to 180 units. Vehicle registration growth outside central London had increased at a rate very similar to that elsewhere. Therefore, he assumed that an increase in generalised cost peculiar to car travel to central London over that period must have accounted for the smaller growth of traffic in central London, i.e., 180 units instead of 270.(Oldfield,1974)

The increased travel cost in London is ascribed to lower journey speeds because of congestion and the imposition of parking charges. Using this assumption the demand elasticity (e) was calculated to be (-1.0) as follows : Peak-hour travel cost of average marginal motorist entering central London :

Value of time	44 pence per hour
Car occupany	1.4
Cost of car journey at speed V,C =	1.0+73.3/V pence per km (including car running costs and occupant's time at speed V km/hour).
Journey length :	9.6 km comprising the following:

2.4 km in central area at 16.9 km/hr. in 1952, and at 13.7 km/hr. in 1964.

5.6 km in inner London at 30.6 km/hr. in 1952, and at 24.2 km/hr. in 1964.

1.6 km in outer London at 30.6 km/hr. in 1952, and at
30.6 km/hr. in 1964.

(these speeds are based on GLC's London Traffic Surveys 1964)

Cost of journey in 1952(pence)		Cost of journey in 1964(pence)	
2.4 km at 16.9 km/hr	12.8	2.4 km at 13.7 km/hr	15.4
5.6 km at 30.6 km/hr	18.9	5.6 km at 24.2 km/hr	22.5
1.6 km at 30.6 km/hr	5.4	1.6 km at 30.6 km/hr	5.4
	37.1		43.3
Parking charges	-		25.0
Total with return journey	74.2		111.6

For the 1964 travel cost Thomson uses a medium all-day parking charge of 25p. The crux of Thomson's argument i that had the cost of 111.6p. per peak car journey been reduced to 74.2p (the same as it was in 1952) then 100 units of traffic would have increased to 270 (as in other urban areas) instead of 180. Therefore a fall in cost from 111.6p. to 74.2p. should produce an increase in traffic of 50% and the elasticity of demand is deduced from

$$\frac{100}{150} = \left[\frac{111.6}{74.2}\right]^{e}$$

$$\text{i.e., } e = -1.0$$

The point of interest here is that it is clear from this example that elasticity of demand is (-1.0). But obviously Thomson used a value of time of 44 pence/hr which is different from the findings of the present work that the value of time is equal to speed in "before" situation times cost of travelling one kilometer. (Oldfield, 1974) commented on Thomson's work, "Another parameter is the value of travel time". Here Thomson used 44 pence per person hour. Investigation to determine this parameter has given rise to values which vary widely (the value recommended by D.O.E. is less than half of Thomson's value), and it is interesting to consider the effect of using another value.

The elasticity values shown in Table 7.c were obtained using values of time of 44 pence and 22 pence per hour and with urban area generalised car cost changing by 10 and 20 per cent over 1952 to 1964. Two central London parking charges are assumed 25p. and 20p.)

Table 7.c

Percentage change in urban area generated car cost, 1952-1964	Elasticity					
	-20	-10	0	+10	+20	Central London parking charges
Value of time 44 p/h	-0.6	-0.8	-1.0	-1.3	-1.8	25p.
Value of time 22 p/h	-0.6	-0.7	-0.8	-1.0	-1.3	
Value of time 44 p/h	-0.7	-0.9	-1.1	-1.5	-2.3	20p.
Value of time 22 p/h	-0.7	-0.8	-1.0	-1.2	-1.7	

Source : TRRL 116 UC

It may be commented that even if Thomson had used the value of time which is found in this study and given by

$$(VOT) = V_b \; B \tag{6.37}$$

the same result concerning the unitary generalised cost of elasticity can be obtained as follows : the cost formula used by Thomson is

$$C = 1.0 + \frac{73.3}{V} \text{ pence per kilometre}$$

(this value includes car running cost and occupants time at speed V kph). Car occupancy assumed by Thomson was 1.4, to remove value of time suggested by Thomson, 44 pence/hr/person

$$C = 1.0 + \frac{73.3-1.4(44)}{V} = 1.0 + \frac{11.7}{V} \tag{7.3}$$

using this cost formula for cost of both after (A) and before (B) as in the following table, using the formula given by 6.49

$$R = \frac{[B(1 + Y)]\bar{L}_b}{\left[\frac{YB}{h} + A\right]\bar{L}_a} \tag{6.49}$$

Table 7.d

After (1952)		Before (1964)	
$\left[\frac{1.4B}{h} + A\right] \times$ Length		$[2.4\ B] \times$ Length	
$\frac{1.4 \times 1.85}{1.23} + 1.69 \quad 2.4 =$	9.11	$2.4 \times 1.85 \times 2.4 =$	10.68
$\frac{1.4 \times 1.48}{1.26} + 1.38 \quad 5.6 =$	16.94	$2.4 \times 1.83 \times 5.6 =$	19.94
$\frac{1.4 \times 1.38}{1} + 1.38 \quad 1.6 =$	5.3	$2.4 \times 1.36 \times 1.6 =$	5.3
	31.36		35.95
Parking charges	-		25.00
Total two way	62.72		96.85

$$R = \frac{GC_b}{GC_a}^{e} = \frac{96.85}{62.72}^{.94} = 1.5$$

In other words, elasticity of demand using the method and (VOT) formulated in this study is -0.94 instead of -1.0 found by Thomson.

where

Y : is car occupancy

$\bar{L}_b$: average trip length (before)

$\bar{L}_a$: average trip length (after)

Other notations as defined before.

Costs at different speeds given in 7.3 for values of A and B in operating cost formula given above are found as in Table 7.d with corresponding trip lengths. In this example, 1964 situation is before, because the assumption is that if the speed increased and parking charges are eliminated, there will be 50% increase of traffic i.e., R = 1.5. The figures used in this example are all probably expanded from a sample size; the original figures used are :

Table 7.e

1952	1964	Traffic index in:
100	270	Urban area
100	180	Central London
	90	Difference

$$\frac{90}{180}\ 100 = 50\%$$

These are the indices used. It is possible to use the following values instead :

Table 7.f

1952	1964	Traffic index in:
100	272	Urban area
100	177	Central London
	95	Difference

$$\frac{95}{177} = 54\%$$

Here there is an alteration of less than ±2% in 1964 indices, errors due to sampling expansion will probably be greater than this.

If the new values as in Table 7.f are used, then :

R = 1.54 and elasticity = -1.0

Oldfield (1974) stated that "Car user's elasticity relative to generalised costs were more closely grouped about the value -1.0".

7.4.2 The Work of Sacco and Hajj, 1976

In order to produce more evidence, and to give extra confidence in the reliability and applicability of the generalised cost model, examination was made on the effect of the energy shortage on transportation patterns and attitudes to car usage.

A study of Dutch Fork area in Columbia, South Carolina (Sacco and Hajji, 1976) found that for a petrol price change from about \$0.35 to \$0.55/gallon between October 1973 and May 1974, the average reduction of traffic on a certain highway reached 12.7 percent.

Applying the model given by formula 6.46 where

$$R = \frac{2B}{\frac{B}{h} + A} \qquad (6.46)$$

To find elasticity of generalised cost :

$$R = 1 - 0.127 = 0.873$$

$$h = \frac{V_a}{V_b} = 1$$ assuming no increase in speed for this amount of volume change.

$$B = 2P_b \qquad (7.1)$$

where

P_b : petrol price before, and on basis 50% of B is petrol price.

$$\therefore\ 2B = 4P_b$$

Substitute the values of R, h and B in 6.46

$$\therefore\quad .373 = \frac{4\ P_b}{\frac{2\ P_b}{1} + A} \qquad (7.2)$$

$$\therefore\quad A = 2.582\ P_b \qquad (7.3)$$

(A) consists of two elements, fuel cost and labour and materials. The increase in petrol price in the short period between October 1973 and May 1974 did not change the labour element of A.

Set

$$A = (X_p + X_L)\ A \qquad (7.4)$$

where

X_p : petrol cost element of A

X_L : labour cost element of A

and

$$X_p + X_L = 1 \qquad (7.5)$$

The new situation brought about by petrol price increase changed the values of these two elements.

Assuming :

$$\frac{X_p}{X_L} = 1.5 \qquad (7.6)$$

from 7.5 and 7.6

$$\therefore \quad X_p = .6 \quad \text{After} \qquad (7.7)$$

$$X_L = .4 \quad \text{After} \qquad (7.8)$$

while for before $X_p = .5$ and $X_L = .5$

$$P_a = AX_p \quad \text{from (7.4)}$$

$$\therefore \quad .6A = P_a \qquad (7.9)$$

$$\text{and} \quad .4A = .67\ P_a \qquad (7.10)$$

$$\therefore \quad A = P_a + .67\ P_a = 1.67\ P_a \qquad (7.11)$$

from 7.3 and 7.11.

$$\therefore \quad 1.67\ P_a = 1.252\ P_b$$

$$\therefore \quad P_a = 1.55\ P_b \qquad (7.12)$$

In other words, petrol price after must equal 1.55 time petrol price before, so that 12.7% of traffic would be reduced.

P_a = Petrol price after = 55 cent/gal. 1974

P_b = Petrol price before= 35 cent/gal. 1973

$$\therefore \quad P_a = \frac{55}{35}\ P_b = 1.56\ P_b$$

These two values (1.55 and 1.56) are close enough to conclude the validity of the model and the assumption about unity of generalised cost elasticity of demand.

Another finding of the study of Sacco and Hajj was the respondent's assessment of their reduction in driving as shown in the following table.

Table 7.g

Reduction		Respondent
Amount	Percent	percent
considerable	30	15.8
moderate	10 to 30	40.6
little	2 to 10	28.1
none	0 to 2	15.5
Total		100.0

Average reduction = 15%

Source : Sacco and Hajj, 1976.

The respondents were asked how much the change in petrol price made to their personal or family driving habits. Average respondent's reduction is 15% against observed reduction of 12.7% revealed by traffic volume counting as shown in Table 7. The respondents have different attitudes towards reduction in car travel. This confirms clearly the impact of household income on such a policy as increasing petrol price.

Table 7.h

Change in average traffic volume

Month	Year	Average daily traffic change
October	1973	-
November	1973	-2.8
December	1973	-10.7
January	1974	-12.7
February	1974	-8.5
March	1974	-8.6
April	1974	-3.1

Source : Sacco and Hajj, 1976.

Table 7. shows that the observed reduction was gradual, indicating that the perceived price of petrol is also gradual, and it diminishes after some time because the wage increase at later stages will cancel out this effect.

7.5 EXAMPLES OF SUDDEN PETROL PRICE CHANGE ON TRAFFIC.

Consider if it is wanted to reduce the traffic on the roads by 50%, then by how much must the cost of travel be increased? Knowing that 50% of the operating cost comprises the price of fuel.

Formula 6.46

$$R = 1.0 - 0.5 = 0.5$$

$$h = \frac{V_a}{V_b} = 1.5 \text{ (increase in speed because of speed-flow relationship)}$$

$$.5 = \frac{2B}{\frac{B}{1.5} + A} \qquad (6.46)$$

$$.33B + .5A = 2B$$

$$A = \frac{1.57}{.5} B = 3.34 \ B$$

$$= 6.68 \ P_b \quad (B = 2 \ P_b)$$

$$X_p + X_L = 1 \qquad (7.5)$$

$$\frac{X_p}{X_L} = 3 \quad \text{(assumed)} \qquad (7.6)$$

$$X_p = .75 \qquad (7.7)$$

$$X_L = .25 \qquad (7.8)$$

$$P_a = AX_p \quad \text{(from 7.4)}$$

$$\therefore \quad .75A = P_a$$

$$.25A = .33\ P_a$$

$$\therefore \quad A = P_a + .33\ P_a = 1.33\ P_a$$

$$\therefore \quad 1.33\ P_a = 6.68\ P_b$$

$$\therefore \quad P_a = 5\ P_b$$

that is to say the petrol price must be increased five-fold to reduce traffic by 50% on the roads.

This is confirmed by Webster, 1977 and we quote the following from TRRL 771. "One way of transferring people from cars to buses if this was desired, would be to make all car travel expensive irrespective of destination. This could be achieved by raising fuel prices but the use of the TRRL model LUTE indicated that fuel price would have to be increased five-fold before the mean journey distance by car was halved". If the policy of increasing petrol price by five-fold is not practical, what will be the petrol price for 20% reduction in traffic?

$$R = 1 - .2 = .8$$

$$h = 1.2 \qquad \text{(assumed)}$$

$$\therefore \quad .8 = \frac{2B}{\frac{B}{1.2} + A}$$

$$.67B + .8A = 2B$$

$$\therefore \quad A = 3.33\ P_b$$

$$X_p + X_L = 1$$

$$\frac{X_p}{X_L} = 1.25 \quad \text{(assumed)}$$

$$\therefore \quad X_p = .55$$

$$X_L = .45$$

$$\therefore \quad .55A = P_a$$

$$\therefore \quad .45A = .8\ P_s$$

$$A = P_a + .8\ P_a = 1.8\ P_a$$

$$\therefore \quad 1.8\ P_a = 3.33\ P_b$$

$$P_a = 1.85\ P_b$$

This indicates, that for petrol price to be altered from 75 pence per gallon to 138 pence per gallon one might expect 20% reduction in car trips. However, this situation might lead to some transference of people from cars to other modes. For increasing R by 50%

$$R = 1.5$$

$$h = .8$$

$$1.5 = \frac{2B}{\frac{B}{.8} + A}$$

$$1.5A = .125\ B$$

$$A = 0.0833\ B$$

$$= .1666\ P_b$$

$$X_p + X_L = 1$$

$$\frac{X_p}{X_L} = 4$$

$$X_p = .8$$

$$X_L = .2$$

$$.8A = P_a$$

$$.2A = .25\ P_a$$

$$\therefore \quad A = P_a + .25\ P_a = 1.25\ P_a$$

$$\therefore \quad 1.25\ P_a = .1666\ P_b$$

$$\therefore \quad P_a = 0.133\ P_b$$

indicating that reducing petrol price from 75 pence/gallon to 10 pence/gallon, the traffic will increase by 50%. Alternatively, what happens if petrol price is reduced by 20%

$$R = ?$$

$$h = 1$$

$$B = 4\ P_b \qquad R = \frac{4\ P_b}{\frac{2\ P_b}{1} + A}$$

$$X_p + X_L = 1$$

$$\frac{X_p}{X_L} = .8$$

$$X_p = .445$$

$$X_L = .555$$

$$.445\ A = P_a$$

$$.555\ A = 1.25\ P_a$$

$$A = P_a + 1.25\ P_a = 2.25\ P_a$$

$$P_a = .8\ P_b$$

$$A = 1.8\ P_b$$

$$R = \frac{4\ P_b}{2\ P_b + 1,8\ P_b} = \frac{4}{3.8} = 1.05$$

The traffic will be increased by only 5% for 20% reduction in petrol price.

The changes in petrol price and in speed for the two situations Before and After as outlined in this section use the generalised cost formula. The car operating cost formula for 1973 is presented diagramatically in Figure 7.8, with the resultant change in value of (R) rate of trip change. In Figure 7.9 a perspective response surface is shown for generated trips with the variation of speed from 20 kph to 40 kph and with different amounts of the route improvement, based on the 1973 data.

It must be noticed that households will lie on different points of the response surface, each according to its position in the study area with respect to the route improved.

The two main factors in the model are the effect of monetary change in the cost of trip, & change in the speed of travel on the network (reflected in the values of both (A) and (h)). While the increase in petrol prices (in real term and introducing parking charges reduce the amount of car travel, the provision of higher speed will increase it.

Both situations represent present day frustrations, firstlyconcerning the environmental impact of car trips on CBD areas, and secondly the poor quality of roads which exist in many areas. This is the important fact of urban life, which is why people ask for better roads. These increase trips by such amount that both user and non-user may suffer afterwards.

There is no simple solution for this paradox inherent in transportation planning. An examination of the model (formula 6.46) reflects exactly this conflict, i.e., it shows how to increase R (number of trips), wanted by a group of people, but in consequence the same group of people, and others also, request a reduction of (R). The compromise between a fair amount of travel without disturbing the environment, needs more than just planning aspects into modelling, which has not yet been investigated.

7.6 SUMMARY AND CONCLUSIONS.

The resources needed for travel consist of both time and money. Each household has a fixed amount of money allocated for travel (travel money budget). The share of travel by each mode depends on the level of service provided by that mode. In addition, there is a travel time budget. These two budgets are interrelated and by different amounts according to household economic status.

Network improvement yields higher speeds for car travellers. Consequently there is a saving in time for the traveller and this implies an increase to his real income if he places any monetary value in time savings. This may encourage the traveller to increase his number of trips, which results in a willingness to pay some extra money by an amount to bring him to a new equilibrium point in the trade-off between time and money.

Any network change affects the relative price of the various commodities or activities to which he allocates his time and money. This is because the components of their price to him, which consists of the generalised cost of travel, has changed. In general, he may be expected to shift his behavior in favour of those activities whose price, in terms of generalised cost, has fallen most. That is, he will tend to change his travel patterns in favour of activities which are at further distances from his location and away from activities which he formally carried out at or near home. The frequency, destination and length of the trips he makes will be increased as a result. These were the various possible reactions to change in the users cost of the transport network as outlined in this chapter.

From the summary on Table 7.4 the following points can be concluded:

Households behave differently in their desire for tripmaking and their response to changes in the lvel of service provided. In order to be precise, different generated trip models must be applied appropriately for each household income group. For example; that group of people who have access to firm's car, the expense of which is borne by the employer, have only the constraint of their own time. This would typically be a high income group, with a consequent characteristic of high appreciation of time, i.e., their time budget will be the same Before and After (Model 1) 1). By contrast, there is the lowest 20% income group who are more transport deprived - especially in car travel. This is shown by their trends of household income and expenditure on running a car. This group will take the opportunity of saving money by not increasing their rate of trips Before and After. They may even lessen their trips if costs go up - as with a fuel price increase (Model 2).

Households in group 2 are likely to continue spending the same money budget on travel by car Before and

After. If there was real improvement, i.e., decrease in cost and time of trip, this group would tend to increase trip rate to a limit permitted by money budget (Model 3).

Lastly, there are the households in the third and fourth income groups. Here the time saved may be appreciated as extra money, even if used for leisure; the rate of trips will rise according to generalised cost budget (Model 4). This indicates clearly that people with different economic backgrounds respond differently to the level of service provided by a transport facility, and each group will behave according to the constraint put on them.

The generated trip models can be a guide for predicting traffic for short range periods, i.e., opening a new motorway, bridge, etc., or investigating the effect of petrol price change on behaviour of travellers in trip-making.

It has been recognised that possibly the generated trip diminishes as the other components grow and crowd it out. Therefore, for long range planning, the model applicable is "General Share Model" which takes account of both generated trips and trip generation, which effectively means joining the trip generation box (as discussed in Chapter 1 (see Figure 1.1.)) with network analysis box. (i.e., the missing arrow mentioned by Wilson (section 6.1) has thus been put back). A further discussion of this concept follows in the next chapter.

CHAPTER 8

TRAVEL PREDICTION, 3

APPLICATION OF GENERAL SHARE MODEL (GSM)

CAR TRIPS

8.1 INTRODUCTION

For long term planning the trip generation could be based on application of GSM to private travel (car trips) and public transport (person trips).

The GSM as formulated in Chapter 6 is applied to compute average trip rate made by households of different income for different trip purpose. The results are presented in the form of tables and diagrams which could be used as a guide for predicting total trip origins at a zonal level.

In this chapter,only car trips are considered, so eventually the subscript used for type of mode (K) is dropped from the formula. The discussion is based on a time unit of one week and trip rates are thus "average weekly" trips. For more specific daily, peak and off-peak trips, the past trend in travel variations can be related to average weekly rates.

The data given in FES reports, 1972, concerns income and expenditure on running a car. Information about travel characteristics is given in NTS 1972/73. These two sets of data can be combined to produce average trip rates. Other important information about car operating costs, given in TRRL report 661 for year 1973, are used although assumptions are made concerning average speeds The available data is used at different levels of disaggregation: First, on average household with only one average speed for all trip purposes : Second, by household income group both on one average speed and for different average speeds by purpose of trip.

Car trip characteristics as given by NTS for year 1972/73 are shown in Table 8.a.

Table 8.a

Purpose	Description	% distance	% trip
1	To and from work	25	31
2	In course of work	19	9
E	Education	-	-
3	Shopping	13	20
4	Entertainment	7	8
5	Personal, social	17	15
6	Holiday, pleasure	19	17
	Total	100	100

Total number of households in the sample = 7,113
Total number of trips = 78,593
Total distance travelled (km) = 964,915

Source : NTS 1972/73

8.2 NOTATIONS AND TABLES

The notations used in application of General Share Model (GSM) for car trip generation are composed of three parts : first the notation for observed data, second the notation for predicted values of observed data and finally the common notations.

H_o : Total number of households in zone of origin, O
H_i : Number of households in zone O, with income group i
P_i : Percentage of households in zone O, wtih income i

Z_1 : Total distance travelled by H_o
$Z_{1i\ell}$: Distance travelled by household in income group i for purpose ℓ
$Z_{1\ell}$: Distance travelled by average household, for purpose ℓ

Z_2 : Total number of trips made by H_o

$Z_{1i\ell}$: Number of trips by household in income group i, for purpose ℓ

$Z_{2\ell}$: Number of trips by average household for purpose ℓ

$\bar{X}$: Average-overall-trip length

$\bar{X}_{i\ell}$: Average trip length for household income group i, for purpose ℓ

X_ℓ : Trip length for average household, for purpose ℓ

C_a : Average-overall-cost per unit distance

$C_{i\ell}$: Average cost per unit distance for household income i, purpose ℓ

C_ℓ : Cost per unit distance for average household, for purpose ℓ

$\bar{C}$: Average-overall-cost per trip

$\bar{C}_{i\ell}$: Average cost per trip for household income i, purpose ℓ

$\bar{C}_\ell$: Cost per trip for average household, for purpose ℓ

ν : Average-overall-speed

$\nu_{i\ell}$: Average speed for household income i, purpose ℓ

ν_ℓ : Speed for average household for purpose ℓ

S_ℓ : Percentage distance travelled for purpose ℓ by H_o

$S_{i\ell}$: Percentage distance travelled by household income group i for purpose ℓ

K_ℓ : Percentage of trips for purpose ℓ, by H_o

$K_{i\ell}$: Percentage of trips for purpose ℓ, by household income i

M : Average household income

M_i : Average household income in group i

N : Percentage of M, spent on running of car

N_i : Percentage of M_i, spent on running of car

E : Money spent on running of car for average household

E_i : Money spent on running of car by income group i

P_ℓ : Percentage of E or E_i spent on travel for purpose ℓ

F : Correction factor

t : Trip rate per week for all purposes

$t_{i\ell}$: Trip rate by income group i, purpose ℓ

t_ℓ : Trip rate for average household, purpose ℓ

T : Total number of trips

T_i : Number of trips for household income group i, all purposes

Q_ℓ : Trip rate for purpose ℓ

$\bar{Q}_\ell$: Average trip rate for purpose ℓ

Q : Total trip rate

1 - for these values see Tables 8.a, b and c, as well as Table 8.1

2 - Predicted values of these notations will appear with additional superscript of (P) for example, predicted value of S_ℓ will be S_ℓ^P

From this notation it is clear that the level of disaggregation is given on three levels :

1. Average overall for the zone, i.e., assuming all trips is of the same nature. The same trip length and average speed is assumed for all purposes. This means only one value for each variable.

2. For household in income groups by purpose of trip, it is possible that there exists different average trip lengths (for same trip purpose) for different household income groups, and different speeds for different purpose and so on. This means different matrices can be constructed for each variable.

3. For average household, it is convenient to produce variables for each trip purpose.

However, the level of disaggregation depends mainly on the data availability and the nature of the study.

The combination of these three levels of disaggregation might be adequate in some circumstances. For example disaggregation of households into income groups, and different time lengths for each purpose, common to all household income groups might be appropriate for some calculations.

Although variables are based on an average for the whole area, there is a possibility that each zone or group of zones has its own trip characteristics reflecting its accessibility. For a more detailed study it would be appropriate to deal with each zone in the study area separately.

Table 8.b

i Income group	M_i Income per week £	N_i Expenditure on car for all trips %	E_i £
1	13	2.1	0.28
2	26	4.11	1.07
3	38.7	4.87	1.85
4	50.3	5.16	2.60
5	86.1	4.65	4.80
Average	42.82	4.57	1.96

Source : FES 1972

Table 8.c

Purpose ℓ	Trip purpose	% of total mileage S_ℓ	% of total trip K_ℓ	Average trip length $\bar{X}_\ell$ (km)
1	Work	25	31	9.7
2	In course of work	19	9	25.3
3	Shopping	13	20	7.8
4	Entertainment	7	8	10.5
5	Personal, social	17	15	13.6
6	Holiday, pleasure	19	17	13.4
	Total	100	100	

Source : NTS 1972/73

To evaluate P , percentage of expenditure allocated to travel for purpose ℓ, a correction must be applied to the values of S_ℓ (percentage distance travelled for purpose ℓ) as follows :

$$P_\ell = S_\ell \; F \tag{6.54}$$

$$F = \frac{C_\ell}{C_a} \; \frac{\sum_\ell S_\ell}{\sum_\ell S_\ell \frac{C_\ell}{C_a}} \tag{6.55a}$$

The notations are as given before. The value of F is in reality a weighted factor applied to the value of S_ℓ in cases only when cost per unit distance is different for different purposes. The value of P_ℓ on this basis, may be calculated using the values of S_ℓ given in Table 8.c, with other values for costs obtained from the operating cost formula for 1973 as given in TRRL 661, and Table 8.d constructed.

Table 8.d

Average cost/unit distance $C_a = \dfrac{\sum^{r} C_\ell}{r}$

$= \dfrac{2.615+2.37+2.15+2.11+2.04+1.95}{6} = 2.206$ pence

		$P_\ell = S_\ell F$
% expenditure on work trip	$=S_1 \frac{C_1}{C_a} = 25\frac{2.615}{2.206} = 29.6$	29
" " " purpose 2	$=S_2 \frac{C_2}{C_a} = 19\frac{2.37}{2.206} = 20.4$	20
" " " " 3	$=S_3 \frac{C_3}{C_a} = 13\frac{2.15}{2.206} = 12.7$	12.4
" " " " 4	$=S_4 \frac{C_4}{C_a} = 7\frac{2.11}{2.206} = 6.7$	6.6
" " " " 5	$=S_3 \frac{C_5}{C_a} = 17\frac{2.04}{2.206} = 15.7$	15.5
" " " " 6	$=S_6 \frac{C_6}{C_a} = 19\frac{1.95}{2.206} = 16.8$	16.5
	$\sum_1^r S_\ell \frac{C_\ell}{C_a} = 101.9$	$\Sigma = 100$

Values of C_1, C_2, C_3, C_4, C_5 and C_6 are from car operating cost formula for 1973, given by $C = 1.29 + \frac{26}{\nu} + 0.000045\nu^2$, speeds assumed are 20, 25, 30, 35, 40 and 60 kph for purpose 1 to 6 respectively.

From these notations, the following expressions are true : (Note that the unit time is a week).

$$\text{Average trip length} = \frac{\text{Total distance travelled in zone 0}}{\text{Total number of trips in zone 0}}$$

$$\therefore \quad \bar{x} = \frac{Z_1}{Z_2} \quad \text{(observed, all purposes)} \qquad (8.1)$$

$$\text{Average trip length for purpose } \ell = \frac{\text{Distance travelled for purpose } \ell}{\text{Number of trips for purpose } \ell}$$

$$\therefore \quad \bar{X}_\ell = \frac{Z_1 S_\ell}{Z_2 K_\ell} = \bar{X}\ \frac{S_\ell}{K_\ell} \quad \text{(observed)} \tag{8.2}$$

where values of S_ℓ, K_ℓ and $\bar{X}_\ell$ can be found in Table 8.c.

Cost per trip for purpose ℓ = Average trip length for purpose ℓ x Cost per unit distance for purpore ℓ

$$\therefore \quad \bar{C}_\ell = \bar{X}_\ell \cdot C_\ell \tag{8.3}$$

$$\text{and} \quad \bar{C} = C_a . \bar{X} \tag{8.3a}$$

Money spent on running of car by household income group i

= Average household income in group i x percentahe of expenditure on running of car

$$\therefore \quad E_i = M_i\ N_i \quad \text{(see Table 8.b)} \tag{6.42}$$

Average cost per unit distance for all purposes

$$= \frac{\text{summation of cost per unit distance for all purposes}}{\text{number of purposes}}$$

$$\therefore \quad C_a = \frac{\sum_{\ell=1}^{r} C_\ell}{r} \tag{8.4}$$

for equal cost per unit distance for all trip purposes

$$C_a = C_\ell \cdot \tag{8.4a}$$

percentage distance travelled for purpose ℓ

$$= \frac{\text{distance travelled for purpose } \ell}{\text{total distance for all purposes}}\ 100$$

$$\therefore \quad S_\ell = \frac{Z_{1\ell}}{Z_1}\ 100 \tag{8.5}$$

percentage trips made for purpose ℓ

$$= \frac{\text{number of trips for purpose } \ell}{\text{total number of trips}}\ 100$$

$$\therefore \quad K_\ell = \frac{Z_{2\ell}}{Z_2}\ 100 \quad \text{(observed)} \tag{8.6}$$

percentage expenditure on running of car for purpose ℓ

= (percentage distance travelled for purpose ℓ) x (correction factor)

$$\therefore \quad P_\ell = S_\ell\ F_\ell \tag{8.7}$$

and

$$F_{\ell} = \frac{C_{\ell}}{C_a} \cdot \frac{\sum_{1}^{r} S_{\ell}}{\sum_{1}^{r} S_{\ell} \frac{C_{\ell}}{C_a}} \quad \text{(see Table 8.c)} \tag{8.9}$$

$$\therefore \quad P_{\ell} = S_{\ell} \frac{C_{\ell}}{C_a} \cdot \frac{\sum_{1}^{r} S_{\ell}}{\sum_{1}^{r} S_{\ell} \frac{C_{\ell}}{C_a}} \tag{8.10}$$

Car trip rate for purpose ℓ by household income group i

$= \dfrac{\text{Expenditure of household income group i on running of car x percentage expenditure for purpose } \ell}{\text{cost per trip for purpose } \ell}$

$$\therefore \quad t_{i\ell} = \frac{E_i \; P_{\ell}}{\bar{C}_{\ell}} \tag{6.41b}$$

Car trip rate for all households, all purposes

$= \dfrac{\text{expenditure on car travel}}{\text{average overall trip cost}}$

$$t^P = \frac{E}{\bar{C}} \quad \text{(predicted)} \tag{6.41a}$$

From observations

trip rate $= \dfrac{\text{total number of trips}}{\text{number of households}}$

$$t = \frac{Z_2}{H_o} \quad \text{(observed)} \tag{8.11}$$

In Table 8.1

Total car trip rate for purpose ℓ by all households

= summation of trip rate for purpose ℓ for all households income groups

$$\therefore \quad Q_{\ell} = \sum_{i=1}^{q} t_i \quad \text{(column summation)} \tag{8.12}$$

Average car trip rate for purpose ℓ

$= \dfrac{\text{total car trip rate for purpose } \ell}{\text{number of households}}$

$$\therefore \quad \bar{Q} = \frac{Q_\ell}{\Sigma i} \tag{8.13}$$

Predicted total car trip rate by household income group i for all purposes.

= summation of trip rate for all purposes by household income group i

$$\therefore \quad T_i = \sum_{\ell=1}^{r} t_{i\ell} \qquad \text{(row summation)} \tag{8.14}$$

then

$$\sum_{\ell} Q_\ell = \sum_{i} T_i = T \tag{8.15}$$

and

$$K_\ell^P = \frac{Q_\ell}{T} 100 \qquad \text{(predicted)} \tag{8.16}$$

(see 8.6 for observed)

Predicted total distance travelled by all households for all purposes

= (summation of trip rates of all purposes for all households) x
(average trip length by purpose)

$$Z_1^P = \sum_i \sum_\ell t_{i\ell} \bar{x}_{i\ell} \quad \text{(predicted)} \tag{8.17}$$

predicted percentage distance travelled for purpose ℓ by household income group i = S_ℓ^P.

$$\therefore \quad S_\ell^P = \frac{\sum_{i}^{q} t_{i\ell} \bar{x}_{i\ell}}{\sum_{i}^{q} \sum_{\ell}^{r} t_{i\ell} \bar{x}_{i\ell}} \cdot 100 \tag{8.18}$$

This formula tells that the percentage of distance travelled for purpose ℓ, is equal to summation over all income groups and over all purposes, of trip rate for purpose ℓ, times average trip length for purpose for households in income group i, (because there is possibility of existence of different trip length for the same purpose for different household income group), divided by the summation over all trip rate for all purposes and all households. However, on the assumption that different household income groups have the same average trip length for the same trip purpose, equation 8.18 can be reduced to

$$\therefore \qquad S_\ell^P = \frac{Q_\ell \bar{X}_\ell}{\sum_\ell Q_\ell \bar{X}_\ell} 100 \qquad \text{(predicted)} \qquad (8.19)$$

predicted average trip length for all purposes.

$$\bar{X}^P = \frac{\sum_i \sum_\ell t_{i\ell} \bar{X}_{i\ell}}{T} \qquad \text{(predicted, all purposes)} \qquad (8.20)$$

predicted average trip length for purpose ℓ .

$$\bar{X}_\ell^P = \bar{X}^P \frac{S_\ell^P}{K_\ell^P} \qquad (8.21)$$

8.3. TRIP RATES FOR AGGREGATE DATA

8.3.1 Trip Rates for Average Household, all purposes.

The observed data given in Table 8.a, b, c and d,all all abstracted from NTS 1972/73 and FES 1972, on the basis of average household income. From these observations the following variables can be computed :-

$$\text{Average trip length} = \frac{\text{Total distance travelled by all households}}{\text{Total number of trips}} \qquad \text{(all purposes)}$$

$$\bar{X} = \frac{Z_1}{Z_2} \qquad (8.1)$$

$$\therefore \qquad \bar{X} = \frac{964{,}915}{78{,}593} = 12 \text{ km (Table 8.a)}$$

$$\text{Average trip per household} = \frac{\text{Total number of trips}}{\text{Number of household}}$$

$$t = \frac{Z_2}{H_o} \qquad (8.11)$$

$$t = \frac{78{,}593}{7{,}113} = 11 \text{ trip/week}$$

(observed, Table 8.a)

Therefore the observed trip rate per household per week is equal to 11 trips for all purposes. On the other hand to predict the number of trips, by relating the household expenditure and trip cost with the number of trips made per household per week, one can proceed as follows :

$$\text{Average trip rate} = \frac{\text{expenditure on travel}}{\text{average trip cost}}$$

$$\therefore \qquad t = \frac{E}{\bar{C}} \quad \text{(predicted)} \qquad (6.41a)$$

$\bar{C}$ can be found from operating cost formula for 1973 given by TRRL report 661 :

where

$$\text{cost} = 1.29 + \frac{26}{V} + 0.000063\,V^2 \quad \text{pence/km}$$

assuming average speed for the data given on national basis for all purposes, = 40 km/hr.

$$\text{cost} = 2.041 \text{ pence/km}$$

$$\therefore \bar{C} = \text{cost per unit distance} \times \text{average trip length}$$
$$= 2.041 \times 12 = 24.5 \text{ pence/trip}$$

This indicates that the average household spends 24.5 pence per trip in 1973 for average trip length of 12 km.

Expenditure on car travel as given in Table 8.b.

$$E = MN \qquad (6.42)$$

where

M = average household income per week

N = percentage of income spent on travel by car.

$$\therefore E = 42.82 \times (4.57\%) = 196 \text{ pence/week.}$$

$$\therefore t = \frac{196}{24.5} = 8 \text{ trip/week} \qquad \text{(predicted)}$$

Therefore, average predicted trip per household per week is equal to 8 trips for all purposes.

$$\text{percentage explained} = \frac{\text{number of trips predicted}}{\text{number of trips observed}}\,100$$

$$= \frac{8}{11}\,100 = 72\%$$

This variation is mainly due to the fact that not all household trips which are observed are paid by the households. Firms and companies contribute substantially by giving help towards car running costs, or in some cases by actually providing a car for the exclusive use of their employees. In support of this, the following is quoted from Transport 2000, 1976 : "the National Travel Survey is helpful in indicating some of the benefits paid or provided by employers to car using employees. Business expenses of some sort or other were received by 28% of all car owners and 22% of privately registered car".

In 1972 there were 12.7m cars in Britain. 40% - 60% of all new cars are company registered. 65% of all British executives have company cars against 38% in the United States (Hamer, 1974). However, other reasons for the discrepancy between 11 trips per week observed and 8 trips per week predicted are :

1. The speed is only assumed.

2. The vehicle operating cost formula is not applicable for periods outside its range. There is the possibility that household income groups might experience different cost per unit distance for the same trip purpose. The items included in operating cost are slightly different from that of FES.

3. The same percentage of distance, and number of trips were applied to all household income groups; these characteristics might differ by income group.

4. The NTS 1972/73 contains data for two different years, while application of expenditure based on FES Report considered only data for 1972.

5. Although the samples came from the same population, the sample of FES is different from that of NTS, i.e., implicitly it was assumed that households in NTS had the same income distribution (20% in each income group). If the income distribution of households in NTS sample is not similar to that in the FES survey then a bias can be expected.

It is worth remembering that the value of time used in TRRL Report 1973 is 81 pence per hour, on the basis of average speed 40 km/hr, the value of time according to this study is 40 x 2.041 = 81 pence/hr. speed multiplied by cost per unit distance.

8.3.2 Trip Rate for Average Household by Purpose of Trip.

It became clear in Section 8.2 that average trip length for purpose ℓ is given by :-

$$\bar{X}_\ell = \bar{X} \frac{S_\ell}{K_\ell} \tag{8.2}$$

where all the terms are as defined before.

Table 8.c shows that average work trip length which is given by :-

$$\bar{X}_{work} = \bar{X} \frac{S_{work}}{K_{work}}$$

$$= 12 \frac{25}{31} = 9.7 \text{ km (purpose 1)}$$

on the same basis, average trip length is worked out for all other purposes.

The formula given by 6.41b

$$t_{K\ell} = \frac{E\ P_{K\ell}}{\bar{C}_{K\ell}} \tag{6.41b}$$

This can be reduced to

$$t_\ell = \frac{E\ P_\ell}{\bar{C}_\ell} \text{ (for mode of car)}$$

In the situation of only one speed assumed for all purposes, the value of P_ℓ can be shown to be equal to S_ℓ, i.e., percentage of E, allocated for travel for purpose ℓ is equal to percentage distance travelled for purpose ℓ.

i.e., $P_\ell = S_\ell$ or $F = 1$ (8.7)

This can be shown by :-

$$P_\ell = S_\ell \frac{C_\ell}{C_a} \frac{\sum_1^r S_\ell}{\sum_1^r S_\ell \frac{C_\ell}{C_a}} \tag{8.10}$$

Average cost per unit distance is equal for all trip purposes in this case.

$$\therefore \quad C_\ell = C_a \tag{8.22}$$

$$\therefore \quad P_\ell = S_\ell \tag{8.23}$$

and

$$\bar{C}_\ell = (\bar{X} \frac{S_\ell}{K_\ell}) C_\ell \tag{8.24}$$

$$\therefore \quad t_\ell = \frac{E \; S_\ell}{\bar{X} \frac{S_\ell}{K_\ell} C_\ell} = \frac{E}{C_\ell \; \bar{X}} K_\ell \tag{8.25}$$

$$\therefore \quad t_\ell = \frac{1.96}{2.041 \times 12} K_\ell = 8 \; K_\ell \tag{8.26}$$

Where the values of E = 196 pence obtained from Table 8.b and C_ℓ = 2.041 from cost formula of 1973, and $\bar{X}$ = 12 from observed data as given above. This formula indicates that average trip rate for each purpose equals 8 times (K_ℓ), where K_ℓ is the percentage of trip for purpose ℓ. If values of K_ℓ from Table 8.c are substituted in formula 8.26 the following trip rates for each purpose are obtained.

t_1 = 8 x .31 = 2.48 average work trip/household/week

t_2 = 8 x .09 = .72 average in course of work trip

t_3 = 8 x .20 = 1.60 average shopping trip

t_4 = 8 x .08 = .64 average entertainment trip

t_5 = 8 x .15 = 1.20 average social trip

t_6 = 8 x .17 = 1.36 average holiday trip

Total trip, $\bar{T}$ = 8.00 per household/week.

To check percentage of distance for each purpose :

$$S_\ell^P = \frac{Q_\ell \; \bar{X}_\ell}{\sum_\ell Q_\ell \; \bar{X}_\ell} \tag{8.19}$$

$$S_1 = \frac{(2.48) \;\; 9.7}{(2.48)9.7+(.72)25.3+(1.6)7.8+.64(10.5)+(1.2)13.6+(1.36)13.4} = \frac{24}{95.8}$$

= 25% i.e., work trips represent 25% of all distances the values of $S_2, S_3, S_4 S_5$ and S_6 are 19,13,7,17 and 19 respectively.

These values of S_{ℓ}^{P} are the same as shown in Table 8.c, which is originally assumed, furthermore, K_{ℓ} for each purpose us automatically satisfied.

To compute the number of trips per zone, the value of ($\bar{T}$ = 8) simply multiplied by the number of households in each zone.

$$TT_{car} = H_o \sum_{\ell=1}^{r} \frac{E.P_{\ell}}{\bar{C}_{\ell}} \quad \text{Total trip by car} \qquad (6.49)$$

$$= 8H_o \quad \text{for each origin zone}$$

These values will be an input for trip distribution. However, if trip distribution is made separately by purpose then

$$T_{car} = H_o \ t_{\ell}$$

$$= 2.48H_o \text{ for work trip and so on for other purposes.}$$

This kind of disaggregation has some disadvantages. While it is evident that higher income groups exhibit higher trip rates for each trip purpose, the application of these trip rates will over-estimate the total number of trips in zones whose average income is under the average of study area, while zones with higher average incomes than the study area will be under estimated. In these circumstances if analysis by household income groups could not be done because of lack of data, some corrections are needed to trip rates in zones believed to be highly prosperous as far as residents income is concerned, as well as to poor income zones.

8.4 TRIP RATES FOR DISAGGREGATE DATA.

8.4.1 Trip Rates by Household Income Group, the same Speed for all Purposes.

The availability of data is the major factor in considering the level of disaggregation of the analysis. The travel characteristics of household by income group might be different, for example average work trip length for higher income groups probably is longer than for lower income groups. In addition, it is probable that percentage of work trips (as measured by K_ℓ) is different by household income groups, as well as percentage of distance travelled for work trip (as measured by S_ℓ). The data on this level of disaggregation is not available from NTS, therefore, the assumption is made that ($\bar{X}_\ell$) average trip length by purpose is common for all household income groups. The same is assumed as far as values of S_ℓ and K_ℓ are concerned.

In Table 8.1 the values of variables is as follows :

Household income groups : i = 5

Number of household in each income group H_i = 20

$\sum_i H_i$ = 100

Average weekly income M_i = as shown in Table 8.b

Percentage of income spent on travel by car N_i = as shown in Table 8.b

Money spent on travel by car E_i = as shown in Table 8.b

where

$$E_i = M_i N_i \tag{6.42}$$

Average trip length by purpose $\bar{X}_\ell$

where

$$\bar{X}_\ell = \bar{X} \frac{S_\ell}{K_\ell} \tag{8.2}$$

Value of $\bar{X}$ overall trip length from NTS survey is 12 km and values of S_ℓ and K_ℓ from Table 8.c.

Expenditure on car travel for purpose ℓ = P

P values are given in Table 8.c.

Average speed for all purpose ν = 40 km/hr.

Cost per unit distance = C_ℓ

C values found from operating cost formula for 1973.

Cost per trip = $\bar{C}_\ell$ (8.3)

where

$$\bar{C}_\ell = C_\ell \cdot \bar{X}_\ell \tag{8.3}$$

On this basis, i.e., one average speed for all purpose, the trip rates $t_{i\ell}$ is computed for each cell in Table 8.1, where

$$t_{i\ell} = \frac{E_i P_\ell}{\bar{C}_\ell} \tag{6.41b}$$

this formula can be reduced for this circumstance to :

$$P_\ell = S_\ell \quad \text{for } F = 1 \tag{8.7}$$

$$\bar{C}_\ell = C_\ell \bar{X}_\ell \tag{8.3}$$

$$\bar{X}_\ell = \bar{X} \frac{S_\ell}{K_\ell} \tag{8.2}$$

$$\therefore \bar{C}_\ell = C_\ell \bar{X} \frac{S_\ell}{K_\ell}, \qquad \bar{C} = C_a \bar{X} \tag{8.3a}$$

$$C_a = C_\ell \tag{8.4a}$$

$$\therefore \bar{C}_\ell = \bar{C} \frac{S_\ell}{K_\ell} \tag{8.27}$$

$$\therefore t_{i\ell} = \frac{E_i S_\ell}{C_\ell \bar{X} \frac{S_\ell}{K_\ell}} = \frac{E_i K_\ell}{\bar{C}} \tag{8.28}$$

For the same household, for different trip purposes

$$\frac{t_{i1}}{t_{i3}} = \frac{E_i K_1}{\bar{C}} \div \frac{E_i K_3}{\bar{C}} = \frac{K_1}{K_3} \tag{8.29}$$

Where 1 and 3 denotes the work and shopping purpose. This indicates that the ratio of trips for two different purposes for the same household income group is the same as ratio of percentage of trips for each purpose (K_ℓ).

For two households in different income groups, for the same trip purpose the ratio is as follows :

$$t_{1\ell} = \frac{E_1 K_\ell}{\bar{C}} \tag{8.30}$$

$$t_{2\ell} = \frac{E_2 K_\ell}{\bar{C}} \tag{8.31}$$

$$\therefore \frac{t_{1\ell}}{t_{2\ell}} = \frac{E_1}{E_2} \tag{8.32}$$

This indicates that for the same trip purpose, the ratio of trip for household income group 1 and 2 are the same as ratio of their expenditure on running of car.

In Table 8.1 :

$$\text{Total trips} = Q$$

$$Q = \Sigma Q_{\ell} = \Sigma T_i \qquad (8.33)$$

$$Q = 40.0$$

Average for one household

$$\bar{T} = \frac{40}{5} = 8 \text{ trips} \qquad (8.34)$$

Total distance travelled

$$L = \Sigma\, Q_{\ell}\, \bar{X}_{\ell} \qquad (8.35)$$

$$= 480 \text{ km.}$$

Checking for values of S_{ℓ}

$$S^{P}_{work} = \frac{L}{Q_{work}\bar{X}_{work}} \qquad (8.5)$$

$$= \frac{480}{12.36 \times 9.7}\ 100 = 25\%$$

This value is the same as observed value.

Other values of (S_{ℓ}) also satisfy this constraint.

Checking for values of K_{ℓ}

$$K^{P}_{work} = \frac{Q}{Q_{work}} = \frac{40}{12.36} = 31\% \qquad (8.6)$$

This value is the same as observed value.

Other values of (K_{ℓ}) also satisfy this constraint.

In Table 8.1 :

The trip rate for a household income group i is denoted by T_i, for all purposes. T_i ranges from 1.12 trips per week for lowest household income group to 16.33 trips for highest income group. This indicates the importance of the income on trip generation.

The values of $\bar{Q}_{\ell}$ is the same values as previously computed in Section 8.3.2, which is given by t_{ℓ}.

8.4.2 Trip Rates by Household Income Groups, with Different Speeds for each Purpose.

The same procedure is repeated as in Section 8.4.1 but assuming different speeds for each trip purpose. The speeds as shown in Table 8.2 are ranging from 20 kph to 60 kph, with lowest speed assumed for work trips on the basis that these trips are performed mostly during peak hours. Again the same formula(6.42)is applied for each cell and ($t_{i\ell}$) number of trips made by income group i for purpose ℓ is computed.

(P_ℓ) is used instead of S_ℓ because the (F) values are not unity as in previous section. The values of P_ℓ used are shown in Table 8.2. The value of ($t_{i\ell}$) for each cell is computed as follows:

$$t_{i\ell} = \frac{E_i \; P_\ell}{\bar{C}_\ell} \qquad (6.41c)$$

For example, work trip rate for household income group 4, (i = 4), for purpose work (ℓ = 1) is :

$$t_{4,1} = \frac{260 \times .29}{25.36} = 2.97 \qquad (6.41c)$$

where

E : expenditure on travel by car = 185 pence for household income group 4 (Table 8.b)

P_ℓ : percentage of E allocated for work trips = .29 (Table 8.d)

$\bar{C}_\ell$: average trip cost

$\bar{C}_\ell$: $C_\ell \cdot \bar{X}_\ell$ (8.3)

where

C_ℓ : cost per unit distance, at assumed speed ν = 20 kph for work trip, from operating cost formula given in TRRL 661 where

$\text{cost} = 1.29 + \frac{26}{\nu} + .000063\nu^2 = 2.615$ pence/km

and average trip length $\bar{X}_\ell$ is given by

$$\bar{X}_\ell = \bar{X} \; \frac{S_\ell}{K_\ell} \qquad (8.2)$$

where $\bar{X}$ is average overall trip length and S_ℓ and K_ℓ is percentage of distance and percentage of trips for work purposes

$$\bar{X}_{work} = 12 \frac{25}{31} = 9.7 \text{ km.}$$

where 12 is computed on the basis of national average

$$\text{Average overall trip length} = \frac{\text{total distance travelled}}{\text{total number of trips}}$$

$$\therefore \quad \bar{X} = \frac{964,915}{78,593} = 12 \text{ km.} \quad \text{(Table 8.a)}$$

values of S_ℓ and K_ℓ is given in Table 8.c where

$$S_\ell = 25\%, \; K_\ell = 31\%$$

In Table 8.2 :

$$T_i = \sum_\ell t_{i\ell} \quad \text{(row summation)} \qquad (8.36)$$

$$Q_\ell = \sum_i t_{i\ell} \quad \text{(column summation)} \qquad (8.37)$$

$$\bar{Q}_\ell = \frac{Q_\ell}{\Sigma i} \qquad (8.38)$$

where

T_i : is trip rate for household income group i (all purposes)

$\bar{Q}_\ell$: is trip rate of average household for purpose ℓ

T_i is ranging from 1 trip per household for lowest income group to 14.8 trips per household for highest income group.

$$T = \sum_i T_i = \sum_\ell Q_\ell \qquad (8.39)$$

$$\bar{T} = \frac{T}{\Sigma i} \qquad (8.40)$$

where

T = total number of trips

$\bar{T}$ = average number of trips

T = 36.25

$$\therefore T = \frac{36.25}{5} = 7.24$$

To satisfy the original constrains regarding S_ℓ and K_ℓ:

$$K_\ell^P = \frac{Q_\ell}{\Sigma Q_\ell} \qquad (8.41)$$

$$= \frac{11.19}{36.3} = 31\% \text{ for work trip, } K = 1$$

K_2, K_3, K_4, K_5 and K_6 can all be reproduced as original values, which is given in Table 8.a.

$$S_\ell^P = \frac{Q_\cdot \bar{X}_\ell}{\sum_\ell Q_\ell \bar{X}_\ell}, \quad \Sigma Q_\ell \bar{X}_\ell = 434 \qquad (8.42)$$

$$= \frac{11.19\ (9.7)}{434} = 25\% \text{ for work trip}, K = 1$$

S_1, S_2, S_3, S_4, S_5 and S_6 can all be reproduced as original values, which is given in Table 8.a.
This shows that the GSM models have the advantage that they are internally consistent.

The predicted average overall distance can also be reproduced as follows :

$$\bar{X}^P = \frac{\Sigma\Sigma\, t_{i\ell}\, \bar{X}_{i\ell}}{T} = \frac{\Sigma\, Q_\ell\, \bar{X}_\ell}{T} \qquad (8.2)$$

$$= \frac{434}{36.2} = 12 \text{ km.}$$

By computing say different work trip lengths for different household income groups, as well as different values of S_ℓ and K_ℓ for different household income groups, the figures in Table 8.c are applied to all household income groups. In reality, however, household income group has its own trip characteristics, i.e. for a detailed study, base year travel characteristics (as in Table 8.c) must be provided for each household income group.

The other information needed relates to cost per unit distance, hence cost per trip for different purposes. The cost formula for 1973 is then applied and the results are shown in Table 8.2, after some assumptions were made about average speed for each purpose. However, the same argument is true for cost per unit distance for different purposes for different household income groups. The cost formula which appears in TRRL reports, usually takes a representative car engine size (1400 cc in 1973), but accepting the fact that households with higher income levels use larger cars, the cost of those will be higher than average. Therefore, there is a need to use different operating cost formula, according to actual engine size by income group. The application of national data avoids any tendency towards over or under estimation of total trip rates. This is because the aggregation of households into income groups is even (20% of household in each income group), but this by no means guarantees that the trip rates for individual household income group is not biased.

The results of trip rates by purpose of trip, from Table 8.2, are presented diagramatically in Figures 8.1 and 8.2. It is evident that the work trips have a major impact on the amount of travel, and the higher income groups always exhibit higher trip rates for each travel purpose.

The scale of income is presented in these graphs both on the basis of discrete income and also on the basis of income groups. The aim of establishing such relationships is obvious, viz : the task of forecasting (number of trips) at a zonal level will be more meaningful if it is done on the basis of household income groups because the effect of inflation has been eliminated. Knowing the number of households in each income group (H_i), and multiplying by appropriate rate of trips by purpose, and summing overall household income groups, the resultant will be total number of trips originated from zone O, which can be used as an input to a trip distribution model.

It is also a fact that average household income and average trip rate fall on the same line for all purposes (Figure 8.1). This average can be used only if the household distribution by income (20% of household in each income group) is spread evenly. These types of curves can be established for any particular area, which might be different from national average. However, for rough estimates, one can apply national trip rates after some correction regarding the character of households in the area under study.

8.5 TRIP RATE CHANGE DUE TO SPEED OR AVERAGE TRIP LENGTH FOR HOUSEHOLD INCOME GROUP i

The effect of change in speed and trip length on trip rate can be found as follows:

$$t_\ell = \frac{E_i \; P_\ell}{\bar{C}_\ell} \qquad (6.41c)$$

$$\bar{C}_\ell = C_\ell \ \bar{X}_\ell \tag{8.3}$$

Two cases are presented :

Case 1 - Improvement : speed increase from 20 kph, with same average trip length

$$t_\ell = \frac{E_i \ P_\ell}{C_\ell \ \bar{X}_\ell} = \frac{E_i \ P_\ell}{\bar{X}_\ell} \quad \frac{1}{C_\ell} = \frac{\pi_1}{C_\ell} \tag{8.43}$$

From speed 20 kph to 40 kph for any trip purpose

$$\frac{t_{\ell 40}}{t_{\ell 20}} = \frac{\frac{\pi_1}{C_{\ell 40}}}{\frac{\pi_1}{C_{\ell 20}}} = \frac{C_{\ell 20}}{C_{\ell 40}} = \frac{2.615}{2.041} = 1.28 \quad \text{increase in rate}$$

From speed 20 kph to 60 kph for any trip purpose

$$\frac{t_{\ell 60}}{t_{\ell 20}} = 1.34 \quad \text{increase in rate}$$

From speed 40 kph to 60 kph

$$\frac{t_{\ell 60}}{t_{\ell 40}} = 1.05 \quad \text{increase in rate}$$

Case 2 - Improvement : building new links or change in land use :

For change in average trip length, same speed

$$\bar{X}_{\ell a} = \alpha \ \bar{X}_{\ell b} \tag{8.44}$$

where $X_{\ell a}$: average trip length After

$X_{\ell b}$: average trip length Before

$$t_\ell = \frac{E_i \ P_i}{C_\ell \ \bar{X}_\ell} \tag{6.41}$$

$$\frac{t_{\ell a}}{t_{\ell b}} = \frac{\frac{\pi_2}{\bar{X}_{\ell a}}}{\frac{\pi_2}{\bar{X}_{\ell b}}} = \frac{\bar{X}_{\ell b}}{\bar{X}_{\ell a}} = \alpha \tag{8.45}$$

∴ the trip rate increase is the same proportion of average trip length decrease, while trip rate increase for change in speed is proportional to cost decrease.

8.6 PREDICTION FOR LONG TERM TRIP GENERATION

As part of a transport planning process, it is usual to divide the area under consideration into a number of zones (Section 1.6), and the unit of analysis is household (Section 1.10). The information needed is the number of households, with their weekly income, in each zone. Collecting such planning data can be part of a travel survey, or can be obtained from other sources, such as the general cencus, the local department of planning etc. Alternatively, past trend information may be used to forecast for some future years ahead.

From Figure 5.3, the position of the income curve for 1985 can be estimated roughly. This forecast, however, even if it involves some error, may not cause much error in the amount of travel forecast by the General Share Model. As outlined in Chapter 5, the average household income for each group can be found, then each household in the zone will lie in a certain group. This calls for the residential location to be assessed, which is the main task of each authority at each level of regional land use planning. While the number of households for the base year can be obtained from survey data, there always remains a tricky forecasting problem in allocating percentage of households for a zone in each income group. As a guide for such a distribution, a Gamma function can be used as outlined in Section 2.4.3.

Other data needed are travel characteristics, average trip length (see Figure 5.13), percentage of distance travelled (by household income group and by purpose of travel). This information can be computed from base year data (Figure 5.12) which is assumed to remain stable over time.

Cost of travel by private car can be found from operating costs formula for base year. Forecasting for target year involves some assumptions about fuel price indices relative to income indices.

The main element in predicting future travel is household income, as shown in Figure 5.3. The forecast of average income for a household in U.K.in 1985 is £200 p/w. Regarding the past trend and the proposed programmes of road construction, there is no significant likelihood of any higher level of service being provided by 1985 for either car or bus travel. The amount of money which will be spent on travel is assumed to remain constant as percentage of household income (6.2%). There is a slight increase in expenditure on travel by car between 1975 and 1985, i.e., from 4.87% to 5.0% : the assumed expenditure on travel by rail remains constant at past period level of 0.5% : this will leave 0.7% for travel by bus. Knowing these figures, the problem of forecasting will be confined to translating fixed money spent on travel into number of trips by mode. This in depends on the future level of service provided and average trip length by mode, which can be predicted from base year travel characteristics, using a proper assignment technique, and the proposed target network.

The other important factor, as far as car trips are concerned, is forecasting ~~the~~ operating cost. A considerable amount of knowledge is required in this concept regarding future economic growth and the probable petrol price index. However, it is sufficient if one assumes that the income indices are a reflection of petrol price indices. Accepting this criterion, the cost per unit distance of car travel at speed v can be presented by :

$$C = \left[1.29 + \frac{26}{\nu} + 0.000063\nu^2\right] \text{ X } \frac{\text{income at 1985}}{\text{income at 1973}}$$

For example, at speed 20 km/hr., cost/km. in 1985 is :

$$C = 2.615 \text{ X } \frac{200}{72.46} = 7.12 \text{ at 1985 prices.}$$

The remaining procedure is a direct application of the General Share Model, and this implies that petrol prices will not rise in real terms between 1973 and 1985

8.7 SUMMARY AND CONCLUSIONS.

The object of the present study is to discuss in quantitative terms, so far as possible with the available data, the factors that determine the amount of travel in a given area. It has been seen how expenditure on private and public transport varies with income, it is also thought that the disaggregation of population by income level represents a logical stratification of the household which is regarded as a basic unit of travel making.

In this chapter the application of the General Share Model (GSM) as formulated in Chapter 6 is applied to car trips. Trip rate by household income group and by purpose of trip is based on average weekly travel as shown in Tables 8.1 and 8.2, and presented diagrammatically in Figures 8.1 and 8.2. The GSM showed a great internal consistency in reproducing the original data. However, the performance of the model as a prediction tool can only be evaluated after its application to a certain urban area for long term transport planning. Its performance for such forecasts can only give adequate results if the related forecasts of involved parameters can be carried out accurately.

The data used is NTS 1972/73 and FES Report 1973, with operating cost formula given by TRRL Report 661 for year 1973. The procedure is elaborated and relaxed for different assumptions in the application of the model in this chapter. However, the backbone is the formula given by :-

$$t_{i\ell} = \frac{E_i \; P_\ell}{\bar{C}_\ell} \qquad (6.41b)$$

where

$t_{i\ell}$ = number of trips, by household income group i for purpose ℓ (weekly)

E_i = expenditure by household income group i on car trip

P_ℓ = percentage of expenditure allocated to purpose ℓ

$\bar{C}_\ell$ = average cost per trip for purpose ℓ

The method of assessing value of E_i became quite clear in previous chapters through the analysis of household income and expenditure trends;

$$E_i = N_i \ M_i \qquad (6.42)$$

where

M_i = average weekly household income group i

N_i = percentage expenditure on running of car

P is shown to be a function of S (percentage trip distance for purpose ℓ); for the same cost per unit distance for all purposes P = S (S can be computed from base year travel characteristics) and for different cost per unit distance for each trip purpose

$$P_\ell = S_\ell \ . \ F \qquad (8.7)$$

where F is a correction factor

$$F = \frac{C_\ell}{C_a} \frac{\sum_1^r S_\ell}{\sum_1^r S_\ell \frac{C_\ell}{C_a}} \qquad (8.9)$$

$$C_a = \frac{\sum_1^r C_\ell}{r} \qquad (8.4)$$

where

C_a = average cost per unit distance for all trip purposes, the value of C_ℓ can be computed from operating cost formula which in turn is a function of speed of a particular trip purpose.

$$\bar{C}_\ell = C_\ell \ \bar{X}_\ell \qquad (8.3)$$

where C_ℓ can be found as shown above, $\bar{X}$ average trip length for purpose ℓ is given by

$$\bar{X}_\ell = \bar{X} \frac{S_\ell}{K_\ell} \qquad (8.2)$$

where

$\bar{X}$: is average overall trip length

K_ℓ : percentage of trips for purpose ℓ

It must be emphasised that $\bar{X}_{\ell}$ is directly related to land use distribution and accessibility in the zone under consideration. These parameters can also be computed from base year travel characteristics.

The application of this model reproduced 72% of the amount of car trips on national basis. The remaining 28% represents travel by firms' cars, the cost of which is not paid by households (NTS 1972/73).

It is found that the number of trips for any particular purpose is higher for higher income group (see Figures 8.1 and 8.2) work trip rates are higher than other trip purposes. The average trip rate for all purposes ranges from 1 for lowest income group to 16 trips per week for highest income group, reflecting the impact of income on car tripmaking and consequently it is vital to predict accurately the household income distribution by income on zonal level.

The change in trip rates also examined due to change in average trip speed, or average trip length, by purpose of trip for certain household income group. It is found that the number of trips will be proportional to the cost per unit distance in comparing Before and After change in speed, and proportional to average trip length Before and After for change in land use or building new roads.

The level of disaggregation is found to be a function of data availability. The ideal application of the model will be on the basis of each zone, thus the accessibility gained by some zones which affect their trip characteristics is not suppressed. The prediction for long term trip generation is related to many side effects, such as prices and income indices. This obviously needs broad understanding of the whole economic situation. However, as a simple guide it has been suggested in this study that the best single item index related to income index is that of petrol price index.

CHAPTER 9

TRAVEL PREDICTION, 4.

PUBLIC TRANSPORT TRIPS.

(BUS AND RAIL)

9.1 INTRODUCTION.

Traditionally so called "comprehensive" urban area transportation studies have given little consideration to public transport planning. Early studies were very much car orientated. "The steadily increasing demand for space was apparent, highway construction funds were readily available and public transport was seen to be, and indeed was, a declining industry" (Constinett, 1970). Recently the role of public transport has been generally accepted in future transport systems.

In the U.K. since 1955 the decline has continued but at a decreasing rate. This can be confirmed by the trend of bus and coach travel as shown in Table 9.a.

Table 9.a

1955	1960	1065	1968	1972	1975
4.19	3.94	3.91	3.82	3.62	3.49

Bus and coach kilometres travelled on all roads (thousand million).
Source : Transport Policy, 1976.

These trends represent a real decrease in social equity, in that people without a car have become less mobile probably as a result of cuts in the service provided. In 1971 buses were running 10% less vehicle miles than in 1961 (Hamer,1974)

The nature of input to public transport passenger cost is responsible for this phenomenon. Cost is mainly labour (60%-70%). In cities the private car and public transport compete for the same road space. "In London without the car, buses could cope with peak-hour traffic flows" (London Transport annual report, 1973).

Data from other European countries indicates clearly that the decline in public transport passenger-kilometres is unique in Britain. Furthermore, forecasts in those other countries envisage stable or increasing volumes of public transport despite rising car ownership.

The common modes for road public transport are mainly buses and coaches. "Public road passenger transport provided by buses and coaches can be divided into two sections, differing substantially in character. On the one hand there is the long distance market in which buses have a relatively small share but which is broadly profitable; on the other hand there is the local distribution market in which buses have a large, though declining share and which is distinctly un-profitable", (Gwillian and Mackie, 1975).

This is mainly due to the fact that this industry is very labour intensive and fuel accounts for less than 10% of total cost.

9.2 Public Transport Characteristics

9.2.1 Reliability of Public Transport Service

The main feature of reliable public transport provision is in its level of service, which includes :

1. Fares; in general, public transport fares may be flat throughout a whole route, or graduated by distance travelled. A flat rate fare throughout a whole route, or on central major part of it, is self-descriptive. It tends to favour the longer passenger trip and penalizes the shorter one, but it is simple to collect. "Fares graduated by distance travelled provide the greatest equity to the passenger if distance travelled is the criterion" (Quinby, H.D., 1976). However, in many urban areas different fare structures exist, including season tickets (Figure 9.1a).

2. Time; the overall travel time for a given passenger trip may be thought of as door-to-door travel time, i.e. the time required for all components of the journey from origin to destination. (1) access time from point of trip origin to boarding stop, (2) waiting time for the vehicle, (3) in vehicle time and (4) walking time to destination. These various times needed for a trip are a function of the frequency of service vehicles on the route, accessibility and route configuration. Type and age of vehicles may also be important as far as passenger comfort and vehicle performance is concerned. The problems of providing high frequency and more accessible routes contribute to increase the total cost of operating a public service which cannot be justified economically. Another inherent contradiction and conflocting dilemma in public transport service is that when waiting time is reduced for some passengers, others will suffer from the result of extra in-vehicle time.

Beside the facts that the true costs of car use are higher than those perceived by the users, and private car travel gives privacy and convenience, the total time needed (door-to-door) is higher for public transport than for car. In one study (Hillman et al, 1973) it was found that the average time needed for short journeys of 3, 5 and 7 kilometres are as shown in Table 9.b.

Table 9.b

Distance in (km)	Car time (mins)	Bus time (mins)	Difference (mins)
3	11	15	4
5	14	20	6
7	17	28	11

9.2.2 Energy Consideration.

There is one main factor which might change the traveller's behaviour in favour of public transport. In the U.K., the transport sector accounts for some 16 percent of total primary fuel and energy consumption and of this about ½ is consumed by cars, and only 3 percent by buses, coaches and taxis in 1974 (Department of Energy, 1976). However, "buses and coaches accounted for about 24 percent of all passenger-journeys and around 12 percent of total passenger miles" (Ball and Percival, 1978). The point is that a very small expenditure on energy is used to produce so many passenger journeys. The efficiency with which buses can use energy can be confirmed from the following table :

Table 9.c

Use of fuel by cars and buses					
		Average system load		Peak loading	
Vehicle	Miles per gall.	passengers	pass-mile per gall.	passengers	pass-mile per gall.
Average U.K. motor car	30	1.3	39	4	120
U.K. 9-ton bus	7	16	112	75	525

Source : Harman, 1974.

More details of energy consumption by mode, given in Table 9.1. From these tables an energy saving would result if many passengers transferred from private to public transport (bus and rail).

Almost the whole energy debate is concerned with how to solve the problem of an unexpected energy gap. If new sources of energy are not utilised efficiently and economically by the end of the century, the appreciation of the world's non-renewable energy resources will grow considerably, then there will be a decline in car usage and this essentially leads to higher public transport.

9.2.3 Environmental Consideration.

The growth of road transport has been, at least in part, responsible for the destruction of many historical buildings, damage to properties and the spread of urban areas into countryside. Roads, and mainly motorways, requires more space than corridors for public transport.

Among many other effects, the relatively safer accident record of public transport, compared with car, might also attract some consideration in future with other environmental side effects of vehicle use, such as noise, fume, etc.

9.3 Conventional Methods used in Public Transport Travel Prediction.

Modal split models are used to estimate the percentage of travellers who will use different types of transport.

There are basically three ways in which modal split is performed and they are referred to as :

1. pre-distribution
2. post-distribution
3. combination or inter-related modal split and distribution.

The type of model used therefore depends on the point in the forecasting process at which the modal choice is made.

In the pre-distribution type procedure total trips are allocated among available modes and separate trip distributions made for public transport and for car.

In the post-distribution procedure total person trips are distributed prior to the modal choice.

To overcome some shortcomings of these two techniques Wilson (1974) introduced a combined procedure in which trip distribution and modal choice are presented in one model. The Ministry of Transport (U.K.) applied this approach for the first time in the SELNEC Transportation Study.

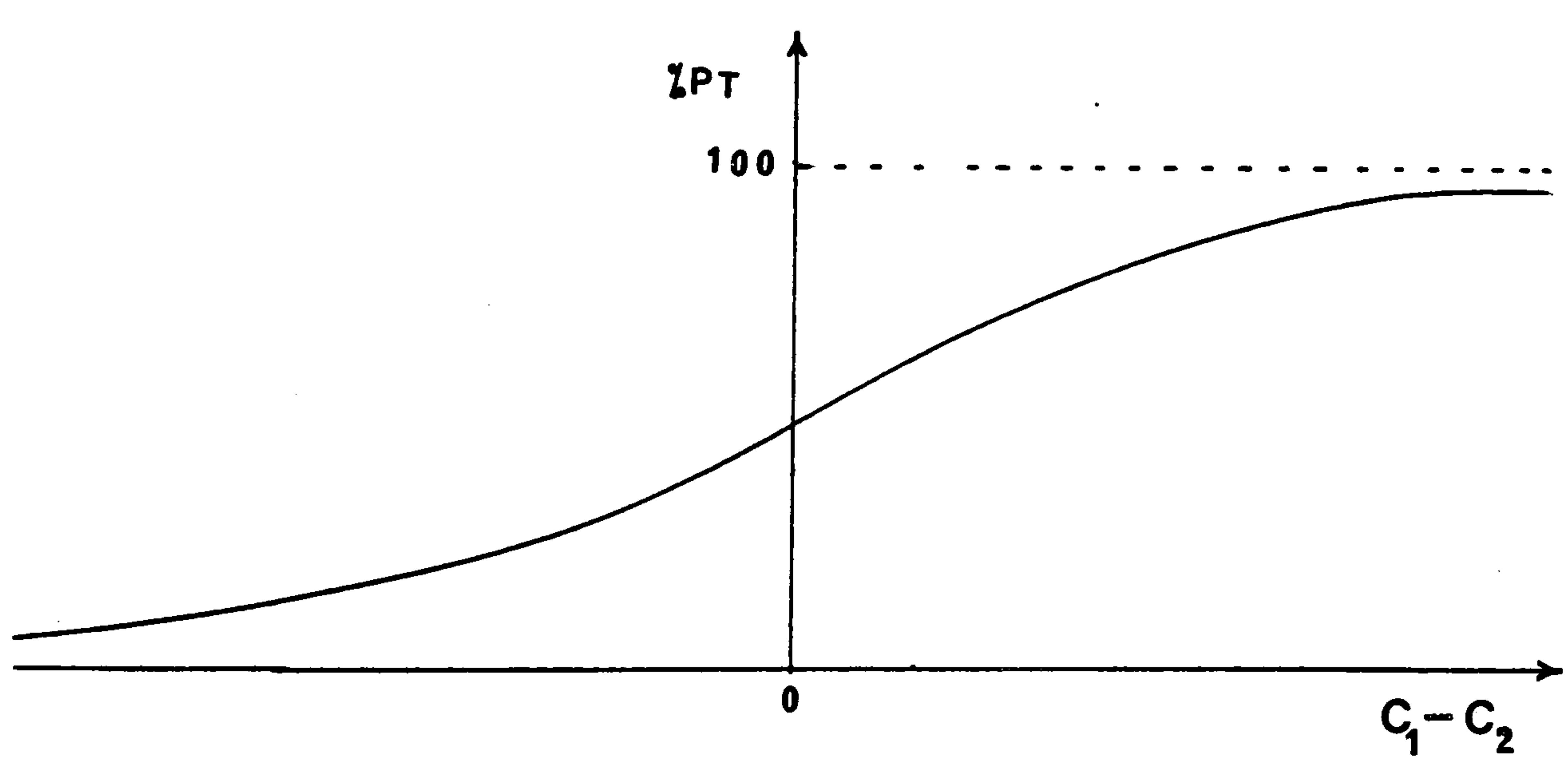
The generalised cost was used in SELNEC models, and the modal split model, followed the distribution model in that study The analysis involved the use of discriminant analysis to explain people's choice of travel mode. The model takes the following shape :

$$\%PT = \frac{1}{1+e^{-\lambda(C_1-C_2)}}$$

where

$\%PT$: percentage trips by public transport

C_1 and C_2 generalised cost of trip by car and public transport respecively. From this it can be seen that the percentage use of public transport is related to the generalised cost difference between the alternative modes via a logistic function. However, "recently attention has been drawn to the weaknesses in the extrapolative method and consider that the shape of the logistic curve currently used is not supported adequately by analysis"(Leitch, 1977)



Source : Wagon, 1976

Diagram 9.a

The following criteria have been used to estimate the value of time, in early modal split studies: the value of travelling time in non-working hours equals 25% of the wage rate; the excess time equals twice the travelling time; travelling time in working hours equals the wage rate.

The modal choice approach in this study is somewhat different from these conventional methods. Application of General Share Model exactly on the same basis as applied for private trips can yield the number of public transport trips by household income group for each purpose.

9.4 HOUSEHOLD SHARE IN TRAVEL BY PUBLIC TRANSPORT.

9.4.1 Introduction

The share of household travel attracted by public transport depends mainly on how the members of each household divide the fixed percentage of income originally allocated for travel by all modes. Consequently, public transport usage and the amount of travel by other modes will be determined by the level of service provided by each mode.

According to this concept, knowing the household income, and percentage of income allocated for travel by each mode, the General Share Model can be applied in the same way as for car trips (Chapter 8).

In the following sections the trends of household expenditure and travel characteristics are more rigorously analysed. All references are based on weekly income, expenditure and travel.

9.4.2 Household Expenditure on Travel by Public Transport.

The method used in Chapter 5 for representing household income and expenditure on travel by car, is repeated for households' expenditure on public transport (bus and rail) for the same period 1965-1968-1972 and 1975.

Figures 9.1 to 9.4 show household expenditure (cumulative) with cumulative household number based on data from FES, Tables 5.1 a;b;c;and d. On the same graphs household income and expenditure on travel by car are superimposed for comparison. This kind of presentation facilitates classification of households into five income groups with 20% of the households in each group. Households in this study include all households, irrespective of whether they own a car or not.

The expenditure for the average household, as well as by income group, is then computed from these curves and shown in Table

Figure 9.5 is the overlapping of Figures 9.1 and 9,4 for years 1965 and 1975 respectively, showing the consistent shift to the right, both for expenditure by mode and income.

9.4.3 Bus Travel,
Average Household.

Figure 9.6 shows average household expenditure on travel by bus for the years under consideration. Curve 3 represents the trend of expenditure on travel by bus as percentage of household income. It falls from 1.63 in 1965 to 0.855 by 1975, which represents about a 50 percent decline in 10 years.

9.4.4 Bus Travel,
Household by income group.

Figure 9.6 shows the expenditure on bus travel for each income group of householders. The consistency of each income group is obvious; all income groups are declining in expenditure on travel by bus; a lower income group always spendsmore than a higher income groups (expressed as a percentage of the household income. The fluctuations throughout the 10 year period are more for the lower income groups than for the higher income groups. Although lower income groups spend a greater proportion of their income on bus travel than do higher income groups, in money terms the higher groups always spend more than the lower groups. This was discussed in Chapter 5 where the real money spent was travel "propensity".

Table 9.d

Income Group	Household propensity		
	Bus	Rail	Car
1	8	5	3
2	16	9	12
3	21	14	19
4	25	22	28
5	29	50	37

9.4.5 Rail Travel,
Average Household expenditure.

In Figure 9.7, average household expenditure on travel by rail is shown. The fixed trend in the service provided by rail is apparent with an almost constant percentage of household income spent on travel by rail (0.5%) throughout the 10 year period.

9.4.6 Rail Travel,
Household expenditure by income group.

Figure 9.8 shows the expenditure on travel by rail for each income group of householders.

The obvious conclusion from the curves is that there are relatively very small fluctuations for each household income group throughout the period. Additionally, in contrast to bus travel, households in higher income groups spend more than those in lower income groups (as a percentage of income), but still the propensity has the same ranking order, i.e., higher income groups have larger propensity than lower income group (see Table 9.d).

9.4.7 Bus and Rail Travel

In figure 9.9, the trend of household expenditure on both bus and rail are shown. The trend is declining, but a more stable trend is obtained when the expenditure on public transport is expressed as percentage of total household expenditure rather than in terms of household income.

In Figure 9.10, the total household expenditure on travel by car, bus and rail, expressed as a percentage of household income, shows a remarkable trend; that is, average household expenditure on travel is almost constant (as presented in Chapter 5), at a value of 6.2%.

. However, expenditure on travel by all modes, as percentage of total household expenditure, shows a rising trend throughout this period (Table 9.e)

The priority for expenditure in different modes of travel, measured both in monetary value and as a percentage of total household income, shows the following travel order :

(1) CAR - (2) BUS - (3) RAIL

Table 9.e

Year	Expenditure on travel by all modes as % of total household expenditure
1965	6.97
1968	7.50
1972	7.64
1975	8.24

9.5 PRICE INDICES AND TRAVEL.

Table 9.2 shows values of indices for variables related to travel, over years between 1965 and 1975. The base year is 1965 when all index values are 100. These indices are also shown graphically in Figures 9.12 and 9.13.

Although the overall effect of inflation is included in this sort of representation, the relative comparison gives some indication as to the way some indices affect the amount of travel. Figure 9.12a represents indices of income, total household expenditure, and the index of expenditure on all goods and services. The trend over the period 1965-1975 showed a consistent increase and in 1975 index values reached 295, 257 and 224 respectively.

Figure 9.12b represents indices of money spent on running a car, including petrol and service. Over the ten year period the trend is also continuously rising with the index values in 1975 to being 371, 284 and 224 respectively. The petrol price index has a direct relation with the amount of travel by car. The figure shows that from 1973 onwards, the petrol price index increased above that for all goods and services. This additiaonal increase was also reflected in the trend of household expenditure on running of the car. The net effect despite the increased expenditure, was less travel, even though households had spent the same percentage, or more, of their income on travelling by car.

The figures in Table 9.f also confirm this conclusion. The total number of car-kilometres travelled suddenly drops as a consequence of the increase in petrol price indices.

Table 9.f

Year	Passenger journey by bus (10^6)	Car-kilometres travelled (10^9)
1972	8.540	184.24
1973	8.490	194.54
1974	8.245	188.96

Source : Transport Policy, 1976 (data for Great Britain)

Figure 9.13a represents indices of bus fares, household expenditure on bus travel, and expenditure on all goods and services. The bus fare index is higher than the all goods and services index. This led (even with higher household expenditure on bus travel) to fewer passenger journeys by bus as in Table 9.f.

Figure 9.13b shows indices of household expenditure on rail fares, and on all goods and services. The last two variables are almost the same throughout the period, leaving a stability in household expenditure on travel by rail. This resulted in an almost constant figure for rail passenger-kilometres (37×10^9 for 1964 36×10^9 by 1974, Transport Policy, 1976).

As an example of the effect of these indices on the amount of travel, the following analysis is made :

Table 9.e

	1965	1975
Bus fare (BF)	100	265
Household expenditure on bus (EB)	100	155
Rail fare (RF)	100	221
Household expenditure on rail(ER)	100	261
All goods and services (AG)	100	224

For year 1975

$$\frac{BF}{AG} = \frac{265}{224} = 1.183$$

$$\frac{EB}{AG} = \frac{155}{224} = 0.61$$

$$\frac{RF}{AG} = \frac{221}{224} = 1.0$$

$$\frac{ER}{AG} = \frac{261}{224} = 1.165$$

This analysis indicates that because the bus fare is higher than all goods and services, there is less demand by the household for this service (travel by bus).

9.6 TRAVEL PREDICTION.

9.6.1 Bus Trip Rate.

The General Share Model is applicable for travel by public transport and the variables needed are as follows:

1. Household income group.
2. Percentage of income spent on travel for certain modes.
3. Cost of travel per unit distance.
4. Average trip length by mode by purpose.
5. Percentage of trip distance by purpose.

Bus Travel Characteristic.

The data from NTS 1972/73 gives the following information :

Total household in the sample = H_o = 7,113

Total mileage/week = Z_1 = 150,485

Total number of trips/week = Z_2 = 46,589

Table 9.f

J	Trip purpose	S_ℓ %	K_ℓ %	$\bar{X}_\ell = \frac{Z_1}{Z_2} \frac{S_\ell}{K_\ell}$ km
1	To and from work	35	35	5.16
2	In course of work	1	1	5.16
E	Education	9	10	4.64
3	Shopping	26	28	4.79
4	Entertainment, sport) eating and drinking)	8	8	5.16
5	Personal social	18	16	5.80
6	Holiday, pleasure	4	3	6.88
	Total	100	100	

Source : NTS 1972/73

Average overall trip length = $\bar{X} = \frac{Z_1}{Z_2}(1.6) = 5.16$ km.

Average trip length by purpose in Table 9.f found on the same basis.

From FES Report 1972, (Table 5.2c) average household expenditure on bus fare is (E) = 50 pence

$$\text{Cost/km.} = \frac{\text{total money spent on bus fare}}{\text{total distance travelled by bus}}$$

$$= \frac{H_o E}{Z_1} = \frac{7113 \times 50}{150,485(1.6)} = 1.45 \text{ pence/km.}$$

This means that the overall average trip length is not considerably different from the average trip lengths for each purpose. Moreover, for bus trips, assuming the flat fare rate throughout the whole day, the percentage by purpose does not need any correction. In other words, the percentage of expenditure on bus travel by purpose is the same as the percentage of distance by purpose. However, for graduated fares by distance, the same procedure as for car trips is applicable (see Figure 9.1 for graduated fare structure).

Table 9.3 is the summary of household income and expenditure on bus travel for 1972, from FES Report. Bus travel characteristics, data from NTS 1972/73, and trip purposes are shown with their average trip length and percentage of total distance. The cost per kilometre, as computed above, is also shown. To compute the average number of trips per household in any income group :

$$t_{i\ell} = \frac{E_i \; P_{i\ell}}{\bar{C}_\ell} \tag{6.41}$$

where

$t_{i\ell}$: is the number of trips for household in income group i for purpose ℓ

$P_{i\ell}$: percentage money spent on travel by income group i for purpose ℓ

$\bar{C}_\ell$: cost per trip for purpose ℓ

E_i : expenditure on bus travel by household income group i

For example, income group 3 spends 55 pence/week on travel by bus, rate of work trips, (purpose 1)

$$t_{3,1} = \frac{.35 \times 55}{7.46} = 2.58 \text{ work trip/week}$$

All other trip rates found on the same basis. The results are shown diagramatically in Figure 9.14 and as is evident, the work trips exhibit greater rates than other purposes. The rates show - by purpose of trip - the frequency of trips for higher income groups is greater than that for the lower income groups. The procedure used in computing the number of trips will satisfy the original constraints put concerning distribution of distance, as well as number of trips for each purpose.

To check the total number of trips made by all households : (Table 9.3)

$$\text{Average trip rate} = \frac{\Sigma T_i}{\Sigma i} = \frac{33.83}{5} = 6.7 \quad \text{(predicted)}$$

$$\text{Average trip rate} = \frac{Z_2}{H_o} = \frac{46.589}{7113} = 6.6 \quad \text{(observed)}$$

To check total distance travelled :

$$\Sigma \bar{Q}_\ell \ \bar{X}_\ell = 34.82$$

$$Z_1 = 34.82 \times 7113 = 247.660 \text{ passenger-km. (predicted)}$$

$$Z_1 = \quad = 240.776 \text{ passenger-km. (observed)}$$

the discrepancies could come from rounding the figures. These values suggest that the model is relaible, and can predict the number of trips and passenger mileage fairly accurately.

9.6.2 Rail Trip Rate.

The same procedure as for bus trip rate is applicable to rail trip rate. The data from NTS 1972/73 for rail travel :

Number of household = 7,113

Number of trips = 3,998

Total distance = 92,419 miles

$$\bar{X} = \frac{92419 \times 1.6}{3998} = 37 \text{ km.}$$

$$\text{Average number of trip/household} = \frac{3998}{7113} = .562 \text{ per week}$$

$$37 \times .562 = 20.8 \text{ km./week.}$$

Average household expenditure on rail fare = 22 pence/week (FES 1972)

$$\therefore \quad \text{Cost/km.} = \frac{22}{20.8} = 1.06 \text{ pence/km.}$$

$$\text{Cost/trip} = 37 \times 1.06 = 39.22 \text{ pence.}$$

According to this information the average trip rate by household income group for all purposes is computed as in Table 9.g.

Table 9.g

Household income group	Expenditure on rail fare pence	Average number of trips $=\frac{\text{Expenditure}}{\text{Cost/trip}}$
1	9	.22
2	10	.25
3	15	.37
4	25	.64
5	55	1.4
Average	22	.56

The values of trip rates as in Table 9.g is average for all purposes. Figure 9.11 shows these values with average car and bus trip rates. The shape of rail trip curve is different from the car and bus curves. Its upward concavity indicates that higher income groups spent proportionally more than lower income groups. The fact that this curve is in a lower position compared with the other two curves indicates that the rate trips are less. However, considering the trip length 37 km. for rail against 12 km. and 5.16 km. for car and bus respectively highlights the nature of rail as long distance mode on national basis.

9.6.3 Long-Term Public Transport Travel Prediction.

The assumptions of constant percentage of household's income to be allocated for travel by all modes (which was the case between 1965-75) is a reasonable one to be continued in the foreseeable future.

The fixed figure concluded in previous chapters was 6.2% of income. In Chapter 8 the assumption made was that 5% would be the share of car trips in 1985. With constant percentage of 0.5% for rail trips this will leave 0.7% for bus trips. The assumption about income in 1985 was also introduced in Chapter 8 (i.e., £200 average weekly income). These figures might not be correct but the relating factors, apart from funds available in future for public transport service improvement, the possible fare increases, should be related to the average income increase. Thus the effect of wrong income prediction could be eliminated and the application of GSM might give accurate results.

9.7 COMMENTS AND CONCLUSIONS.

Urban problems such as energy shortages, congestion and increasing highway costs (both financially and environmentally) are prompting communities to re-assess the need for adequate public transport. The consumers encouragement to rely less on private car can only be achieved by providing appropriate public transport service. The popularity of car is mainly due to the convenience, comfort, privacy and door-to-door journey, and these factors also explain why the perceived car cost is less than the actual cost. Apart from privacy (which is not needed for all kinds of trip purposes) all other factors can be achieved to a certain degree to improve the competitive position of public transport against car by encompassing various service alternatives such as conventional bus and rail, metro car and bus pooling, taxis, and dial-a-bus and park-and-ride, and shopper mini-buses. The integration of some of these modes with high technology and well designed financed systems will provide fast, smooth, quiet and frequent public transport service.

Identification of feasible transportation system alternatives to serve the community, not on the basis of profitability, will be achieved by adopting the community goals which provide guidelines including priorities on the role and importance of public transport for various community groups (e.g., old age pensioners, school children and commuters) and by investigating in depth the consumer attitudes and scale of preference of factors related to level of service, such as waiting time, walking time, in-vehicle time, number of transfers and fares. In addition to other factors, like comfort and seat availability.

The assumption in most early transport studies that car ownership is a major factor in the measure of mobility, is a misleading one.

In Europe the public transport share of travel, measured in passenger-kilometers, is increasing at the same time as car-ownership. A study in the U.S.A. showed that in Orange County (1.7 million population), 97 percent of all households have at least one private vehicle, and 62 percent have more than one. The expansion of public transport from five buses in 1972 to a fleet of 103 buses in 1974 has resulted in passenger travel increasing from 25,000 to more than 520,000 a month. Another 111 buses were added during 1975. Of those 67 were for expansion of demand-responsive transportation (DRT) service and 44 for improved service on the fixed routes (Fielding et al, 1976). These authors added the comments that only 3 percent of households did not have access to a car, and even this minority had friends and relatives who provided essential transportation. Yet these statistics are deceiving; of 1.7 million people residing in the Orange County, it is estimated that 500,000 do not drive, they are dependent on others for transportation.

In the U.K. very few examples exist of any sort of integrated public transport facilities. However, consideration of a range of options from high road investment with conventional bus services to low cost road improvement with massively extended public transport might result in much better solutions to urban transport problems.

Some unpublished reports show that the data from other European countries indicate clearly that the decline in public transport passenger-kilometres is unique in Britain. Furthermore, forecasts in these other countries envisage stable or increasing volumes of public transport despite rising car ownership.

In this chapter household share of public transport both by bus and rail on national level has been analysed. Throughout the period 1965 to 1975 there is a consistent trend of expenditure on travel by rail of 0.5% of the average household's income. There is also a constant percentage of the average household's income spent on travel by all modes (6.2%). By fixing the share of car travel, the remainder will be the share of bus travel.

For bus travel, lower income groups spend a greater proportion of their incomes than higher income groups, but in money terms higher income groups spend more than the lower income groups. Thus households in higher income groups have a greater "propensity", and travel more, than households in lower income groups.

The indices of cost of travel by all modes except bus have increased at a slower rate than the general cost of living as measured by the "all goods and services" index. The bus cost index has risen at a faster rate than the general cost of living. The net effect of this is that there has been a decline in expenditure on bus travel.

The GSM was applied to rail trips. Compared to travel by other modes, the trip rate for travel by rail is very small. However, the average trip length is 37 km, which is much greater than the averages for car (12 km) and bus (5.16 km) journeys. This reflects the nature of rail as a long distance mode of travel.

CHAPTER 10

TRAFFIC ASSIGNMENT

RELATIVE ATTRACTIVENESS METHOD

10.1 INTRODUCTION.

"At a certain stage of traffic analysis and/or transporation planning, it becomes necessary to compare the demand for individual vehicular transport against the availability of existing networks. The demand for transport can be presented by an origin/destination (O/D) matrix in which the various trips between different zones are quantified. The trips may refer to an existing situation and be directly derived from O/D survey, or be obtained from generation and distribution models (Martin et al 1961) according to hypothesis of future territorial development" (Tagliacozzo, 1973).

The network is represented by a graph in which the various links and nodes indicate real or hypothetical roads and intersections, respectively. Each link or node is properly defined by one or more parameters describing its function characteristics. Thus "Traffic assignment is the transference or allocation of travel demand (in terms of a matrix displaying the number of persons or vehicle trips between origins and and destination in a particular area)to an existing or proposed road or transit network in order to determine corridor, route, link or intersection volumes in the planning process and for design of the system facilities" (Dulton and Harmelink, 1974).

Traffic assignment is usually the last major stage of analysis leading to the evaluation of future transportation proposals. With the advent of high speed computers the assignment of traffic volumes to large networks has been made possible. Since the late fifties many assignment techniques have been developed (Chapter 2). However, a common fault lies in their lack of convergence to a given criterion (Lucas and Davidson, 1974).

In almost all studies, the journey unit used was time (minutes) for specifying the link length. This direct dependence on time and hence on speed on the network is the main reason why discrepancies exist between observed and predicted volumes.

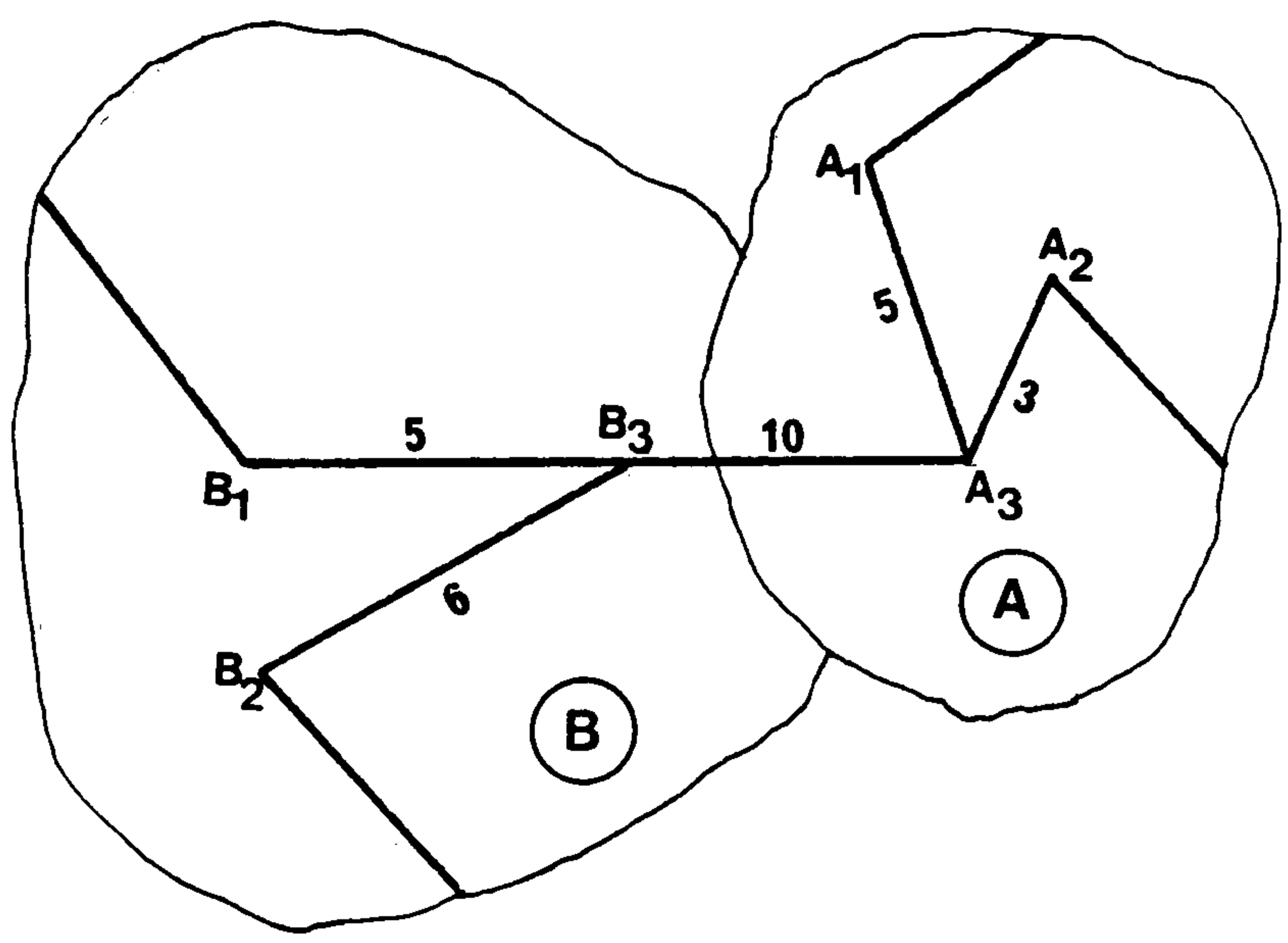
Instability in the conventional assignment techniques becomes apparent when a slight, insignificant, change in input yields a significantly different output.

In this chapter a new method for traffic assignment is outlined which can be used independently of link time he model depends on relative attractiveness of each available route. A better understanding of the whole assignment process can be achieved by using this type of model, which is in fact a gravity type model (not used before in any form in assignment). The advantage of this type of model is that it can be calibrated separately for peak hour, or for a twenty-four hour day. Such flexibility for calibration makes this model significantly different from conventional techniques. Another advantage of this method is that it provides the values for the parameters needed in a "feed-back" process required for the trip generation models outlined in previous chapters. These parameters are "average trip length" and "percentage distance travelled" for each trip purpose used in the modelling process. Before formulation and application of the assignment model, it is necessary to define the assignment criteria. That is, to define the concepts which road users follow in selecting their urban paths with other related parameters used in network description.

10.2 LOAD LIST AND ZONE CENTROID.

Traffic assignment is that part of the transportation system analysis whereby the given set of trip interchanges (trip table) is allocated or loaded onto the specified route network. A network consists of a set of links and nodes with the nodes representing intersections and the links the roadways between intersections.

Usually a study area is divided into zones and for each zone there is one or more points on the network where traffic originates and terminates. These points are called "zone centroids" and in this work each centroid is the mid-point of a suitable link. The diagram below is a simple example representing a two-zone study area with zones A and B.



Figures on the links represent journey units between the nodes.

Diagram 10.a

There are three possible centroids for each zone.

Table 10.a

Centroid zone A	Centroid zone B	Minimum path
A_1	B_1	20
	B_2	21
	B_3	15
A_2	B_1	18
	B_2	19
	B_3	13
A_3	B_1	15
	B_2	16
	B_3	10

From this table it is possible to observe that the centroid has an effect on the assignment stage, because different centroids give different shortest paths. This suggests that it is desirable to have a very close look at the structure and housing systems, intensity of dwellings and feeder's of major links for each zone. By doing this, a proper portion of total traffic origins from each zone can be allocated to a certain centroid. A load list table can then be prepared to reflect this fact. Some studies use the centre of gravity of a zone as the centroid and it is connected to nearby nodes. The links between the centroid and the nodes of the network are termed "Centroid Connectors". An estimated measure of travel time should be given to each centroid connector to reflect the average time required for trips beginning or ending in that zone to leave or reach the zone. The precise specification of these centroid connector links requires much care, attention and practical experience as their travel time allocation and geographical description can have considerable influence on the choice of route assumed to and from that zone (Lane et al, 1974).

This is a major difficulty in simulating the real situation, because vehicles, especially cars, originate at different points in space. The above procedure will inevitably lead to many details being omitted from the network description; many relatively unimportant links may not be included which will affect the routes of the shortest paths. This is one reason for invalidity of comparison between the predicted volumes with obzerved ones. Hutchison, 1974 stated that "there are a number of potential sources of error in this type of comparison and these include : (1) errors in the origin-destination matrix assigned to the traffic network, (2) errors due to over simplification of the coded network, (3) errors in the assignment technique, and (4) errors in the observed traffic volumes".

10.3 NETWORK DESCRIPTION FOR COMPUTER ANALYSIS.

Most transportation planning studies use computer techniques to assign interzonal traffic to road networks. The techniques all require the road network to be described numerically, but the work involved in preparing a numerical description from a plan of the network is laborious and likely to suffer from inaccuracy.

The "Automatic Network Description" system has been devised to overcome these difficulties and to enable the user to prepare a numerical description quickly and accurately by using the D-MAC analyser (1).

After storing the network description, it is easy to recover it and to produce as many alternatives as required in the assignment stage. This can be done by defining the "journey units" used in the network description. The sections (links) of the network can be valued for transportation planning purpose in combinations of three units - distance, time and cost.

Considering one unit of distance of a section, as say 1 km, this can have many values in terms of time (mins.); if a vehicle is travelling at an average speed of 30 km/hr. then the time length of 1 km is 2 minutes.

A cost unit can also be used - either the actual cost or that perceived by the user.

The basic network description which is fed into the computer is in the form of coordinates of the nodes represented by physical distance between nodes. To deal with the separation of any two points in terms of time, which is often done in conventional transportation planning, a weight can be given to each section according to the journey time of traffic on it. Many other facilities are available to modify network descriptions.

(1) For more detail see user's guide in the Traffic and Highway Section, University of Strathclyde.

After giving a proper journey unit to each link in the network, most transport models use an build a minimum tree from an origin zone to all destination zones, expressed in the same journey units as used in the network description. This important aspect of computer capacity, not only in storing such a huge amount of data but in producing the lengths of the shortest points (dij) for each origin destination pair in the O-D table, makes transportation planning possible.

The value of the computer must be emphasised in transportation planning, to investigate the effect of a single improvement as well as major improvements on the whole study area. This becomes possible only by using large computer capacity.

10.4 JOURNEY UNITS USED IN NETWORK DESCRIPTION

In this study three types of journey units are used for network description :

1. Distance
2. Time
3. Generalised cost

The length of a link in terms of distance is the physical distance between the two nodes connected by the link. However, for time units an assessment of the traffic speed on the links is required.

A generalised cost unit for network description is obtained according to the following procedure: resources needed to traverse a unit distance at speed ( )kph and

Money cost = B from operating cost formula

Time = $\frac{1}{\nu}$ hours

Time cost = time x value of time (VOT)

(VOT) = νB

$\therefore$ Time cost = $\frac{1}{\nu} \nu B = B$

Generalised cost (GC) = money cost + time cost

= B + B = 2B

2B represents the length in terms of (GC) for links with highest speed, for links with half of the highest speed

Money cost = A = A from operating cost formula

Time = $\frac{1}{.5\nu} = \frac{2}{\nu}$ hours

Time cost = time x value of time

= $\frac{2}{\nu}\,\nu A = 2A$

Generalised cost (GC) = 2A + A = 3A

Similarly at speed $\frac{1}{3}$ of highest speed

(GC) = 4A

Assuming highest average speed equals 60 kph, the following table presents the weights which can be used in network description.

Table 10.b

Type	Speed	Journey unit				Weight		
		Distance	Time	Cost	GC	Dist.	Time	GC
	kph	km	min.	pence/km				
0	60	1	1	1.95	2B = 3.95	1	1	1
1	30	1	2	2.2	$3A_1$ = 6.60	1	2	1.67
2	20	1	3	2.615	$4A_2$ = 10.46	1	3	2.64
3	48	1	1.25	1.98	$2.25A_3$ = 4.45	1	1.25	1.12

It is interesting to note that the length of the link in terms of generalised cost can easily be established. Its weight lies between weights of both time and money, as shown in Table 10.b.

10.5 MEASURES OF ACCESSIBILITY IN TRANSPORTATION PLANNING.

10.5.1 Accessibility Index of a Point.

Accessibility (A) has played a major explanatory role in spatial economic theories of the city. It has been considered to be the key variable in the determination of urban rents, densities and land uses (Dalvi and Martin, 1976).

However, attention has centred on the role of accessibility in trip attraction as well as trip generation in urban areas, i.e., on the question of whether changes in accessibility associated with urban transport investment have any effect on travel demand. This is essentially a hypothesis about travel behaviour of certain groups of travellers.

In trip distribution models, the gravity models almost always include some measures of accessibility. In some studies by Wilson (1974) the concept of accessibility was introduced jointly with competition for defining spatial interaction framework.

There are of course many possible ways of defining accessibility, according to the measure needed in the model.

The index of accessibility, which is not directly related to activity, is the one which is introduced here and used in the assignment stage. The index gives a weighting to a point in the network according to its centrality with respect to all other points. From this it is possible to judge the relative importance of the node or section, or even the zone under consideration.

If this index is expressed as a percentage, of the total accessibility of the network any individual zone possesses a value of (A%) which evaluates its centrality and the ease of reaching it from all other zones. Thus a more accessible link or zone is one with a higher (A) value and it can be found that : (Al-Sarraj, 1975)

$$A_i = \frac{\sum_i^n \sum_i^n d_{ij}}{\sum_j^n d_{ij}} / n^2 \quad 100 \qquad (10.1)$$

where

A_i : accessibility index of point i

d_{ij} : minimum path from i to j

$\sum_j$: the summation overall j s (row summation

$\sum_i$: the summation overall i s (column summation)

n : number of points or zones

In practice the accessibility index for a point represents the ease of reaching that point from all other points measured in terms of the journey units used. For example, a zone may be accessible in terms of time but less so in terms of distance.

10.5.2 Accessibility Index of a Route

The "A" as in formula 10.1 can be used to compute the accessibility of a route, which can be defined as the average accessibility of all links in a route. It can be shown that the decrease of "A" with increase of distance from the centre of town is similar to a regular decline in the intensity of land use development, as distance from CBD area increases. Since vehicle movement is a function of building activities in the town (Buchanan, 1965) it is reasonable to expect most vehicle movement in the CBD area and the amount of traffic decreasing with the decrease in accessibility outwards from the town centre. Similarly, low speeds on links and more delay at intersections are experienced in the inner city compared with the suburbs.

To avoid speed and delay measurements (needed for conventional assignment models) the primary objective of this work is to define the accessibility index of links in terms of distance, measured from the network geometry. This accessibility index, has been used as a proxy variable to relative speed and delays at intersections in the assignment model.

10.6 DIAMETER OF NETWORK

The diameter of a network (DON), can be represented in many ways to serve the purpose for which it is constructed.

In this study the most suitable method is to use the distance journey units in the network description. Then if minimal trees are built for all zones, the maximum length of the shortest point journey on origin and destination (in journey units), represents the network description (DON).

If zone centroids or load lists are changed, the "DON" might change accordingly. If any new section is added to the network, again "DON" might be changed.

If the average trip length (by purpose) can be expressed as a percentage of "DON", then comparison of one area with another will be more meaningful. In these circumstances care must be taken in fixing boundary zones and the load list.

In mathematical notations

$$\delta(G) = {}_{x}\mathrm{Max}_{y}\ d\ (x,y) \quad \text{(Kansky} \qquad)$$

where

$\delta(G)$ is the diameter of the network (or graph) and the expression means the maximum shortest path between all O-D pairs.

10.7 BEST ROUTE BETWEEN A PAIR OF O-D

It is important to note that the engineer is judging "best" in terms of quickest or cheapest route with reasonably accurate information available. The driver on the other hand is judging "best" based on number of travel and service variables and must guess about conditions of the whole route before making a trip. The engineer and the driver may be basing their judgment on different variables, and certainly basing their decisions on different information (Whole and Martin, 1967).

The engineer modelling the assignment process probably has incomplete information about traffic speeds, flows and delays on the network. In many cases, the delays at individual junctions will be ignored or "averaged out" to give the effect thought to be required.

The driver is the main element in making a selection from a number of paths linking his origin to his destination. He choses the path which will give him the "best" value for a number of variables characterising the network and his trip.

Whilst it is difficult to assess each driver's knowledge of his area network so that account may be taken of differences of behaviour due to personal variations in knowledge of available paths, it can be assumed that at least they are all familiar with some overall character of available routes for any particular trip purpose.

On this basis, it is thought that the best unit of analysis is the driver. The criteria which motivates the driver's decision in making a route choice are those parameters which can be perceived easily and quantified to some extent in the driver's mind. This approach then requires the production of not only one path between a pair of O.D., but a number of (almost shortest) routes, each of which is thought to be the "best" for a group of drivers. This calls for not only a minimum path algorithm (which is well established and used in all conventional assignment techniques) but to find the (N) best path in the network.

There have been many attempts to solve the problem of (N) best route, among them Hoffman and Pavley, 1959, and many others, no practical algorithm has yet been published for finding N best paths. A computer program prepared in the Traffic and Highway Section of the Civil Engineering Department, University of Strathclyde, was successful in finding N number of routes - according to the users criteria - between each pair of O-D.

10.8 DATA FOR ANALYSIS

Data for the town of Hamilton was available in the University of Strathclyde from a survey and analysis undertaken in 1969. The study area consists of the Burgh of Hamilton, and its location is shown in Figure 10.1. The population of Hamilton in the year of survey was about 46,000 comprising of 13,000 households. On average 52,000 vehicles enter and leave the study area during the 12 hour working day. Two thirds of the vehicles are private cars.

Hamilton was divided into 76 traffic zones (Figure 10.2). The area outside the study area was divided into 10 external zones (Figure 10.3). The existing network is shown in Figure 10.4, and it consists of about 200 links. Traffic was counted at certain points in the network to provide a check on the modelling process.

The accessibility contour lines shown in Figure 10.5 are based on formula 10.1 which was evaluated for each link. The results are presented in Table 10.5. The assignment model was applied to one data from Hamilton. The load list used is shown in Table 10.4.

10.9 NUMBER OF ROUTES BETWEEN A PAIR OF O-D IN A CERTAIN NETWORK

Theoretically, there are countless numbers of routes in a network between a pair of O-D, and the minimum path is only one of them.

A detailed work on Hamilton network (Figure 10.4) showed that the total number of routes (using distance as a journey unit) available for an average pair of O-D (for total of 677 pairs of O-D tables) changes with the value given to CP, where

$$CP = \frac{L_{max} - L_{min}}{L_{min}} 100 \qquad (10.2)$$

where

CP : critical percentage allowed for deviation from minimum path

L_{min} : length of minimum path

L_{max} : length of maximum "allowable" path

The average number of routes found for different values of (CP) are shown in Table 10.c.

Table 10.c

Percentage over shortest route CP %	Average number of routes for one pair of O-D
0	1
5	2
10	5
15	12
20	28
25	65

This table presented disgrammatically on a semi-log scale in Figure 10.6 gives a resultant straight line and made the task of extrapolation for higher values of (CP) relatively easy. Actual computer runs were made until CP = 20%. for CP = 25 % and the values as shown in Table 10.c are only a projection because of time restriction on computer use.

However, this does indicate a definite conclusion, viz:- that the number of routes increases dramatically as CP increases beyond 10%.

It is interesting to note that within only 5% deviation from the shortest path, there is on average a second alternative route available. There is no reason why this second alternative should not be one of the driver's choice, knowing that, in practice, as far as route length is concerned, any discrimination between these two routes (similar in other aspects apart from their length) generally is not possible. Especially this is so in urban areas with their relatively short trip lengths.

It is found that the number of routes is also a function of route length for the same value of (CP) i.e., the number of routes between a pair of O-D with minimum path of 5 km. is more than that for a pair of O-D with minimum path of 2 km. However, considering only the traffic movements in the study area, and the fact that movement between two zones is also a function of separation, this gives in the case of Hamilton a net effect of increasing the total number of routes for the whole study area as the CP value increases, till a maximum is reached. Further increases in the CP value cases a decrease in the number of routes.

Table 10.2 shows that for deviation of CP = 10% there is a total of 3405 routes in different bands for 677 pairs of O-D. All these routes have been analysed in terms of length, expressed as percentage of network diameter (DON) as already defined. The paths have been grouped in classes of intervals equal to 1/10 of (DON) and for CP = 1% in 1% increments until CP = 10%. Therefore, the first cell in the table is the number of routes including the paths having a length between 0 and 0.1 (DON), which is 12, i.e., there are 12 routes from a total of 3405 routes used by all travellers with length of up to 10% of network diameter comprising shortest routes and 10% deviation from shortest route, and so on for other cells of the table. It is interesting to note that within the total of first column with 807 routes, 677 routes represent the minimum paths (L_{min}) and 130 routes differ by only 1% from that of L_{min}. The set L_{min} route comprises only 20% of all routes.

Table 10.2 has been converted into a frequency table and this is presented diagrammatically in Figure 10.7 with the first column omitted to facilitate a better perspective view of the situation. This diagram illustrates that route distribution is characterised by both the network configuration and land-use in the study area.

Although the journey unit used in the network analysis is distance, time and generalised cost as a journey unit are also investigated. Table 10.3a shows a number of routes for each cell as before, in terms of time unit journeys. The total number of routes is 1985, which is substantially less than that for the distance journey unit calculation. The first column shows a total of 729 routes, of which 677 are L_{min}, 52 routes are within 1% increase over L_{min}, and the set of L_{min} routes represents 34% of total number. Table 10.3b represents the several routes analysed in terms of "distance" length. The totals for each band (row and column) compared with those of Table 10.3a, shows that there are great differences between time and distance route frequency distributions.

Table 10.4 is based on generalised cost. The number of routes is 2200, and this value lies between the values for the distance reached and that for the time network. Furthermore, if all these three networks are thought of as in terms of speed in the network, then the distance network represents the ideal situation with the same speed on all links, and all 3405 routes have the same average speed. This number of routes then represents the maximum number of routes which can be found in this network for a given CP value and O-D table.

10.10 FACTORS AFFECTING THE DRIVER'S DECISION IN CHOOSING A CERTAIN ROUTE

10.10.1 Introduction

In the present work the parameters considered to influence drivers in choosing a certain route are only those which can be measured fairly accuratelt. Other factors such as scenery and safety have not been considered. Nevertheless it is possible to give assumed values concerning these parameters if it is thought they are important factors in a driver's decision making. The factors considered here are :

1. Length of the alternative route compared to the length of the minimum path.

2. Average width of the route, which is a function of speed and flow.

3. Delay at intersections, which is a function of number, type and position of the intersection in the study area network.

The impact of these and other related factors will be presented in the following section.

10.10.2 Length of Minimum Path Versus Alternative.

A study of comparison of driver's route choice criteria and those used in current assignment process was undertaken by Ractliffe, 1972). In home-based work trips by private car drivers, comparison was made between the chosen routes and calculated minimum routes by a number of route choice criteria, viz:- distance, time and cost. The conclusion of this study was "in general the majority of drivers attempt to minimise their routes with approximately three-quarters succeeding in choosing a route not exceeding 10 per cent longer than the minimum route"

Among other findings of the study was that "the single routing assigneat technique is shown to be considerably less accurate than the multiple routing technique when simulating 'real' trip assignment".

In another study by Tagliacozzo, 1973, analysis of the paths is related to the users motivation in making a route choice, showed that only 55 per cent of the paths are of length between L_{min} and 1.1 L_{min} and the ratios of L_{max} and L_{min} for some routes was 1.5.

In "Westminster route choice survey" (Wright, 1976) analysis of different samples of drivers' behaviour in choosing a route showed that about 65% of drivers chose alternatives which were either the shortest route itself or routes whose length was greater by 10% of that of the shortest route.

Summarising: the number of available routes between a pair of zones depends on the CP value. Recognising the difficulty of "route following" survey process for assessing the drivers behaviour in deviating from the minimum path, the CP value can only be assessed empirically based on information from other studies.

It is found that 10% represents a proper figure both for computational purpose and model calibration.

10.10.3 Average Width of the Route.

In a study area there is likely to be considerable variation in the of links in the road network.

Most probably, the travellers on any particular journey will use a combination of streets with different widths. Furthermore, the factors which reduce the effective width of the link, such as the number of parked vehicles and/or one-way sections, are also appreciated by the motorist.

Traffic flow and speed are a function of roadway width, and the number of traffic lanes provided is realised by the motorist more readily than theoretical speed-flow relationship. Narrow lanes have a lower capacity than the standard 12 ft. lanes and overtaking is more restricted in narrow routes. Such restrictions affect drivers comfort and increase potential hazards.

Table 10.d gives the capacities of lanes from 9 ft. to 12 ft. in width expressed as percentage of the capacity of a 12 ft. lane.

Table 10.d

Lane width (ft.)	% of 12 ft. lane capacity	
	2-lane	Multi-lane
12	100	100
11	88	97
10	81	91
9	76	81

Source : Highway Capacity Manual, 1965, pp.89.

Although these percentages are derived from uninterrupted flow conditions, they may be used to represent "relative capacity" for each width of road, in a model. From observations before and after the imposition of waiting regulations in London, it has been estimated that traffic speed was increased by about 2.5 mph for every 100 parked vehicles per mile removed from streets in the central area with an average width of 40 ft. (Charles Worth et al, 1959). If substantial parking is observed in the study area, its effect can be taken into account by modifying the relative capacity of the appropriate links.

Table 10.e shows the relation of carriageway width to capacity and their weighted values. The "width"

as an attractiveness parameter can be built into the model as net physical dimensions which are easy to measure from city plans, or as capacity weights. The higher the value (as average of the route) the more attractive the route. Any difference in using width or weight of capacity only affects the calibrating parameters

Table 10.e

Carriageway width ft.	Capacity p.c.u./day	Weight of capacity	Weight of width
1	2	3	4
Dual 48 ft.	66,000	7.33	8.00
Dual 36 ft.	50,000	5.55	6.00
Dual 24 ft.	33,000	3.66	4.00
33 ft.	15,000	1.66	1.37
24 ft.	16,500	1.83	2.00 (one-way)
24 ft.	9,00	1.00	1.00

Capacity of different carriageway width and their relative weights.

10.11 RELATIVE ATTRACTIVENESS TRAFFIC ASSIGNMENT MODEL (RATA).

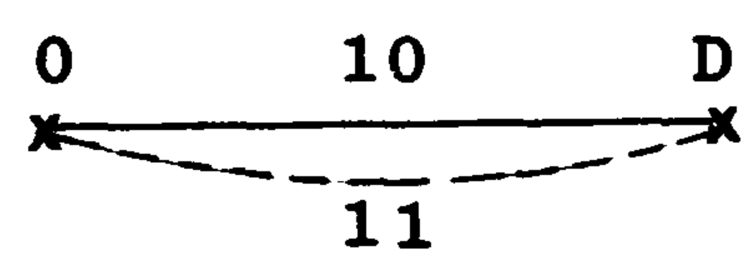
The model is based on comparing all available routes between a pair of O-D with shortest route. The comparison is based on factors affecting the driver's decision in choosing one route rather than the other.

Network description can be based on any journey unit of time, cost or distance. The difficulty of measuring time and speed in networks to a certain accuracy, and its sensitivity led to using the length of the routes (in distance units) as a more appropriate measure. One main advantage of this is from the physical structure of the layout since the routes can be measured and scaled fairly accurately. The concept of the model is as follows :

Assuming two routes available between a pair of O-D, shortest route with 10 journey unit, the alternative with 11 journey unit,

$$L_S = 10$$

$$\therefore \quad L_1 = 11$$



where L_S : length of shortest and L_1 : length of first alternative.

Assuming total traffice travelling between this pair of O-D is 1000 vehicles, and it is found 600 vehicles travelling via shortest route, and 400 vehicles via the alternative. Then the model becomes :

$$(AEFF)_K = \left[\frac{L_S}{L_K}\right]^{\alpha} \tag{10.3}$$

$$(Proportion)_K = \frac{(AEFF)_K}{\sum_K (AEFF)} \tag{10.4}$$

$$(TR)_K = T.(Proportion)_K \tag{10.5}$$

where

$(AEFF)_K$ = Effective attractiveness of route K

$(Proportion)_K$ = Percentage of traffic via route K

$(TR)_K$ = Total traffic via route K

T = Total traffic for the pair of O-D under consideration.

K = S for shortest route

= 1 for first alternative

= 2 for second alternative and so on

α = is calibrating factor

In this example

$$(AEFF)_S = \left[\frac{L_S}{L_S}\right]^{\alpha} = \frac{10}{10}^{\alpha} = 1$$

$$(AEFF)_1 = \frac{10}{11}^{\alpha} = \frac{10}{11}^{\alpha} = (.909)^{\alpha}$$

$$\Sigma(AEFF) = 1 + (.909)^{\alpha}$$

$$(Porportion)_S = \frac{(0.909)^{\alpha}}{1+(0.909)^{\alpha}} = \frac{600}{1000} = 0.6$$

$$(Proportion)_1 = \frac{(0.909)^{\alpha}}{1+(0.909)^{\alpha}} = \frac{400}{1000} = 0.4$$

Value of α to satisfy this equation equals 4.25. This value is reproduced for the load on the route for base year, therefore this value can be used for target year. The range of values for α is as follows :

$\alpha = 0$: the traffic will be diverted equally between the routes available

$\alpha = 1$: each route takes traffic in proportion to its length

$\alpha = \infty$: all the traffic will travel via shortest route. (i.e., all-or-nothing)

The model in 10.3 dealt with comparison of length only, the other factors effect (as described earlier) can be put into the model on the same basis, the general shape of the model may be as follows :

$$(AEFF)_K = \left[\frac{L_S}{L_K}\right]^{\alpha}\left[\sigma + \frac{A_S}{A_K}\right]\left[\frac{R_S}{R_K}\right]^{\beta}\left[\frac{Q_K}{Q_S}\right]^{\gamma} \quad (10.6)$$

$$(Proportion)_K = \frac{(AEFF)_K}{\Sigma_K(AEFF)} \quad (10.7)$$

$$(TR)_K = T. \ (Proportion)_K \quad (10.8)$$

where

$(AEFF)_K$ = Effective attractiveness of route K

(Proportion) = Percentage of traffice diverted to route K

TR = Traffic via route K

T	=	Total traffic from O to D
L_S	=	Shortest route length
A_S	=	Accessibility index for route L_S
R_S	=	Number of intersections via L_S
Q_S	=	Average width for route L_S
K	=	From 1, 2.... N

where N number of availabe routes

L_K, A_K, R_K and Q_K are as above, for alternative route

α, σ, β and γ : calibration parameters.

It is important to notice that the all-or-nothing method is a special case of the above model, i.e., by setting K = 0, or CP = 0, no alternative or no deviation from shortest path is allowed.

Formula 10.8 can be rewritten as :

$$(TR)_K = T.\frac{\left[\frac{L_S}{L_K}\right]^{\gamma}\left[\sigma + \frac{A_S}{A_K}\right]\left[\frac{R_S}{R_K}\right]^{\beta}\left[\frac{Q_K}{Q_S}\right]^{\gamma}}{\sum_K \left[\frac{L_S}{L_K}\right]^{\gamma}\left[\sigma + \frac{A_S}{A_K}\right]\left[\frac{R_S}{R_K}\right]^{\beta}\left[\frac{Q_K}{Q_S}\right]^{\gamma}} \qquad (10.9)$$

Formula 10.9 is in fact a gravity type model, i.e., total traffic between a pair of O-D is diverted to Kth best route, proportionally, to the relative attractiveness of that route.

This is analogous to :

$$T_{ij} = O_i \frac{T_{ij} \; f(C_{ij})}{\Sigma T_{ij} \; f(C_{ij})}$$

where

T_{ij}	:	Number of trip interchanges between zone i and j
O_i	:	Total number of trips originating in zone i
$f(C_{ij})$	:	Friction factor
C_{ij}	:	Time, cost or distance

10.12 APPLICATION OF RELATIVE ATTRACTIVENESS TRAFFIC ASSIGNMENT (RATA) METHOD

10.12.1 Introduction

The model given by equation 10.9 can be applied to predict the amount of traffic along each potential route between a given pair of origin and destination zones, and the total traffic on any link in the network will be the result of the accumulation of traffic for all pairs of O-D, via all routes. This model was applied to Hamilton O-D table, using all three types of unit journey, time, cost and distance. In each case satisfactory results were obtained, and any difference only occurs in the calibration parameters. The benefit of this model is that by using distance as the journey unit it can free the planner from collecting data concerning speed and delay measurements.

The procedure used is shown as a flowchart in Appendix -8-. the prerequisite for any assignment involves both the O-D table and network. The value for (CP) as defined before is assumed to be 10%. The lengths of routes found between a pair of O-D are between the shortest route 9L_S) and 1.1 L_S. The first alternative route is denoted by L_1, and the second by L_2, the K and N by L_K and the last by L_N, where N is the total number of routes between the given pair of O-D.

The process of allocating traffic to each of the N routes is now carried out on the basis of equation 10.9.

Calibration is undertaken by assuming various arbitrary values for the parameters involved

(α, β, γ, and σ). Several computer runs are made fixing values foa all parameters and tracing the effect of change in each one of them in turn. The best values could be those which give as reasonable results as possible comparing the predicted and observed volumes (See Appendix 9). However, the exact matching of predicted with the observed, even if this could be attained, is nor necessarily the best criterion, for reasons which have been outlined earlier.

Conventional assignment techniques were also applied to the same data for Hamilton. Apart from one section (section 42) the volumes predicted by RATA in the last row of Appendix -9- (for values of CP = 10, $\alpha = 1.0$, $\sigma = 1.0$, $\gamma = 2.0$ and $\beta = 1.5$) are closer to the observed traffic than any volumes predicted by other methods.

10.12.2 Example of Route Availability

The procedure used by the computer programme is the same as given in Appendix -8-. As an example of route following procedure and the method of application of the model, some examples extracted from the computer output are presented here.

1. One one route available -
   Origin-Section 161, Destination - Section 146.
   Origin-Section 165, Destination - Section 104.

Table 10.6 shows two cases where there is no alternative to the shorter route between an origin and a destination. Consequently all traffic follows the shortest path; the first pair are relatively close to each other. However, the tendency of creating more routes following greater separation of O-D points is shown in Figure 10.6 and is based on average values. In addition it is possible that the network configuration might also permit the existence of only one route for a given value of CP. These routes are shown on network 10.1. It must be emphasised that any other possible route between these two pair of O-D is greater than 1.1 L_S. (where L_S is the shortest path length) it is discarded from analysis.

2. Two routes available - Origin-Section 161,- Destination - Section 167.

   Origin-Section 165,- Destination - Section 82.

In Table 10.6, the case of an addition to any existing shortest route, an alternative route presentation is given here with a deviation of 10% from shortest route. Network 10.2 shows the routes for these pairs of O-D, and all other possible routes with lengths greater than 1.1 L_S is discarded from analysis.

3. Three routes available - Origin-Section 30, Destination - Section 82.

In Table 10.7 there are only two routes with deviation from shortest route by not more than 10%. These routes are shown in Network 10.3.

4. Four routes available - Origin-Section 137, Destination - Section 170.

In Table 10.7, four routes are found and presented in Network 10.4.

5. Five routes available - Origin-Section 177, Destination - Section 139.

In Table 10.8 there are five routes which are also presented in Network 10.5. An illogical diversion has formed in route 5 which is the same as the shortest route apart from a short variation as shown in the Network 5. However, such unacceptable results can be eliminated by modifying the network layout.

6. N routes. The separation of Origin from Destination will determine the number of available routes for a given value of (CP) in a certain network. However, as an example of the maximum number of routes between a

pair of O-D in Hamilton. It is found that 53 routes exist between Section 7 and 169 with only 10% deviation from shortest path (see Table 10.9).

10.13 COMPUTATION PROCEDURE.

Referring back to Table 10.7 and the calculation for four route which exists between Origin Section 137 and Destination Section 170, the following information is abstracted from Table 10.7.

Table 10.f

Route				
1	$L_S = 3949$	$A_S = .5000$	$R_S = 16$	$Q_S = 16.31$
2	$L_1 = 4225$	$A_1 = .4986$	$R_1 = 16$	$Q_1 = 14.81$
3	$L_2 = 4329$	$A_2 = .5401$	$R_2 = 16$	$Q_2 = 13.60$
4	$L_4 = 4089$	$A_3 = .5211$	$R_3 = 14$	$Q_3 = 13.46$

Critical route length given by

$$L_S + 0.1\ L_S = 3949 + 395 = 4344$$

all routes are equal or less than critical route length

$$\therefore \qquad L_K = L_S + (CP)L_S$$

Number of intersections for each route is actually equal to number of links in the route minus 1. However, the (-1) is omitted from the calculation. Accessibility index is computed as a mean value for all links in the route with the width of each route in feet. This also represents the mean value of all links in the route.

The speed shown in Table 10.7 is related to the journey units in the network description; the time length and distance length is the same. Consequently the resultant speeds on all links are the same.

The model as in equation 10.9 applied to each route in turn gives the following result :

$$(TR)_K = T \cdot \frac{\left[\frac{L_S}{L_K}\right]^{\alpha}\left[\sigma + \frac{A_S}{A_K}\right]\left[\frac{R_S}{R_K}\right]^{\beta}\left[\frac{Q_K}{Q_S}\right]^{\gamma}}{\sum_{K}^{N}\left[\frac{L_S}{L_K}\right]^{\alpha}\left[\sigma + \frac{A_S}{A_K}\right]\left[\frac{R_S}{R_K}\right]^{\beta}\left[\frac{Q_K}{Q_S}\right]^{\gamma}} \qquad (10.9$$

$$(EFF)_S = \left[\frac{3949}{3949}\right]^1 \left[1 + \frac{.5}{.5}\right]\left[\frac{16}{16}\right] \left[\frac{16.31}{16.31}\right]^{2.0} = 2.0$$

$$(EFF)_1 = \left[\frac{3949}{4225}\right]^1 \left[1 + \frac{.5}{.4986}\right] \left[\frac{16}{16}\right]^{1.5} \left[\frac{14.81}{16.31}\right]^{2.0} = 1.5442$$

$$(EFF)_2 = \left[\frac{3949}{4329}\right]^1 \left[1 + \frac{.5}{.5401}\right] \left[\frac{16}{16}\right]^{1.5} \left[\frac{13.60}{16.31}\right]^{2.0} = 1.2213$$

$$(EFF)_3 = \left[\frac{3949}{4089}\right]^1 \left[1 + \frac{.5}{.5211}\right] \left[\frac{16}{14}\right]^{1.5} \left[\frac{13.46}{16.31}\right]^{2.0} = 1.5751$$

$$\sum_K EFF = 6.3406$$

$(Proportion)_S = \frac{2.0}{6.3406} = .3154$ percentage traffic via shortest route

$(Proportion)_1 = \frac{1.5442}{6.3406} = .2435$ percentage traffic via alternative 1

$(Proportion)_2 = \frac{1.2213}{6.3406} = .1926$ percentage traffic via alternative 2

$(Proportion)_3 = \frac{1.5751}{6.3406} = .2484$ percentage traffic via alternative 3

$(TR)_S = 98 \times .3154 = 30.98$

$(TR)_1 = 98 \times .2435 = 23.92$

$(TR)_2 = 98 \times .1926 = 18.92$

$(TR)_3 = 98 \times .2484 = 24.40$

The values of (Proportion) via each route multiplied by 98 (the amount of traffic between the pair of O-D under consideration) gives a result which is the traffic via each route and consequently via all links along that particular route.

Network 10.4 represents the routes found in this example.

The effect of one-way traffic on a link can be observed in the Hamilton network.

It is found that the one-way street this affects both the length of shortest path as well as the number of routes within each CP value. Section 34 in the Hamilton in this network is a one-way street and thus traffic is obliged to make a diversion around this section. However, the resultant load on any particular link will most probably accumulate to a greater extent on those links which appear in more routes. <u>This argument essentially calls not for improvement to links which are already heavily loaded, but rather to improvements on other links.</u> On building a new link care must be taken not to bring the heavily loaded links into the paths of those O-D pairs which are now not using these heavily loaded links. Table 10.10 is a sample representing a final result of accumulation of traffic on each link.

10.14 AVERAGE TRIP LENGTH

Using the RATA model a total number of 52,438 trips are assigned to the network using different journey units. The following information is obtained :-

Table 10.g

	Network journey unit		
	Distance	Generalised cost	Time
Total number of routes	3405	2200	1985
Total length of all routes	13.258	7.970	7.160 x 10^6
Total vehicle distance(A)	146.433	146.204	147.856 x 10^6
Total vehicle time (B)	148.115	220.109	289.084 x 10^6
Weight of journey unit(C)	$\frac{289}{147.8}$	$\frac{289}{147.8}$	$\frac{289}{147.8}$
Actual vehicle time (D)	286.3	285.8	289.084 x 10^6
D = A x C			
Parameter values in the model σ	1.0	1.0	1.0
(CP)%	10	10	10
α	1.0	1.0	1.0
β	1.5	1.5	1.5
γ	2.0	0.0	0.0
Network diameter (ϕ)	6650	6650	6650(Distance unit)
Average trip length ($\bar{X}$)	2793	2788	2820(Distance unit)
$\bar{X}$ as percentage ϕ	42	42	42.4

Note: there is a possibility of different network diameters existing if different journey units are used in the network description. (As seen in Tables 10.3 and 10.4). However, in Table 10.2 a distance journey unit network diameter is considered as standard for computing $\bar{X}$ as percentage of o

Tables 102, 103, 104 and 10.g show that there is a possibility of using any desired journey unit in the network description. The routes between a certain pair of O-D for different journey units in the network description not only changes the number of routes within any given CP value, but it might create entirely different routes. The results of using different values showed consistency in the total vehicle distance, time and average trip length. The value of average trip length, expressed as the network diameter, is an important factor for comparing the variations of this parameter over time, as well as between two areas at the same point of time. The use of this parameter, and the related average trip length is needed for trip generation models outlined in previous chapters. However, the average trip length by purpose of trip can also be computed when the data for such disaggregation is available.

The value of γ which represents the capacity power in the model for cost and time unit journey in network description is set to zero to eliminate the effect of width of the link in question.

10.15 TRIP LENGTH DISTRIBUTION.

Percentage trip distance travelled on routes of different lengths is as follows :

Table 10.h

Journey unit in network description	Length of route as a percentage of network diameter									
	10	20	30	40	50	60	70	80	90	100
Distance	.30	4.0	12.0	15.4	17.8	16.0	14.9	12.3	5.4	1.8
G.cost	.3	4.0	13.7	15.6	20.2	15.4	15.3	10.9	3.8	.8
Time	.3	4.7	16.6	16.8	17.8	18.4	14.4	8.2	2.5	.2

The differences between values in each column results from the existence of different number of routes for the same pair of O-D and same (CP) value for different journey units in the network description. However, most journeys are confined between 30%and 80%of the network's diameter, and as shown previously, average journey length is about 0.4 ϕ. Therefore, most trips are of a length about half of the maximum available shortest route in the network.

10.16 SUMMARY AND CONCLUSIONS.

The most fundamental element of any traffic assignment technique is to select a criterion which explains the choices made by drivers from the number of potential paths available between one origin and one destination.

Wardrop (1952) has identified two criteria which might be used to predict the paths taken between a pair of O-D by motorists. These are :-

1. the trip times on all the routes actually used are equal and less than those which would be experienced by a single vehicle on any unused route.

2. the average journey times of all motorists is minimum, which implies that the aggregate vehicle hours spent in travelling is minimum.

Wardrop's first criterion suggests that the drivers act selfishly and attempt to minimise their individual travel times through a network. This criterion is equivalent to the average cost-pricing principle of economic theory. The second criterion suggests that drivers act so as to minimise total travel time spent by all drivers on the network. This implies that the individual drivers are aware of the way in which their choice of route influences the change in the total travel time experienced by all drivers. His second criterion is equivalent to the marginal cost-pricing principle of economic theory.

Almost all conventional assignment techniques used one of these principles. However, Hutchinson,(1974) observed that some limited empirical testing of these two criteria has been performed and the evidence available would suggest that motorists behave according to some intermediate criterion. The criterion used in this study suggests that the driver is not aware of the real speed-flow relationship on links which comprise his route. Rather more fundamentally he makes his decision to choose one route from a number of potential routes, and this decision relates to the relative attractiveness of the route. This implies that all drivers are seeking to experience the same speed, which is equivalent to using distance units in the network description.

The obvious measures of relative attractiveness which can easily be appreciated by the average driver are those of average width of the route, and the number, type and location of intersections along the route. The assignment model then compares each available route as defined by its attractiveness parameters with that of the shortest route. Thus, the model assumes the shape of gravity type model. This model was applied here to the available data for Hamilton using three types of journey units in network description. All three types seem to yield satisfactory results because of the flexibility of the model. The total number of routes found in the calculations using different journey units, revealed that the maximum number of routes occurred when the distance journey unit was used. The use of distance journey units unit implies the same "constant" speed for all journeys. Thus, the traffic flow could be distributed more evenly on the network through modifying the network to achieve virtually the same average speed on all links.

However, to avoid using time as a criterion, with its inherent potential for distortion, as well as the difficulty of data collection, the alternative parameters employed in (RATA) model are mostly physical characteristics of the network which can be measured fairly easily and accurately i.e., very sensitive parameters are changed to less sensitive parameters. Additionally, this model provides estimates for values of parameters required as "feedback" to the travel demand models (Chapter 6) concerning average trip length ($\bar{X}$) and also gives percentage distance travelled for each trip purpose (S_ℓ).

CHAPTER 11

SUMMARY AND CONCLUSIONS

11.1 Introduction.

The object of this study has been to discuss in quantitative terms, so far as possible with available data, the factors that determine the amount of travel. This is the basic information necessary for urban transportation planning.

The conventional "four-step" transportation model framework (Figure 1.1) has been reviewed, and it is found that it involves the collection and analysis of large volumes of data. It is concluded that this process is static rather than dynamic, it is unwieldly inflexible and slow. Furthermore, it is by no means certain whether, with associated complexity and cost, the level of detail is well matched to the planning process concerned.

It may also be suggested that these conventional models rely on behavioural hypothesis which are often much cruder than the apparent sophistication of the main model. This sophistication of the model technique is questionable until the behavioural basis is strengthened (Baylsis, 1977). A further criticism is that the structural defficiency of conventional transport models is their failure to establish an inter-relationship between the number of trips made and the character and price of transportation service actually available (Whol and Martin, 1967).

This research has attemped to construct econometric models, in which demand for travel is made sensitive to the level of service provided by the transport system. The models set out in this study may provide an opportunity for effecting substantial improvements in urban area travel forecasting. An important feature of the work is that all models presented are simple in concept and application and they require relatively small amounts of data to be collected.

The prediction of future travel demand is centred around the use of consumer-behaviour theory from economics. This theory leads to the attempt to build what may be referred to as "Budget Models" and a "General Share Model" (GSM). These models are formulated on the basis of making some assumptions about the elasticities of travel demand. There is an inbuilt sensitivity to the level of service provided by different transport systems. To achieve this, a new method of "value of non-working time" has been developed By applying the principle that the amount of travel is governed by household budgets of time and money, it is possible to estimate the effect on the numbers of trips and their length caused by modifying the road system, or by otherwise changing the costs of travel. The models therefore depart from the traditional four-stage transportation planning.

To complement these travel demand models a new approach to traffic assignment has been developed with methods using concepts of "relative attractiveness" and "accessibility" of routes to simulate drivers' choice of route. Additionally, this process provides estimated values of parameters required as "feed-back" to travel demand model

11.2 SOURCE OF DATA.

1. Family Expenditure Survey (FES) Annual Reports.
2. National Travel Survey (NTS) 1972/73.
3. Operating cost formula as presented by Road Research Laboratory.

The FES and NTS are both based on national trends using average weekly as a unit of time. The data belongs to all households irrespective of car or non-car ownership.

11.3 HOUSEHOLD AS A UNIT OF DECISION-MAKING.

The attempt to identify firstly the decision-making unit conventionally led most transportation planners to define the behavioural unit of analysis to be a household. A convenient basis for their analysis involved using the household characteristics of travel behaviour at individual

level as well as aggregated into groups. It should be noted, however, that the terms "household" "individual" or "consumer" may be used interchangeably.
To justify the use of households as the behavioural travel unit required very careful indepth analysis of travel behaviour, both for average household and by household income groups. Moreover, this indepth research reached the point where the demand for transport models and measurement of income, cost and travel time elasticities came together. Its success therefore contributes not only to the better performance of different models but to their linkage and therefore towards a generalisatiion of the theory of transport demand.

11.4 DEMAND FOR TRAVEL.

Basically any demand for travel is to fulfil the consumers satisfaction. Trips are usually intermediate goods, which are jointly demanded with other economic goods. The trip then forms an integral part of some larger activity.

In the economic sense, "the amount of commodity that a consumer will be prepared to buy in a given period depends upon the price charged, the quality of the commodity, the service supplied with it, the price of related (substitute or complementary) commodities, his preference between alternative commodities, his income and his expectation (of future income and prices)" (Seldom et al, 1975). On this basis, the principle of economics, as far as demand and supply is concerned (which provides explanation for other economic phenomena) should also apply to consumer's behaviour in travel.

11.5 RESOURCES NEEDED FOR TRAVEL.

Time and money are the resources which are needed for travel. The simple act of moving from point A to another point B in space will take a certain amount of money and time (depending on the mode of travel). And since time and money are limited resources they can be budgeted and allocated. In fact these two resources act as a constraint one upon the other as far as travel is concerned. For example a person having the use of a company car, the cost of which is borne by the employer, is nevertheless constrained by his own time-budget factor which effectively restricts the amount of travel benefit which may be derived from such a facility. On the other hand, if a person is unemployed he can allocate most of his time to travelling if he wishes, but he is deterred by his money budget from so doing. These two examples are hypothetical and extreme. Nevertheless, all individuals are subject to these limitations.

Transport improvements normally lessen both time and cost of travel. Consequently there is a strong link between the amount of travel and transportation planning.

11.6. INCOME AND AMOUNT OF TRAVEL

To relate the quantity of travel demand to the many variables required for a general econometric model, as mentioned in Section 11.4, is not practicaable. Therefore, attempts have been made in many previous studies to isolate the variables considered to be the most important, and to relate the quantity of demand to any changes then. Most commonly, the factors are car-ownership, household size, and number of wage earners in the household, and urban density in the area of residence. All these factors, as revealed in this study, are significantly related to household income (Table 5.d and 5.e).

Values of these variables are ascertainable for time past but great uncertainties are attached to their values in future years. Consequently, in this study, the stratification of households is based only on the level of income. Implicitly these different household income legels show a stable relationship in so far as car-ownership and related variables are concerned.

11.7 HOUSEHOLD INCOME GROUPS.

Income significantly affects the total amount of transport consumed at any given service level. "The higher the income level, the greater number of trips made" (Gwilliam and Mackie, 1975). Accordingly, grouping of households into a number of income groups is found to be necessary..

In this study disaggregation of households into five income groups was convenient for analysis purposes with 20% of households in each income group. Consequently households in each income group contains both car and non-car ownership.

11.8 HOUSEHOLDS EXPENDITURE ON TRAVEL.

Family Expenditure Survey (FES) annual reports for years 1965-1968-1972 and 1975 were analysed.

In FES reports, total expenditure represents expenditure on goods and services, while income is a gross weekly amount before the deduction of income tax. Concerning the veracity of data involving "income" and "expenditure" it may be observed that "comparison of the results of the surveys over successive years justifies confidence in their general reliability" (FES, 1975). The data analysed in FES reports which cover all transport and vehicle expenditure : "On average, each household spends almost a constant percentage of income on travel by all modes".

11.9 TRAVEL PREDICTION.

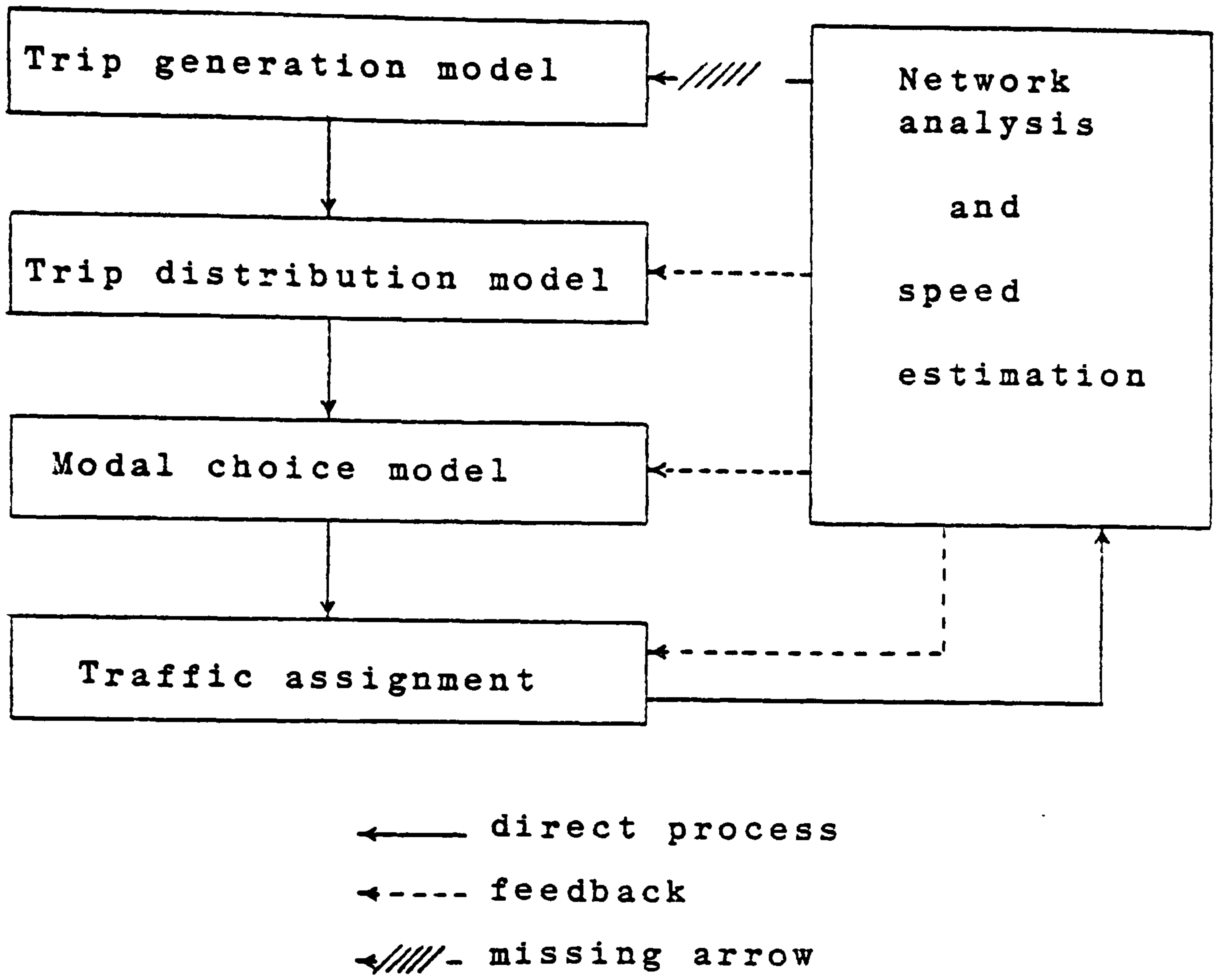
The minimisation of travel time or cost is generally an objective in transportation planning. However, transport models usually ignore the fact that when travel time or cost is reduced, the number of trips will rise.

The provision of a new or improved transport facility may well result in a greater amount of travel activity than previously existed. Whol and Martin, 1967 commented that this situation - more travel - means more trips, and presumably more community desires are being satisfied. This situation is closely analogous with the economic theory of demand and the associated concept of consumer surplus.

The major structural deficiency of traffic forecasting models is their failure to establish an interrelationship between the number of trips made, or travel volume, and the character and price of the transportation service actually available.

In the four-step conventional transport model (Diagram 11.a) there is a feed-back from a network analysis box to only three steps, i.e., trip distribution, model choice traffic assignment. However, Wilson, 1974 stated that "it would be theoretically correct to connect the network analysis box (Diagram 11.a) with an arrow to the trip-generation box, since the rate of trip generation could be expected to vary with ease of travelas measured by travel time and cost. Unfortunately, no one has yet succeeded in building an effective elastic trip generation model of this kind".

The main objective of this study is to introduce a new and simpler approach, with relatively little effort needed for data collection. Based on economic theory of consumer's behaviour, it is possible to put back "the missing arrow" mentioned by Wilson (as discussed in Chapter 2). The value of inserting that "missing arrow" into the analysis process is that it enables a new degree of sensitivity to be



Transport model

Diagram 11.a

achieved by the modified model which incorporates the effects of the service offered by each mode.

The modified transport models can be represented as in Figure 6.1. Trip generation models have absorbed modal split models, and from the start of the transport planning process, private travel - car trips, as well as public transport - person trips by bus - are predicted separately. Others, like external trips, which use the network and commercial vehicles are also treated separately, and total load on each link of the network is checked at the assignment stage.

Trip distribution might give better results if separated on the same basis of disaggregation, i.e. by household income groups by purpose, on the grounds that different household income groups show different average trip lengths for different purposes.

11.9.1 Household Expenditure on Travel

Analysis of household expenditure on different items of transport shows that "expenditure on total travel for all households (including car and non-car ownership) is a fixed 6.2 percent of household income. Allocation of this amount between different modes of travel depends on the levels of service provided by the modes".

11.9.2 Vehicle Speed and Operating Cost

The speed of vehicles has significant economic, safety, time and service (comfort and convenience) implications. In this study vehicle speed is found to be a useful tool related to estimates of vehicle operating cost. The formula presented by Road Research Laboratory, "Vehicle Operating Cost" (TRRL 661).

11.9.3 Travel Characteristics

The primary source of information used in this study concerning travel characteristics is the National Travel Survey (NTS) 1972/73 which is the latest in a series of comprehensive enquiries about people's travelling habits. No significant differences were found between the 1972 survey and the earlier 1966 survey. This indicates that on average, trip length distance ($\bar{X}$) stays quite stable over time for the main modes of travel, car bus and train. This finding might also be applied in urban areas.

11.9.4 Observed Trip Rates

The amount of travel expressed as number of trips per week for average household income is given by:

$$t = \frac{\text{Distance travelled by mode k}}{\text{Average trip length}} = \frac{Z}{\bar{X}} \qquad (11.1)$$

Number of trips by different modes is as follows:

$$t_c = \frac{Z_c}{\bar{X}_c} = \frac{96}{12} = 8 \qquad \text{car trip/week}$$

$$t_b = \frac{Z_b}{\bar{X}_b} = \frac{34.5}{5.16} = 6.69 \quad \text{bus trip/week}$$

$$t_r = \frac{Z_r}{X_r} = \frac{20.8}{40} = 0.52 \text{ rail trip/week}$$

Figure 5.12 shows percentage of total distance and percentage of trips on average, covered by a household for each trip purpose. There were no corresponding figures available for 1965, but in spite of this it seems reasonable to assume that little change has occurred in these percentages over time. The average trip lengths by purpose of trip are also shown on the same figure. The average overall trip length ($\bar{X}$) equals 12 km for car trip.

11.10 GENERAL SHARE MODEL (GSM)

The trip rates and trip length distributions have been unified in the General Share Model which enables forecasts to be made of the amounts of travel by different modes.

All input values required by the model can be computed from base year data. Evidence is presented to suggest that the parameter values remain stable over time. However, due to land use development some changes in parameter values might need to be examined. Such modifications can be easily carried out.

Applying this GSM model reproduced 72% of the observed cars trips from NTS. The remaining 28% of trips represents travel by firms car, the cost of which is not paid by a household.

11.11 ANALYSIS OF CAR TRAVEL

Analysis of car trip data shows the importance of household income in determining the amount of car travel. Consequently it is vital to predice accurately the household income distribution if adequate forecasts of travel are to be obtained.

11.12 ANALYSIS OF BUS AND RAIL TRAVEL

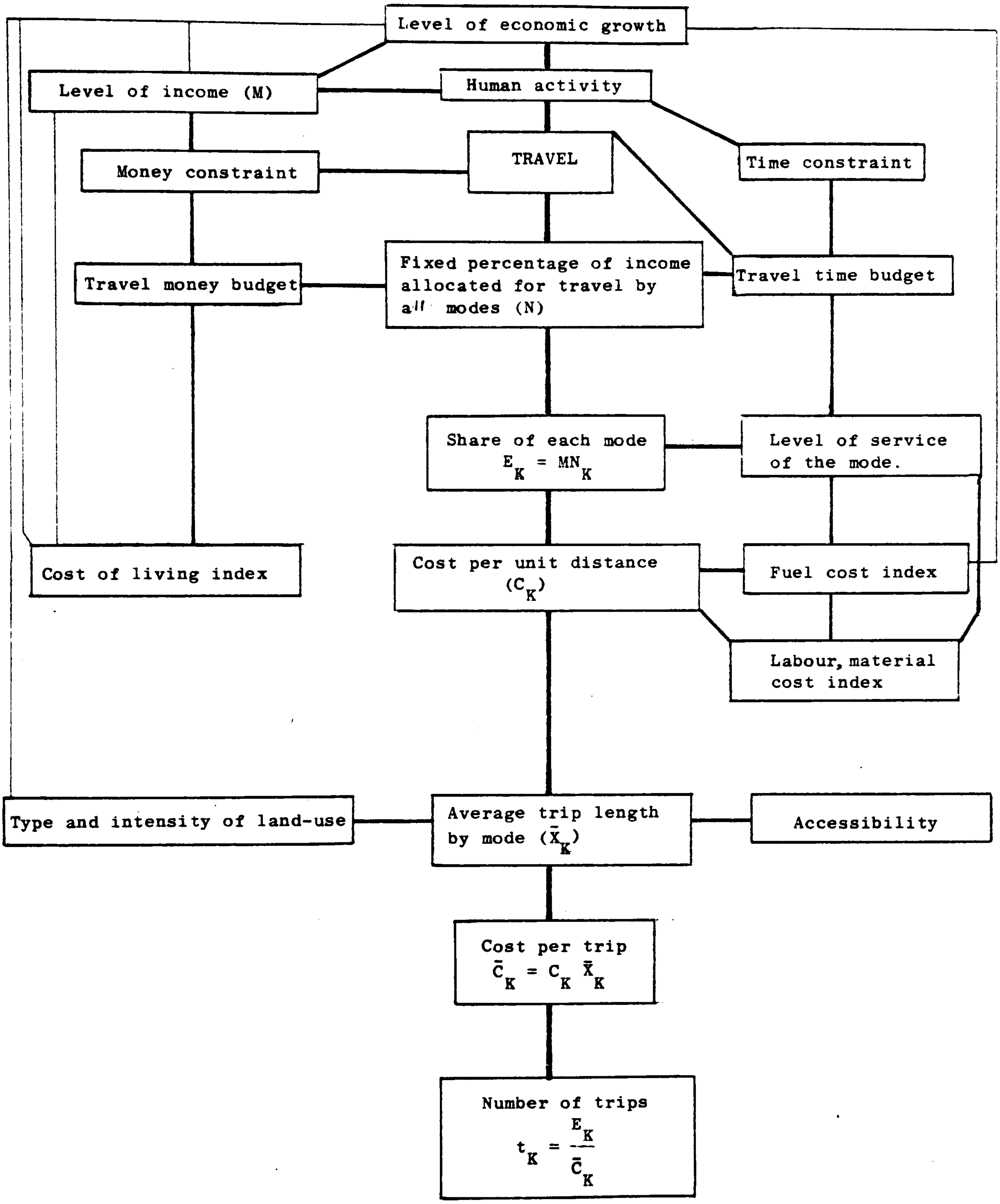
Again the importance of household income is emphasised. Although the amounts of travel by bus and rail are much less than by car, they show a similar relationship to the amount of money available.

11.13 Long Term Travel Forecast

The GSM, as formulated, and the method of its application based on national data, show internal consistency in reproducing observed travel amounts for car, bus and rail. However, GSM can probably be applied to any particular study area as a travel forecast model, and its performance will depend mainly on the accuracy of forecasting the household income distribution of the area. The model may be applied for any level of disaggregation of household group or trip purpose. An important component determining the level of service of each mode is its vehicle speed and this will need to be measured locally.

The assumption behind GSM is that households, as a function of normal activity, are engaged in work, shopping, etc., and these activities involve travelling. Thus, travel can be regarded as an integral part of human activity which is bound by a 'time constraint' and this in turn also reinforces the concept of a "travel time budget", which in turn reacts as a constraint on the amount of travel itself. The effect of a time constraint (in the long term) results in a fixed percentage of household income being allocated for all travel. This fixed percentage of a household's income can be regarded as a "travel money budget" which jointly with "travel time budget" limits the time and money allocated for travel. The proportions of the budgets spent on each mode depends on the level of service provided by the modes.

Diagram 11.b represents the inter-relationships between the causal variables and the amount of travel by each mode.



Factors affecting demand for travel

Diagram 11.b

Future travel demand involves many factors which essentially require assumptions about future income levels, fares, fuel costs, etc. Such trends could be better assessed through proper integration of economic planning and the provision of a transport infrastructure.

11.14 GENERATED TRIPS

Network improvement yields higher speeds for car travellers. Consequently there is a saving in time for the traveller and this implies an increase to his real income if he places any monetary value in time savings. This may encourage the traveller to increase his number of trips, which results in a willingness to pay some extra money by an amount to bring him to a new equilibrium point in the trade-off between time and money.

Any network change affects the relative price of the various commodities or activities to which he allocates his time and money. This is because the components of their price to him, which consists of the generalised cost of travel, has changed. In general, he may be expected to shift his behaviour in favour of those activities whose price, in terms of generalised cost, has fallen most. That is, he will tend to change his travel patterns in favour of activities which are at further distances from his location and away from activities which he formally carried out at or near home. The frequency, destination and length of the trips he makes will be increased as a result. These were the various possible reactions to change in the users cost of the transport network.

It is commonly accepted that each new transport facility or each improved facility may cause induced or generated traffic to appear along the section of road directly or indirectly affected by the improvement, with other traffic being diverted, because the new level of attractiveness of such a particular route contains improved links.

This additional traffic is observed with the opening of the new facility, and has continued as a stable and slightly increasing component for at least the first four or five years as revealed by records covering this period (Schmidt and Campbell, 1956).

In time it becomes increasingly difficult to isolate and measure this component, and it possibly diminishes as the other components grow and crowd it out.

Generated traffic is composed of trips previously inhibited by inadequacies in quality and operational characteristics of the existing facilities. Little consideration has been given to the issue of "frustrated travel", i.e., those journeys which people would like to make but do not, because they are deterred by the shortcomings of transport facilities, including good roads (Stephen, 1972).

Using such criteria a family of "Budget Models" has been formulated in Chapter 6, and its application presented in Chapter 7. The main feature of these models is that they can be used as a guide to predict generated traffic for short range periods, i.e., opening a new motorway, bridge etc., or investigation into the effect of petrol price change on behaviour of travellers in trip-making.

11.15 VALUE OF TIME (VOT) FOUND IN THIS STUDY

While analysing the budget models, the VOT emerged as a result of one assumption made, viz:; After improvement, percentage increase of consumer's money outlay is equal to percentage increase of his time saving. According to this assumption it is found that:

$$VOT = BV_b$$

i.e., value of time saved (not used in working) equals the cost per unit distance (before at speed V_b) multiplied by average vehicle speed for each of the occupants. This value, integrated into the models resulted in a "generalised cost model" which can have many meaningful applications (presented in Chapter 7).

In the Generalised Cost Model the two main factors are the effect of monetary change in the cost of making trips and changes in the speed of travel on the network. While an increase in petrol prices (in real terms) and the introduction of parking charges reduce the amount of car travel, the provision of higher speed will increase it. See Figure 7.8.

Both situations represent present day frustrations. The first concerns the environmental impact of car trips on town centres; the second is a reflection of the poor quality roads which exist in many areas. These are important facts of urban life. Better roads are desired although they increase trips by such an amount that both user and non-user may suffer afterwards.

There is no simple solution to this paradox which is inherent in transportation planning. The compromise between a fair amount of travel without disturbing the environment, needs more than just planning aspects into modelling, which has not yet been investigated.

11.16 TRAFFIC ASSIGNMENT

A new approach to traffic assignment has been developed using the concepts of "relative attractiveness" and "accessibility" of routes. This is in reality a gravity type of model which provides a better simulation of driver's behaviour in route choice. In addition, the model provides an estimation of parameters needed as a feed-back process required in trip generation stage.

The model is called here the Relative Attractiveness Assignment Model (RATA). An important requisite for its application is a method of finding N best paths in the network. A program made available for this study carried out this task successfully.

It is found that the number of routes between a pair of O-D, mainly depends on the value of (CP) where CP represents the percentage deviation from minimum path. Evidence is presented to show that a value of CP = 10% is reasonable for practical purposes.

It is important to notice that the all-or-nothing method is a special case of the RATA model.

The obvious measures of relative attractiveness which can easily be appreciated by the average driver are those related to Ø average width of the route, number, type and location of the intersections along the route. The assignment model then compares each available route as defined by its attractiveness parameters with that of shortest route. Thus, in fact the model assumes the shape of gravity type model. This model was applied here to the available data for Hamilton using three types of journey units in the network description. All three types yielded satisfactory results and demonstrated the flexibility of the model. The maximum number of acceptable different routes occurred only when "distance" journey units were used. This implies that the traffic flow could be distributed more evenly throughout the network by modifying the network to achieve virtually the the same speed on all links.

However, to avoid using time as a criterion, with its inherent potential for distortion, as well as difficulty of data collection, the alternative parameters employed in (RATA) model are mostly physical characteristics of the network which can be measured fairly easily and accurately, i.e. the very sensitive parameters are changed to less sensitive parameters. Additionally, this model provides estimates for values of parameters required as "feed-back" to the travel demand models (Chapter 6) concerning average trip length ($\bar{X}$) and also gives percentage distance travelled for each trip purpose (S_ℓ). (See Chapter 10).

REFERENCES

REFERENCES

AASHO, "A Policy on Geometric Design of Rural Highways. American Association of State Highway Officials, Washington, D.C. 1954.

Aitken, J.M., "Trip Distribution", University of Strathclyde, Note. T.20.

Alonson, W., "Locational Land Use", Harvarad University Press, Cambridge, Mass. 1964.

Al-Sarraj, A.H., "Accessibility of Road Network and TRaffic Assignment", M.Sc., Thesis, University of Strathclyde. 1975.

Bell, R.R., and Percival, A.J.P., "Public Transport - the Uncertain Future" The Journal of the Institution of Highway Engineers, March 1978.

Batty, M., "Urban Modelling",Cambridge Press. 1976.

Bayliss, D., "Urban Transport Research Priorities", Transportation, Amsterdam, Vol. 6, No.1. March 1977.

Beesly, M.E., "The Value of Time Spent in Travelling, Some New Evidence". Economica, Vol. 31, May 1965.

Berry, D.S., "Traffic Characteristics", Traffic Engineering Handbook.Washington. 1965.

Blunden, W.R., "The Land-Use Transport System", Pergaman Press. 1971.

Bridle, R.J., and Cleary, S.M., "Accessibility and Traffic Synthesis" The Journal of the Institution of Highway Engineers, October, 1969.

Broadbent, T.A., "Zone Size and Spatial Interaction in Operational Models", Centre of Environment Studies, CES-WIN-106., London. 1969.

Buchanan, C., et al, "TRaffic in Town" HMSO, 1963.

Burrell, J.E., "Multiple Route Assignment and its Application to Capacity Restraint" 4th International Symposium on Theory of Traffic, Karlsruhe, Germany, 1968.

Charlesworth, G., and Paisley, J.L., "The Economic Assessment of Returns from Road Work", Proc. Inst.Civ.Engrs. Vol. 14(229-54), Nov. 1959

Claffey, P.J., "Vehicle Operating Characteristics", Transport and TRaffic Eng. Handbook, Inst.of Traffic Eng. Prentice-Hall, 1975.

Clarke, M.I.,"Modelling the Traffic Interaction Between and Urban Study Area and External Regions", PTRC Proceedings, Urban Traffic Models,Vol.1, June 1973.

Constinett, P.J., "Public Road Transport Analysis", PTRC Symposium Proceedings, 1970.

Dalton, D. M., and Harmelink, M.D., "Multipath Traffic Assignment Development and Thesis", Ontario Ministry of Transportation and Communications, Research and Development Division, RR 189.

Dalvi, M.Q., and Martin, K.M., "The Measurement of Accessibility : Some Preliminary Results", Transportation, Amsterdam, Vol.5(pp.17-42)1976.

Dawson, R.F.F., "The Economic Assessment of Road Improvement Schemes", Road Research Technical paper No. 75. HMSO 1969.

Department of Energy, U.K., Energy Paper No. 10, HMSO 1976.

Dickey, J.W., "Metropolitan Transportation Planning", McGraw-Hill, 1975.

Douglas, A.A., and Lewis, R.J., "Trip Generation Techniques", Traffic Engineering & Control Nov. 1970, Feb. 1971.

Dyos, H.J., and Alcroft, D., "British Transport an Economic Survey from Seventeenth Century to the Twentieth",Penguin Books. 1969.

Economic Trends, U.K., No.2 1976.

Elander, S., "Accessibility Entropy and Distribution and Assignment of Traffic", Transportation Research,Vol.11,No.3,June 1977.

Evans, L., and Herman, R., "A Simple Calculation of Fuel Consumption in Urban TRaffic System", Traffic Engineering & Control,Aug./Sept. 1976.

FES. 1965-1975, "Family Expenditure Survey", Dept. of Employment, HMSO 1975.

Fielding, G.J., Bankenship, D.P., and Tardift, T., "Consumer Attitude Towards Public Transport", Transportation Research 563,Washington,D.C.1976.

Forbes, J., "Mapping Accessibility", Scottish Geographic Magazine, LXXX 1964.

Garner, B.J., Charley, R., and Haggett, R., "Model of Urban Geography and Settlement Location", Mettuem, London, 1976.

Goodwin, P.B., "Travel Choice & Time Budget", PTRC Summer Annual Meeting, University of Warwick, 1976.

Gwilliam, P., and Mackie, J., "Economics and Transportation Policy", George Allen & Unwin, London. 1975.

Hagerstrand, T., "What about people in regional Science", Regional Science Association, Vol. 24,pp.7-21.

Hamer, M., "Wheels within Wheels a Study of Road Layby", Published by Friends of the Earth, London 1974.

Hansen, W.G., "How Accessibility Shapes Land Use", Journal of American Institute of Planning, Vol. 13. 1959.

Harrison, A.J., "The Economic of Transport Appraisal", Croon Helm, 1974.

Harman, R.G., "Fuel in Transport", Traffic Engineering and Control,Feb/March 1974.

Highway Capacity Manual, Highway Research Board, Special Report 87, Washinton,D.C. 1965.

Hills, P., "Economic Evaluation", PTRC Spring Course in TRansportation Model Theory, 3-7 May, 1976

Hoffman, W., and Pauley, R., "A Method for the Solution of the Nth best Path Problem" Journal of the Association for Computation and Machinery, Vol.6, pp.506-514. 1959.

Johnson, D.B., "Efficient Algorith for Shortest Path in Sparse Network", Journal of Association for Computation Machinery. Vol.24, No.1, pp.1-13. 1977.

Kansky, K.J., "Structure of Transportation Network" University of Chicago Press. 1965.

Kell, J.H., "Traffic Studies", Traffic Engineering Handbook,Washington,D.C. 1965.

Kraft, G., and Wohl, M., "New direction for passenger demand analysis and forecasting", Transportation Research,Vol.1,pp.211 1967.

Lane, R., Powell, T.J., and Smith, P.P., "Analytical Transport Planning"Duckworth 1971.

Leibbrand, K.,"Traffic Generation and Assignment Models", Traffic Quarterly,July 1977.

Levinson, H.S.,"Urban Travel Characteristics", Transportation and Traffic Handbook, Inst. of Traffic Eng.Prentice-Hall 1976.

London Transport Annual Report, 1973.

Lucas, C., and Davidson, K.B.,"Quantitative Evaluation of Traffic Assignment Methods", University of Queensland,Dept. of Civ. Eng. Bulletin,No.17, May 1974.

Martin, B.V., et al, "Principles and Techniques of Predicting Future Demand for Urban Area Transportation", MIT Report, No.3 1970.

Matson, W.S., and Hurd, S.F.W., "Traffic Engineering", McGraw-Hill, 1955.

Moore, E.F., "The Shortest Path through a Maze", International Symposium in Theory of Switching. 1957.

McIntosh, P.T., and Quaramby, D.A., "Value of Time", D.of E.,MAU Note 179, Dec. 1976.

McRath, D.C., "Appropriate Relationship between Comprehensive Planning and Transportation Planning", Transportation, Amsterdam, Vol. 1. 1972.

Neuburger, H., "User Benefit in Transport and Land Use Plans", Journal of Transport Economics and Policy, Jan. 1971.

NTS, 1972/73 "National Travel Survey", D.of E., London HMSO (in 3 volumes) 1976.

OECD, "Urban Traffic Models,possibility for Simplification", Paris. 1974.

Oldfield, R., "Elasticities of Demand for Travel", TRRL Report 116 UC, 1974.

Overgaard, K.R., "Traffic Estimation in Urban Transportation Planning", Acta Polytechnica Scandinavia, Copenhagen. 1966.

Phibrick, A.T.C., "Transportation Gravity Models", University of Queensland,Dept. of Civ.Eng. Bulletin No.15, Dec. 1971.

Potter, S., "Counting the Cost", Transport Report, A Monthly Distillation of Transport News, Vol.2, No.4, April 1978.

Quinby, H.D., "Mass Transportation Characteristics", Transportation and Traffic Handbook (Institution of Traffic Engineers) Prentice-Hall, 1976.

Rigby, J.P., "An analysis of travel patterns using the 1972/73 National Travel Survey", TRRL Report 790

Sacco, J.F., and Hajj, H.M., "Impact of Energy Shortage on Travel Pattern and Attitude", Transportation Research Record No.561. 1976.

Salterm R.J., "Highway Traffic Analysis and Design", MacMillan. 1974

Sayer, R.A., "Gravity models and spatial auto correlation, or atrophy in urban and regional modelling", Area Vol.9 No.3 1977.

Shimbel, A., "Structural parameters of Communication Network", Bulletin of Mathematical and Biophysocs XV (1953) pp.501-507.

Shmidt, R.E., and Campbell, M.E., "Highway Traffic Estimation", ENO. 1956.

Stephen, P., "Town Against Traffic", Andre Deutch 1972.

Stonier, A.W., and Hague, D.C., "A textbook of Economic Theory", Longman 1975.

Stopher, P.R., and Meyburg, A.H., "Urban Transportation Modelling and Planning" Lexington Books. 1977.

Tanner, J.C., "Forecast of Vehicle and Traffic in Great Britain",TRRL Report LR 650.

Thomson, J.M., "An evaluation of two proposals for traffic restraint in Central London Journal of the Rotal Statistics Society Series A, Vol.130 Part 3 1967.

Thrift, N., "An introduction to Time-Geography" University of Norwich, East Anglia, CATMOG 13 1977.

Transport Policy, U.K. 1976.

Transport Statistics G.B. 1965-1975.

TRRL, Research on Road Traffic, HMSO 1975.

Wabe, J.S., and Coles, O.B., "Cost of Providing Bus Transportation Urban Area", PTRC Semminal Proc.25-29, June 1973.

Wagon, D.J., "Public Transport Analysis" "TRC Spring Course, Transportation Mode Theory Lectures 10 and 11, 3-7 May 1976.

Wardrop, J.G., "Some theoretical aspects of Road Traffic Research", Proc.Inst.Civ.Eng. Vol.1 pp.325. 1952.

Wardrop, J.G., and Charlesworth, G., "A Method of Estimation speed and flow of Traffic from moving vehicle", Proc.Inst.Civ.Eng. pp.158-171, Fe. 1954.

Wattleworth, J.A., "Traffic Flow Theory", Transportation and TRaffic Engineering Handbook, Inst. of Traffic Engineers Prentice-Hall. 1976.

Webster, F.U., and Cabbe, B.M., "Road Research Technical Paper No.56, HMSO 1965.

Webster, F.U., "Urban Passenger Transportation, some Trends and Prospects", TRRL Report LR 771. 1977.

Whol, M., and Martin, N., "Traffic System Analysis for Engineers and Planners", McGraw-Hill 1967.

Wickstrom, G.U., and Grant, A.A., "Planning for Implementation", Transportation, Amsterdam, Vol.1 1972.

Wilson, A.G., "Urban and Regional Models in Geography and Planning", Wiley. 1974.

Wooton, H.J., and Pick, G.W., "A Method for Trip Generated by Household", Journal Transport & Economics and Policy) Vol.1 No. 2, May 1967.

Wright, C., and Orrom, H., "The Westminster Route Choice Survey", Traffic Engineering and Controlm Aug./Sept. 1976.

Zahavi, Y., "Travel Time Budget and Mobility in Urban Areas", Federal Highway Administration, Washington, D.C., May 1974.

Zahavi, Y., "Travel Characteristics in Cities of Developing and Developed Countries", Staff Working Paper 230,Washington,D.C. March 1976.

TABLES

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
No of Car	Time min	Distance Km		Distance per Unit time Km		Speed KPH		Concentration Car/Km	Average time min	Percentage in time	Cumulative Percentage in time	Percentage in space	Cumulative Percentage in space			Formula (9)		Formula (10)
* f_i	* t_i	* D	$f_i t_i$	$D_i = \frac{D}{t_i}$	$f_i D_i$	$V_i = \frac{D}{t_i}$ **	$f_i V_i$	$\frac{f_i}{V_i}$	$\bar{t} = \frac{\sum f_i t_i}{f_i}$	$\frac{f_i}{\sum f_i} 100$	from Col 11	$\frac{f/V}{\sum f/V}$	from Col 13	fV^2	$\frac{\sum fV^2}{\sum f}$	σ_t^2	$\frac{\sum f_i V_i}{\sum \frac{f_i}{V_i}}$	σ_s^2
10	1.0		10	1.0	10.00	60	600	.166		20	100	14.67	100	36000				
15	1.2	1.0	18	.833	12.50	50	750	.300	1.36	30	80	26.50	85.43	37500	2200	84	2029.41	83.05
20	1.5		30	.666	13.33	40	800	.500		40	50	44.16	58.93	32000				
5	2.0		10	.500	2.50	30	150	.166		10	10	14.67	14.67	4500				
$\sum$ 50			68		38.33		2300	1.133		100		100		110000				

*measured columns all other columns are calculated

Applying different formula deriven in section 4.3 one can calculate values of V_t and V_s:

$$\bar{V}_t = \frac{D}{t} = \frac{\frac{\sum f_i D_i}{\sum f}}{t} = \frac{\frac{38.33}{50}}{1} \times 60 = 46.0 \quad \text{.......... Formula (4.2)}$$

$$\bar{V}_t = \frac{\sum f_i D_i}{t \sum f_i} = \frac{38.33}{1 \times 50} 60 = 46 \quad \text{.......... Formula (4.3)}$$

$$\bar{V}_t = \frac{\sum f_i V_i}{\sum f_i} = \frac{2300}{50} = 46 \quad \text{.......... Formula (4.4)}$$

$$\bar{V}_s = \frac{ND}{\sum t_i f_i} = \frac{50 \times 1}{68} 60 = 44.12 \quad \text{.......... Formula (4.5)}$$

$$\bar{V}_s = \frac{D}{\bar{t}} = \frac{1}{1.36} 60 = 44.12 \quad \text{.......... Formula (4.7)}$$

$$\bar{V}_s = \frac{\sum f}{\sum \frac{f}{V}} = \frac{50}{1.133} = 44.12 \quad \text{.......... Formula (4.8)}$$

Example of space (V_s) and time (V_t) mean speeds

Table 4.1

	TOTAL INCOME						EXPENDITURE ON TRANSPORT (£)							
							ITEM				Cumulative Col.4 x Col.			
Year	Range of Income (£)	Av. Weekly Hh. Income (£)	No. of Households	% of Household	Cumulative Col. 4	Cumulative Col.4 x Col.2	77	78	80	81	77	78	80	81
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	Under 5	4.26	112	3.3	3.3	14.06	-	-	.032	.075	-	-	.1	.25
1	5 - 10	7.20	401	11.82	15.12	100.22	.01	.04	.033	.134	.118	.47	.49	1.83
9	10 - 15	12.50	387	11.41	25.56	242.85	.15	.29	.056	.309	1.83	3.78	1.13	5.36
	15 - 20	17.49	529	15.60	42.13	515.69	.30	.59	.067	.355	6.51	12.98	2.18	10.87
6	20 - 25	22.43	553	16.30	58.43	883.30	44	.88	.120	.411	13.68	27.32	4.13	17.56
	25 - 30	27.24	486	14.33	72.76	1271.65	63	1.01	.136	.494	22.71	41.79	6.08	24.64
5	30 - 40	34.21	515	15.18	87.94	1789.96	2.20	1.58	.196	.534	56.11	65.75	9.0	32.75
	40 - 50	44.25	223	6.57	95.51	2081.68	4.32	2.22	.279	.545	84.49	80.36	10.9	36.33
	50+	69.53	183	5.39	100	2456.45	2.01	2.64	.469	.617	95.32	95.60	13.42	39.66
	Total		3392		Y	X_1		X_2						
	Under 6	5.1	189	2.63	2.63	13.41	.05	.1	.003	.099	.13	.26	.007	.26
	6 - 8	6.87	374	5.20	7.83	49.13	.07	.15	.04	.114	.50	1.04	.2	.86
1	8 - 10	9.04	273	3.80	11.63	83.48	.125	.20	.02	.141	.97	1.80	.29	1.39
	10 - 15	12.31	671	9.34	20.97	198.45	.159	.25	.046	.234	2.45	4.13	.72	3.58
9	15 - 20	17.64	728	10.13	31.10	377.14	.487	.69	.05	.318	7.38	11.12	1.23	6.81
	20 - 25	22.59	963	13.40	44.50	679.84	.722	.89	.09	.393	17.06	23.05	2.43	12.07
6	25 - 30	27.53	965	13.43	57.93	1049.57	1.0	1.25	.086	.450	30.49	39.83	3.56	18.18
	30 - 35	32.42	814	11.33	69.26	1416.89	1.58	1.64	.12	.426	48.39	58.42	5.01	22.95
8	35 - 40	37.31	631	8.53	77.79	1735.15	1.85	2.06	.16	.483	64.17	76.0	6.41	27.07
	40 - 50	44.35	765	10.64	88.43	2207.03	1.91	2.19	.22	.491	84.50	99.29	8.84	32.30
	50 - 60	54.27	385	5.36	93.79	2497.92	2.61	2.83	.31	.609	98.48	114.46	10.52	35.56
	60+	32.59	426	5.93	100	2987.68	3.88	3.39	.58	.535	121.50	134.56	14.00	39.60
	Total		7184		Y	X_1		X_2						

Sample Size

Expenditure of all Households on Transport by Income of Household for

YEARS 1965 and 1968

(a , b)

TABLE 51

TOTAL INCOME						EXPENDITURE ON TRANSPORT							
Range of Income (£)	Av. Weekly Hh. Income (£)	No. of Household	% of Household	Cumulative Col. 4	Cumulative Col.4 x Col.2	ITEM				Cumulative Col.4 x Col.			
						77	78	80	81	77	78	80	81
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Under 10	8.39	442	6.3	6.3	52.85	.01	.05	.01	.14	.06	.31	.06	.88
10 - 15	12.43	605	8.62	14.92	160.00	.08	.26	.05	.24	.75	2.55	.5	2.95
15 - 20	17.39	423	6.03	20.95	264.86	.19	.43	.12	.33	1.9	5.15	1.2	4.94
20 - 25	22.49	477	6.80	27.75	417.80	.72	.98	.07	.41	6.79	11.81	1.7	7.73
25 - 30	27.44	513	7.31	35.06	618.38	1.21	1.22	.10	.51	15.64	20.51	2.4	11.45
30 - 35	32.59	553	7.88	42.94	875.19	1.29	1.48	.13	.50	25.80	32.17	3.4	15.40
35 - 40	37.56	630	8.98	51.92	1212.48	1.66	1.79	.15	.49	40.71	48.24	4.8	19.80
40 - 45	42.46	656	8.05	59.96	1554.28	1.72	1.94	.16	.57	54.55	63.86	6.0	24.39
45 - 50	47.32	530	7.55	67.52	1911.55	2.26	2.46	.20	.57	71.62	82.43	7.6	28.69
50 - 60	54.73	833	11.87	79.39	2558.11	2.86	2.87	.26	.63	105.56	116.5	10.7	36.16
60 - 80	68.47	880	12.54	91.93	3416.72	3.66	3.34	.39	.68	151.46	158.38	15.6	44.69
80+	107.13	567	8.08	100	4282.33	5.55	4.68	.83	.66	196.31	196.2	22.2	50.02
Total		7017		Y	X_1		X_2						

Expenditure of all Households on Transport by Income of Household for

YEAR 1972

(c)

TABLE 5.1

INCOME						EXPENDITURE (£)							
						ITEM				Cumulative Col.4 x Col			
Range of Income (£)	Av. Weekly Hh. Income (£)	No. of Household	% of Household	Cumulative Col.4	Cumulative Col. 4 x Col. 2	77	78	80	81	77	78	80	81
1	2	3	4	5	6	7	8	9	10	11	12	13	14
Under 15	12.79	263	3.65	3.65	46.68	.10	.20	.09	.19	.36	.73	.3	.69
15 - 20	17.46	507	7.04	10.69	169.60	.08	.32	.04	.20	.93	2.98	.6	2.10
20 - 25	22.56	374	5.19	15.88	286.68	.25	.56	.05	.30	2.25	5.89	.9	3.66
25 - 30	27.45	325	4.51	20.39	410.48	.43	.95	.09	.35	4.16	10.17	1.3	5.23
30 - 35	32.58	278	3.86	24.25	536.24	.83	1.23	.26	.46	4.41	14.92	2.2	7.01
35 - 40	37.53	258	3.58	27.83	670.60	.87	2.02	.11	.48	10.52	22.72	2.9	8.73
40 - 45	42.65	259	3.58	31.41	823.29	1.29	2.51	.17	.62	15.14	31.70	3.5	10.95
45 - 50	47.57	258	3.58	34.99	993.59	1.14	2.87	.21	.49	19.22	41.46	4.2	12.70
50 - 60	55.28	640	8.88	43.87	1484.47	1.61	2.67	.23	.56	33.51	65.36	6.3	17.67
60 - 70	65.09	703	9.76	53.63	2119.75	2.24	3.66	.25	.68	55.38	101.08	8.7	24.31
70 - 80	74.94	652	8.68	63.31	2770.23	3.09	3.87	.38	.66	82.76	134.68	11.2	30.16
80 - 90	84.96	583	8.09	70.40	3457.56	3.05	4.76	.27	.72	107.43	173.18	13.4	35.98
90 - 100	95.05	461	6.40	76.80	4065.88	3.09	4.85	.39	.76	127.20	204.22	15.9	40.85
100 - 120	108.93	691	9.59	86.39	5100.71	4.46	5.49	.53	.84	170.00	256.87	21.0	48.90
120 - 150	133.15	504	6.99	93.38	6031.43	5.08	6.53	.84	.95	205.50	302.52	26.8	55.55
150+	195.87	447	6.20	100.00	7245.82	7.11	8.16	1.29	1.04	250.00	353.11	35.0	62.00
Total Average	72.45	7203	100	Y	X_1	2.5	3.53 X_2	.35	.62				

Notes

Item 77 Car Purchase

Item 78 Maintenance and Running of Car

Item 80 Rail Fare

Item 81 Bus Fare

Y with X_1 and X_2 are Columns 5, 6 and 8 are represented graphically in FIG. 8.3.

Expenditure of all Households on Transport by Income of Household for YEAR 1975

(d)

TABLE 5.1

Income group i	Household income (weekly) M_i	Average weekly household expenditure																				
		ITEM NUMBER j														$Pr = (X_i/\Sigma_i X_i)$ 100						
		Expenditure (£) X_{ij}							Expenditure % of income X_{ij}/M_i							Percentage share (propensity pr.)						
		77	78	80	81	Total	78,80 81	80,81	77	78	80	81	Total	78,80, 81	80,81	77	78	80	81	Total	78,80 81	80,81
1	7.8	.05	.07	.04	.17	.33	.28	.21	.64	.96	.55	2.18	4.32	3.69	2.73	1.05	1.56	6.41	8.58	2.77	3.87	8.03
2	16.2	.25	.51	.06	.33	1.16	.91	.39	1.54	3.18	.41	2.03	7.16	5.62	2.45	5.26	10.77	9.98	16.66	9.53	12.27	14.97
3	21.0	.35	.79	.10	.40	1.64	1.29	.5	1.66	3.74	.47	1.90	7.77	6.14	2.38	7.36	16.52	14.90	20.20	13.46	17.36	18.86
4	30.0	1.51	1.20	.16	.50	3.01	1.86	.66	3.83	4.0	.53	1.66	10.02	6.20	2.20	24.21	25.10	23.84	25.25	24.71	25.00	24.89
5	47.8	2.95	2.20	.30	.58	6.03	3.08	.88	6.17	4.61	.63	1.21	12.62	6.44	1.21	62.10	46.02	44.86	29.29	49.51	40.78	33.23
$\sum X_i$	122.8	4.75	4.78	.67	1.98	12.18	7.43	2.55								100	100	100	100	100	100	100
$\bar{X} = \frac{\Sigma X_i}{5}$ 24.56 ($\bar{M}$) Av.income		.95	.95	.13	.39	2.43	1.48	.53														
$\bar{X}$ as % of $\bar{M}$		3.86	3.89	.54	.61	9.92	6.05	2.15														

Notes

Item 77 Car purchase Item 78 Maintenance and running of car Item 80 Rail fare Item 81 Bus fare	Total expenditure on transport
Items 78,80, 81	Total expenditure on travel
Items 80,81	Total expenditure on travel by public transport

Source : FES Report
FIG. 5.3

Expenditure of all households on transport for year 1965

TABLE 5.2a

Income group i	Household income (weekly) M_i	Average weekly household expenditure — ITEM NUMBER j — Expenditure (£) X_{ij}							Expenditure % of income X_{ij}/M_i							$Pr = (X_i/\Sigma_i X_i)\ 100$ — Percentage share (propensity pr.)						
		77	78	80	81	Total	78,80 81	80,81	77	78	80	81	Total	78,80, 81	80,81	77	78	80	81	Total	78,80 81	80,81
1	9.5	.12	.24	.03	.17	.56	.44	.20	1.31	2.5	.33	1.78	5.96	4.61	2.11	2.05	3.58	4.57	8.58	3.66	4.71	7.53
2	19.0	.5	.71	.06	.33	1.10	1.10	.39	2.63	3.73	.33	1.73	8.43	5.79	2.01	8.23	10.59	9.0	16.66	10.37	11.75	14.66
3	26.5	1.15	1.15	.1	.40	2.8	1.65	.50	4.33	4.33	.37	1.51	10.56	6.21	1.88	18.93	17.16	14.28	20.20	18.11	17.59	18.65
4	35.0	1.5	1.9	.15	.50	4.05	2.55	.65	4.28	5.42	.42	1.43	11.25	7.27	1.85	24.69	28.35	21.42	25.25	26.20	27.18	24.25
5	59.4	2.8	2.7	.35	.58	6.43	3.63	.93	4.71	4.54	.59	.97	10.83	6.10	1.56	46.09	40.29	50.71	29.29	41.64	38.75	34.88
$\sum X_i$	149.4	6.07	6.7	.70	1.98	15.45	9.38	2.68								100	100	100	100	100	100	100
$\bar{X} = \frac{\Sigma X_i}{5}$ 29.88 ($\bar{M}$) Av. income		1.21	1.34	.14	.39	3.09	1.87	.53														
$\bar{X}$ as % of $\bar{M}$		4.06	4.48	.46	1.32	10.34	6.27	1.79														

Notes

Item 77 Car purchase
Item 78 Maintenance and running of car
Item 80 Rail fare
Item 81 Bus fare
} Total expenditure on transport

Items 78,80, 81 } Total expenditure on travel

Items 80,81 } Total expenditure on travel by public transport

Source : FES Report
FIG. 5.3

Expenditure of all households on transport for year 1968

TABLE 5.2b

Income group i	Household income (weekly) M_i	Average weekly household expenditure																				
		ITEM NUMBER j														$Pr = (X_i/\Sigma_i\ X_i)\ 100$						
		Expenditure (£) X_{ij}							Expenditure % of income X_{ij}/M_i							Percentage share (propensity pr.)						
		77	78	80	81	Total	78,80 81	80,81	77	78	80	81	Total	78,80, 81	80,81	77	78	80	81	Total	78,80 81	80,81
1	13.0	.14	.28	.09	.22	.69	.55	.27	1.08	2.1	.38	1.70	5.30	4.23	2.07	1.43	2.85	4.54	8.8	2.97	4.1	7.5
2	26.0	.86	1.07	.10	.43	2.46	1.6	.53	3.3	4.11	.38	1.65	9.46	6.15	2.04	8.77	10.92	9.10	17.2	10.60	11.94	14.72
3	38.7	1.75	1.85	.15	.55	4.30	2.55	.70	4.52	4.78	.38	1.42	11.11	6.59	1.81	17.85	18.87	13.63	22.0	18.53	19.02	19.44
4	50.3	2.65	2.60	.25	.60	6.10	3.45	.85	5.26	5.16	.49	1.19	12.12	6.86	1.69	27.04	26.56	22.72	24.0	26.29	25.74	23.61
5	86.1	4.4	4.0	.55	.70	9.65	5.25	1.25	5.11	4.65	.63	.81	11.20	6.10	1.45	44.90	40.81	50.00	28.0	41.59	39.18	34.72
$\sum X_i$	214.1	9.8	9.8	1.10	2.50	23.2	13.4	3.6								100	100	100	100	100	100	100
$\bar{X} = \frac{\Sigma X_i}{5}$ 42.82 ($\bar{M}$) Av. income		1.96	1.96	.22	.50	4.64	2.68	.72														
$\bar{X}$ as % of $\bar{M}$		4.57	4.57	.51	1.16	10.83	6.25	1.68														

Notes

Item 77 Car purchase
Item 78 Maintenance and running of car
Item 80 Rail fare
Item 81 Bus fare
— Total expenditure on transport

Items 78,80, 81 — Total expenditure on travel

Items 80,81 — Total expenditure on travel by public transport

Source : FES Report
FIG. 5.3

Expenditure of all households on transport for year 1972

TABLE 5.2c

Income group i	Household income (weekly) M_i	Average weekly household expenditure																				
		ITEM NUMBER j														$Pr = (X_i / \Sigma_i X_i)\ 100$						
		Expenditure (£) X_{ij}							Expenditure % of income X_{ij}/M_i							Percentage share (propensity pr.)						
		77	78	80	81	Total	78,80 81	80,81	77	78	80	81	Total	78,80, 81	80,81	77	78	80	81	Total	78,80 81	80,81
1	20	.23	.46	.06	.25	1.00	.77	.31	1.15	2.3	.32	1.25	5.0	3.87	1.57	1.84	2.6	3.71	8	2.87	3.44	6.5
2	44	1.17	2.44	.2	.50	4.31	3.14	.7	2.66	5.54	.45	1.13	9.79	7.08	1.58	9.36	13.82	11.42	16.1	12.31	13.95	14.44
3	65	2.35	3.60	.25	.65	6.85	4.5	.9	3.61	5.53	.38	1.0	10.53	6.91	1.38	18.8	20.39	14.2	21	19.57	20.00	18.57
4	90	3.25	5.0	.35	.80	9.4	6.15	1.15	3.61	5.55	.38	.89	10.44	6.83	1.28	26.0	28.32	20	25.8	26.85	27.33	23.73
5	143	5.5	6.15	.88	.90	13.43	7.93	1.78	3.84	4.30	.61	.63	9.40	5.55	1.25	44.0	34.84	50.57	29	38.37	35.24	36.73
$\sum X_i$	362	12.5	17.65	1.75	3.10	35	22.5	4.84								100	100	100	100	100	100	100
$\bar{X} = \frac{\Sigma X_i}{5}$ 72.46 ($\bar{M}$) Av.income		2.5	3.53	.35	.62	7.0	4.5	.96														
$\bar{X}$ as % of $\bar{M}$		3.45	4.87	.48	.85	9.66	6.21	1.33														

Notes

Item 77 Car purchase
Item 78 Maintenance and running of car
Item 80 Rail fare
Item 81 Bus fare
] Total expenditure on transport

Items 78,80, 81] Total expenditure on travel

Items 80,81] Total expenditure on travel by public transport

Source : FES Report
FIG. 5.3

Expenditure of all households on transport for year 1975

TABLE 5.2d

	Total Household Expenditure and Income (£)		Expenditure on Item No.: a – I (£) b – % of total household income							Expenditure on Items 78, 80 and 81 as % of Income Income Groups					Propensity as % Share on Items 78, 80, 81 Income Groups				
ITEM	Income	Expenditure	77	78	80	81	Total	78, 80, 81	80, 81	1	2	3	4	5	1	2	3	4	5
YEAR			a b	Expenditure (£) As % of Income (%)															
1975	72.46	54.58	2.5	3.53	.35	.62	7.0	4.5	.969	3.87	7.08	6.91	6.83	5.55	3.44	13.95	20.0	27.33	35.24
			3.45	4.87	.483	.855	9.66	6.21	1.337										
1972	42.82	35.06	1.96	1.96	.22	.50	4.64	2.68	.72	4.23	6.15	6.59	6.86	6.10	4.10	11.94	19.02	25.74	39.18
			4.57	4.57	.513	1.167	10.80	6.25	1.681										
1968	29.88	24.93	1.215	1.34	.14	.396	3.09	1.87	.536	4.61	5.79	6.21	7.27	6.1	4.71	11.75	17.59	27.18	38.75
			4.06	4.48	.468	1.325	10.34	6.27	1.793										
1965	24.56	21.22	.95	.956	.134	.396	2.43	1.48	.53	3.69	5.62	6.14	6.20	6.44	3.87	12.27	17.36	25.00	40.78
			3.86	3.89	.546	1.612	9.92	6.05	2.157										

Summary of Household Expenditure on Transport

TABLE 5.3

TABLE 5.4

PERCENT

	Work			Shopping			Social		
	C	B	R	C	B	R	C	B	R
<1.6 1.2	6.2	2.6	0	12.8	5.2	0	8.1	1.8	1.6
1.6-3.2 2.4	9.4	11.1	.9	15.2	21.1	2.0	9.0	11.9	0
3.2-4.8 4.0	21.7	27.0	3.9	22.0	32.0	18.0	18.2	24.8	13.1
4.8-8 6.4	20.3	27.9	9.3	22.6	22.6	16.0	23.6	23.6	18.0
8-16 12	23.9	23.2	26.8	21.5	14.4	26.0	23.0	23.0	23.0
16-24 20	10.2	5.4	24.6	4.6	3.8	6.0	7.7	6.6	14.8
24-40 32	6.1	2.5	23.2	5.1	.8	32.0	13.7	8.3	29.5
40 + 50	2.2	.2	11.6	0	0	0	0	0	0
Total	100	100	100	100	100	100	100	100	100
Average trip length	10.43	7.79	22.0	7.7	6.05	16.4	11.0	9.54	16.8
Average all purposes		12.0			8.3			36.4	

Trip length distribution by mode by purpose

Source : Rigby, 1977
NTS 1972/73

C : car
B : bus
R : rail

P	Max. (R−1) %	$\frac{\text{Lay Money}}{\text{Money Before}} 100 = \phi_m$ Max. ϕ_m %	$\frac{\text{Time Saved}}{\text{Time Before}} 100 = \phi_t$ Max. ϕ_t %	Remarks
-3/5	-14	$\frac{.88}{2.615} = +33$ (save)	$\frac{3 - 1.5 \times .86}{3} = 57$	P = -3/5, Rate = 1 - .14 = .86 (Deterioration)
-2/5	0	$\frac{.58}{2.615} = +22$ (save)	$\frac{3 - 1.5 \times 1}{3} = 50$	P = -2/5, Rate = 1, Save time + save money
-1/5	14	$\frac{.29}{2.615} = +11$ (save)	$\frac{3 - 1.5 \times 1.14}{3} 100 = 43$	P = -1/5, Rate = 1 + .14 = 1.14 (more trips and more time)
0	28	0 = 0 (No save)	$\frac{3 - 1.5 \times 1.28}{3} 100 = 36$	P = 0, Rate = 1 + .28 = 1.28 No save money, save time (Money Budget)
1/5	42	$\frac{.29}{2.615} = -11$ (Lay)	$\frac{3 - 1.4 \times 1.42}{3} 100 = 29$	P = 1/5, Rate = 1 + .42 = 1.42 (Lay money and save time)
2/5	56	$\frac{.58}{2.615} = -22$ (Lay)	$\frac{3 - 1.5 \times 1.57}{3} 100 = 22$	P = 2/5, Rate = 1 + .56 = 1.56 (Lay money + save time with equal % (Generalised Cost Budget)
3/5	71	$\frac{.88}{2.615} = -33$ (Lay)	$\frac{3 - 1.5 \times 1.71}{3} 100 = 14$	P = 3/5, Rate = 1 + .71 = 1.71 (Lay Money and save time)

TABLE 7.1 cont.

P	Max. (R-1) %	$\frac{\text{Lay Money}}{\text{Money Before}} 100 = \emptyset_m$ Max. $\emptyset_m$ %	$\frac{\text{Time Saved}}{\text{Time Before}} 100 = \emptyset_t$ Max. $\emptyset_t$ %	Remarks
4/5	86	$\frac{1.17}{2.615} = -45$ (Lay)	$\frac{3 - 1.5 \times 1.86}{3} 100 = 7$	P = 4/5, Rate = 1 + .86 = 1.86 (Lay money and save time)
1	100	$\frac{1.46}{2.615} = -56$ (Lay)	$\frac{3 - 1.5 \times 2}{3} = 0$	P = 1, Rate = 1 + 1 = 2 (Lay more money, no time saved (Time Budget)
1	2	3	4	5

Money and Time Saved for Different Values of P.

(Low Range of Improvement Speed 20 to 40 Km/h)*

TABLE 7.1

*The values in the table is for max. $\emptyset_m$ only, and the whole Route Improved, D = 1.

Speed	h	R_t	R_m	B	A	$R = \frac{2Bh}{hA+B}$	$P = \frac{R - R_m}{R_t - R_m}$
20	1	1	1	2.615	2.615	1	
40	2	2	1.28	2.615	2.04	1.56	.388 = 2/5
60	3	3	1.34	2.615	1.95	1.85	.307 = 1.5/5
80	4	4	1.30	2.615	2.018	1.96	.244 = 1.25/5
100	5	5	1.20	2.615	2.18	1.93	.192 = 1/5
120	6	6	1.085	2.615	2.41	1.84	.153 = .75/5

Rate of Generated Trips for Different Speeds

TABLE 7.2

P	Max. (R - I)%			
		Speed		
	40	60	80	100
-1	-42			
-4/5	-28	-100		
-3/5	-14	- 66	-128	
-2/5	0	- 33	- 75	-132
-1/5	14	0	- 22	- 56
0	28	33	31	20
1/5	42	67	84	96
2/5	57	100	137	172
3/5	71	133	191	248
4/5	85	167	246	324
1	100	200	300	400

Value of P
(High Range of Improvement Speed 20 to 100 Km/hr)

TABLE 7.3

Model	Consuming	Constraint resource	Pay Extra Money	Save Time	Applicable To:	Notation*
1	K	Time	Yes	No	20% highest income group, mostly using firms cars, travel saturated, using Air Travel	M+,T0
2	K_1	Money	No (save)	Yes	20% Lowest income group, not travel frustrated, contains old, unemployed and pensioners	M-,T-
3	K_5	Money	No	Yes	Second 20% income group, seeking saturation	M0,T-
4	K_6	Gener-ated Cost	Yes	Yes	Third and Fourth income group, less saturated, less travel by air	M+,T-

*Sign + indicates to pay extra
- indicates to save
0 no pay no save
M and T is Time and Money

Household Travel Characteristics and Trip Generation Models Applicable for each Household Income Group

TABLE 7.4

Income group	% of household	Income	Expenditure on running of car		Description common for all household income groups		Trip purpose ℓ						Trip rate $t_{i\ell}$, $t_{i\ell} = \frac{E_i S_\ell}{\bar{C}_\ell}$ (ℓ)						T_i
	%	£	$E_i = M_i N_i$																
i	H_i	M_i	N_i	E_i			1	2	3	4	5	6	1	2	3	4	5	6	All purpose
1	2	3	4	5	6	7	8						9						10
1	20	13	2.1	28	Average trip length km	$\bar{X}_\ell$	9.7	25.3	7.8	10.5	13.6	13.4	.35	.10	.22	.09	.17	.19	1.12
2	20	26	4.11	107	% expenditure on travel for purpose $\ell = P_\ell = S_\ell$	S_ℓ	25	19	13	7	17	19	1.35	.39	.87	.35	.65	.74	4.35
3	20	38.7	4.87	185									2.33	.68	1.51	.60	1.14	1.28	7.54
					Average speed kph	ν			40										
4	20	50.3	5.16	260									3.28	.96	2.12	.85	1.6	1.8	10.61
					$C = 1.29 + \frac{26}{\nu} + .000063\nu^2$ pence/km	C_ℓ			2.04										
5	20	86.1	4.65	400									5.05	1.47	3.27	1.31	2.45	2.78	16.33
$\Sigma = 5$					Cost trip $\bar{C}_\ell$ $\bar{C}_\ell = C_\ell \bar{X}_\ell$	$\bar{C}_\ell$	19.8	51.6	15.9	21.4	27.7	27.33							
												$Q_\ell =$	12.36	3.6	7.99	3.20	6.01	6.79	(40) T
										$t_\ell =$	$8K_\ell =$	$\bar{Q}_\ell =$	2.47	.72	1.6	.64	1.2	1.36	(8) $\bar{T}$

Source : NTS 1972/73
FES 1972
TRRL 661

Weekly household car trip rate

TABLE 8.1

Income group	% of household	Income	Expenditure on running	of car	Description common for all household income groups		Trip purpose ℓ						Trip rate $t_{i\ell}$, $t_{i\ell} = \frac{E_i P_\ell}{\bar{C}_\ell}$ (ℓ)						T_i
	%	£	$E_i = M_i$	N_i															
i	H_i	M_i	N_i	E_i			1	2	3	4	5	6	1	2	3	4	5	6	All purpose
1	2	3	4	5	6	7	8						9						10
1	20	13	2.1	28	Average trip length km	$\bar{X}_\ell$	9.7	25.3	7.8	10.5	13.6	13.4	.32	.09	.21	.08	.15	.17	1.02
2	20	26	4.11	107	% expenditure on travel for purpose ℓ	P_ℓ	29	20	12.4	6.6	15.5	16.5	1.22	.36	.79	.32	.60	.67	3.96
					Assumed speed	ν	20	25	30	35	40	60							
3	20	38.7	4.87	185	$C=1.29+\frac{26}{\nu}+.000045\nu^2$								2.11	.62	1.37	.55	1.03	1.2	6.85
					Cost/km pence/km	C_ℓ	2.615	2.37	2.15	2.11	2.04	1.95							
4	20	50.3	5.16	260	Cost/trip = $\bar{X}_\ell C_\ell$	$\bar{C}_\ell$	25.36	60	16.77	22.15	27.74	26.13	2.97	.87	1.92	.77	1.45	1.64	9.62
5	20	86.1	4.65	400									4.57	1.33	2.96	1.19	2.23	2.52	14.80
$\Sigma=5$	100											Q_ℓ =	11.19	3.27	7.24	2.91	5.47	6.18	(36.25) = T
												$\bar{Q}_\ell$ =	2.24	.66	1.45	.58	1.1	1.24	(7,24) = T

Source : NTS 1972/73
FES 1972
TRRL 661

Weekly household car trip rate, by household income group by purpose of trip.
(see FIG. 7.12 and 7.13)

TABLE 8.2

Passenger Transport Energy Consumption (cal. per passenger mile)

Method	Capacity	Speed	Primary Fuel Consumption	
			Direct Consumption	Indirect Consumption
Walking	1	4mph	100	-
Cycling	1	15mph	23	-
Small motorcycle	1	25mph	290	325
Large motorcycle	2	70mph	345	390
Average car	4	70mph	350	390
Small car	4	60mph	240	270
Large car	5	70mph	585	655
Actual car	average capacity		1,200	-
Coach	50	60mph	70	80
Actual bus/ coach	average capacity		350	-
Diesel train	770	80mph	65	73
Electric train	770	80mph	28	100
Actual train	av. capacity		620	
Jumbo jet		500mph	58¼	650

After Mick Hamer, from New Scientist 8.11.75, Times 3.10.75.

TABLE 9.1

Year	Average Income	Average Expenditure	Money Spent on Running Car	Money Spent on Bus Travel	Money Spent on Rail Travel	* Petrol Price/ Gallon Retail	** Bus Fare/Km (including Coaches)	*** Rail Fare/Km (Full Fare)	**** All Consumer Expenditure on Goods and Services	***** Average Trip Length (Km)	
	£ (index)	£ (index)	£	£	£	£	Pence	Pence	Index	Bus	Rail
1965	24.56	21.22	.95	.40	.134	.255	.6	.85		5.50	33.2
	100	100	100	100	100	100	100	100	100	100	100
1968	29.88	24.93	1.34	.39	.14	.2975	.68	.90		5.8	34.1
	122	117	141	98	104	116	113	106	111	105	103
1972	42.82	35.06	1.96	.50	.22	.3515	.99	1.32		6.5	39.3
	175	165	206	125	164	138	165	155	144	118	118
1975	72.46	54.58	3.53	.62	.35	.725	1.59	1.88		6.6	46.0
	295	257	371	155	261	284	265	221	224	120	138
(*)	1	2	3	4	5	6	7	8	9	10	11

Comparison of Petrol Price Index with Other Items

TABLE 9.2

(*) SEE FIG. 6.11 and 6.12

* Transport Statistics G.B. 1965 - 1975 Table (4)

** Transport Statistics G.B. 1965 - 1975 Tables 9, 43a, 44a

*** Transport Statistics G.B. 1965 - 1975 Table 67(e)

**** Transport Statistics G.B. 1965 - 1975 Table 8

***** Transport Statistics G.B. 1965 - 1975 Tables 9, 43a, 44a.

Income group	% of household	Income	Expenditure	on travel on bus travel	Description common for all household income groups		Trip purpose ℓ						Trip rate ($t_{i\ell}$) $t_{i\ell} = \frac{E_i P_\ell}{\bar{X}_\ell}$ (ℓ)						
	%	£	$E_i = M_i N_i$																
i		M_i	N_i	E_i			1	E	3	4	5	6	1	E	3	4	5	6	T_i
1	2	3	4	5	6	7	8						9						10
1	20	13	1.7	22	Average trip length km	$\bar{X}_\ell$	5.16	4.64	4.79	5.16	5.8	6.88	1.03	.29	.83	.23	.47	.09	2.97
2	20	26	1.65	43	% expenditure on travel for purpose ℓ	P_ℓ	35	9	26	8	28	4	2.02	.58	1.61	.43	.92	.17	5.79
					Cost per km	C_ℓ			1.45										
3	20	38.7	1.42	55	Cost per trip = $\bar{X}_\ell C_\ell$	$\bar{C}_\ell$	7.46	6.71	6.93	7.46	8.39	9.95	2.58	.74	2.06	.59	1.18	.22	7.47
4	20	50.3	1.19	60									2.81	.80	2.25	.64	1.29	.24	8.11
5	20	86.1	,81	70									3.28	.94	2.63	.75	2.50	.28	9.47
												Q_ℓ =	11.72	3.35	9.38	2.68	5.36	1.0	33.83
	Average			50								$\bar{Q}_\ell$ =	2.34	.67	1.87	.53	1.07	.2	6.766

Source : NTS 1972/73
FES 1972

Weekly household bus trip rate, by household income group by trip purpose.

TABLE 9.3

GEDIAS SYSTEM - PART3 TRAFFIC ASSIGNMENT
RELATIVE ATTRACTIVENESS METHOD

TEST SARRAJ
SARRRAJ

LOADLIST 49030

ZONE	LOAD	SECT	ZONE	LOAD	SECT	ZONE	LOAD	SECT	ZONE	LOAD	SECT
1	0.100	169	2	0.100	168	3	0.100	172	4	0.100	157
5	0.100	170	6	0.100	171	7	0.100	173	8	0.100	163
9	0.100	165	10	0.100	164	11	0.100	74	12	0.100	161
13	0.100	162	14	0.100	180	15	0.100	178	16	0.100	175
17	0.100	176	18	0.100	177	19	0.100	30	20	0.100	155
21	0.100	153	22	0.100	157	23	0.100	158	24	0.100	159
25	0.100	160	26	0.100	73	27	0.100	147	28	0.100	145
29	0.100	144	30	0.100	142	31	0.100	145	32	0.100	148
33	0.100	133	34	0.100	130	35	0.100	149	36	0.100	150
37	0.100	151	38	0.100	152	39	0.100	95	40	0.100	97
41	0.100	91	42	0.100	93	43	0.100	92	44	0.100	103
45	0.100	102	46	0.100	99	47	0.100	101	48	0.100	103
49	0.100	104	50	0.100	106	51	0.100	90	52	0.100	115
53	0.100	36	54	0.100	116	55	0.100	128	56	0.100	134
57	0.100	136	58	0.100	138	59	0.100	139	60	0.100	137
61	0.100	123	62	0.100	125	63	0.100	126	64	0.100	122
65	0.050	118	65	0.050	117	66	0.100	114	67	0.050	111
67	0.050	110	68	0.100	113	69	0.100	108	70	0.100	139
71	0.100	100	72	0.100	56	73	0.100	56	74	0.100	119
75	0.100	121	76	0.100	104	77	0.032	15	77	0.068	7
78	0.053	21	78	0.026	23	78	0.011	82	78	0.010	15
79	0.029	15	79	0.016	7	79	0.034	21	79	0.011	23
79	0.010	82	80	0.045	15	80	0.045	7	80	0.010	21
81	0.049	23	81	0.016	21	81	0.013	82	81	0.008	15
81	0.014	67	82	0.061	7	82	0.025	57	82	0.014	15
83	0.058	23	83	0.021	82	83	0.021	83	84	0.055	57
84	0.035	7	84	0.010	67	85	0.041	21	85	0.034	15
85	0.012	7	85	0.006	82	85	0.007	23	86	0.022	57
86	0.050	67	86	0.028	7						

END OF LOADLIST

TABLE 10.1 HAMILTON LOAD LIST.

FREQUENCY TABLE (TIME)
TIME DIAMETER OF NETWORK IS 6650

PERCENTAGE OF DIAM.	PERCENTAGE OVER SHORTEST ROUTE 1	2	3	4	5	6	7	8	9	10	TOTAL
10	12	0	0	0	0	0	0	0	0	0	12
20	65	2	3	0	1	0	0	0	0	2	73
30	136	9	9	7	3	7	8	8	10	9	206
40	146	28	13	4	16	28	21	36	27	20	339
50	174	33	16	19	28	44	34	23	30	45	446
60	130	28	17	47	46	47	41	60	108	100	624
70	83	23	31	28	27	21	85	101	92	112	603
80	45	15	37	14	30	70	108	122	136	91	668
90	13	1	11	6	15	46	49	61	67	79	348
100	3	1	3	0	6	8	17	14	16	18	86
TOTAL	807	140	140	125	172	271	363	425	486	476	3405

END OF TABLE

(a)

FREQUENCY TABLE (DISTANCE)
DISTANCE DIAMETER OF NETWORK IS 6650

PERCENTAGE OF DIAM.	PERCENTAGE OVER SHORTEST ROUTE 1	2	3	4	5	6	7	8	9	10	TOTAL
10	12	0	0	0	0	0	0	0	0	0	12
20	65	2	3	0	1	0	0	0	0	2	73
30	137	8	9	7	3	7	8	7	12	8	206
40	146	25	15	4	17	28	21	35	27	21	339
50	172	35	16	18	29	44	34	23	30	45	446
60	129	30	15	48	44	47	43	58	107	103	624
70	83	23	31	28	27	21	82	101	95	112	603
80	44	16	37	14	29	68	112	121	134	92	667
90	13	1	11	6	13	48	48	61	70	78	349
100	3	1	3	0	6	8	17	14	15	19	86
TOTAL	804	141	140	125	169	271	365	420	490	480	3405

END OF TABLE

(b)

TABLE 10.2 DISTANCE ROUTE DISTRIBUTION.

FREQUENCY TABLE (TIME)
TIME DIAMETER OF NETWORK IS 12980

PERCENTAGE OF DIAM.	PERCENTAGE OVER SHORTEST ROUTE 1	2	3	4	5	6	7	8	9	10	TOTAL
10	9	0	0	0	0	0	0	0	0	0	9
20	64	1	2	0	1	0	1	0	0	0	69
30	119	4	3	0	6	2	0	6	10	7	157
40	133	5	8	10	4	8	18	9	17	16	228
50	151	8	6	8	29	25	17	37	19	36	336
60	121	8	10	23	40	35	28	32	49	50	396
70	87	20	3	28	29	29	23	30	37	43	329
80	34	7	9	17	25	12	23	32	34	53	246
90	7	1	6	10	3	13	22	21	40	63	186
100	4	0	0	0	0	0	5	3	7	10	29
TOTAL	729	54	47	96	137	124	137	170	213	278	1985

END OF TABLE

(a)

FREQUENCY TABLE (DISTANCE)
DISTANCE DIAMETER OF NETWORK IS 7276

PERCENTAGE OF DIAM.	PERCENTAGE OVER SHORTEST ROUTE 1	2	3	4	5	6	7	8	9	10	TOTAL
10	14	0	0	0	0	0	0	0	0	0	14
20	79	0	1	0	0	0	0	0	0	4	84
30	169	18	6	4	2	3	1	6	3	31	243
40	161	17	7	2	5	16	16	11	6	62	303
50	145	15	12	17	33	18	13	12	5	95	365
60	112	15	9	20	22	18	14	14	10	129	363
70	63	15	16	13	7	14	30	24	17	109	308
80	27	5	8	4	16	31	15	14	5	106	231
90	4	1	2	1	5	6	8	1	8	31	67
100	0	0	0	0	0	0	0	0	0	7	7
TOTAL	774	86	61	61	90	106	97	82	54	574	1985

END OF TABLE

(b)

TABLE 10.3 TIME ROUTE DISTRIBUTION.

FREQUENCY TABLE (TIME)
TIME DIAMETER OF NETWORK IS 9738

PERCENTAGE OF DIAM.	PERCENTAGE OVER SHORTEST ROUTE 1	2	3	4	5	6	7	8	9	10	TOTAL
10	8	0	0	0	0	0	0	0	0	0	8
20	62	0	0	4	0	0	1	0	1	0	68
30	123	0	3	4	5	4	6	5	7	5	162
40	123	6	18	6	16	8	10	21	18	13	239
50	153	14	18	25	9	24	17	26	31	34	351
60	108	19	20	19	24	38	50	47	52	45	422
70	85	14	13	33	19	42	28	45	32	76	387
80	35	4	9	15	21	30	34	41	54	92	335
90	10	2	1	2	21	9	25	28	47	40	185
100	3	0	1	1	2	1	5	11	10	9	43
TOTAL	710	59	83	109	117	156	176	224	252	314	2200

END OF TABLE

(a)

FREQUENCY TABLE (DISTANCE)
DISTANCE DIAMETER OF NETWORK IS 6882

PERCENTAGE OF DIAM.	PERCENTAGE OVER SHORTEST ROUTE 1	2	3	4	5	6	7	8	9	10	TOTAL
10	13	0	0	0	0	0	0	0	0	0	13
20	68	0	2	0	0	0	0	0	0	2	72
30	147	10	8	5	4	5	2	5	5	20	211
40	149	25	8	2	11	17	17	13	6	41	289
50	165	21	15	16	24	30	18	13	6	72	380
60	129	25	14	33	30	28	26	21	9	97	412
70	77	21	13	10	15	13	41	30	30	121	371
80	35	12	22	10	7	37	43	25	6	116	313
90	9	1	6	1	10	20	11	8	13	33	112
100	0	0	0	0	4	2	7	0	1	13	27
TOTAL	792	115	88	77	105	152	165	115	76	515	2200

END OF TABLE

(b)

TABLE 10.4 GENERALISED COST ROUTE DISTRIBUTION.

ACCESSIBILITY INDEX FOR EACH SECTION

0.318	0.319	0.302	0.422	0.394	0.354	0.494	0.523	0.597	0.633
0.689	0.585	0.507	0.440	0.411	0.360	0.382	0.406	0.395	0.416
0.389	0.350	0.362	0.440	0.549	0.568	0.563	0.539	0.475	0.597
0.603	0.621	0.662	0.658	0.737	0.722	0.695	0.692	0.507	0.610
0.547	0.618	0.690	0.700	0.710	0.728	0.756	0.732	0.737	0.676
0.649	0.621	0.567	0.565	0.532	0.497	0.417	0.682	0.543	0.693
0.563	0.525	0.505	0.489	0.465	0.412	0.358	0.482	0.461	0.454
0.461	0.523	0.556	0.575	0.552	0.532	0.524	0.518	0.495	0.454
0.432	0.391	0.446	0.487	0.514	0.551	0.583	0.610	0.553	0.726
0.386	0.446	0.481	0.531	0.564	0.519	0.489	0.694	0.615	0.542
0.617	0.636	0.654	0.662	0.717	0.726	0.700	0.645	0.550	0.637
0.701	0.689	0.646	0.655	0.684	0.670	0.649	0.608	0.535	0.434
0.432	0.627	0.548	0.520	0.547	0.636	0.657	0.650	0.679	0.629
0.639	0.587	0.528	0.523	0.490	0.494	0.475	0.462	0.423	0.371
0.395	0.407	0.436	0.441	0.464	0.467	0.525	0.600	0.650	0.668
0.622	0.621	0.586	0.563	0.576	0.549	0.521	0.604	0.502	0.570
0.571	0.517	0.510	0.474	0.465	0.479	0.427	0.380	0.384	0.437
0.461	0.463	0.518	0.541	0.522	0.514	0.528	0.535	0.545	0.535
0.664	0.589	0.390	0.553	0.561	0.568	0.000	0.631	0.695	0.000
0.000	0.582	0.598	0.000	0.000	0.000	0.000	0.000	0.000	0.000
0.000	0.000	0.000							

TOTAL = 104.91

Accessibility indices for Hamilton network (distance journey unit).

TABLE 10.5

```
ROUTES FROM ORIGIN 161  TO DESTINATION 146  CRITICAL ROUTE LENGTH = 1800  TOTAL TRAFFIC = 43
-----------------------------------------------------------------------------------------------

ROUTE  1  IS :    -146    72    73    87   161
LENGTH(T) = 1636  LENGTH(D) = 1635.43  NO. OF SECTIONS =  5  MEAN A(L) = 0.5399  MEAN CAP =    12.57  SPEED = 59.98

NUMBER OF ROUTES =  1  L(S) = 1636  L(D) =  1635  A(S) = 0.5399  R(S) =  5  Q(S) =    12.57  SUM A(EFF) =  2.0000
ROUTE  1  MEAN A(L) = 0.5399  L = 1636  A(EFF) =  2.0000  PROPORTION = 1.0000  TRAFFIC = 43.14

ROUTES FROM ORIGIN 161  TO DESTINATION 167  CRITICAL ROUTE LENGTH = 1648  TOTAL TRAFFIC = 102
-----------------------------------------------------------------------------------------------

ROUTE  1  IS :    -167  -165    84    85    86   -74    87   161
LENGTH(T) = 1498  LENGTH(D) = 1498.45  NO. OF SECTIONS =  8  MEAN A(L) = 0.5217  MEAN CAP =    11.12  SPEED = 60.02

ROUTE  2  IS :    -167   166   -77   -76   -75   -74    87   161
LENGTH(T) = 1576  LENGTH(D) = 1575.38  NO. OF SECTIONS =  8  MEAN A(L) = 0.5305  MEAN CAP =    14.88  SPEED = 59.98

NUMBER OF ROUTES =  2  L(S) = 1498  L(D) =  1498  A(S) = 0.5217  R(S) =  8  Q(S) =    11.12  SUM A(EFF) =  5.3771
ROUTE  1  MEAN A(L) = 0.5217  L = 1498  A(EFF) =  2.0000  PROPORTION = 0.3719  TRAFFIC = 38.07
ROUTE  2  MEAN A(L) = 0.5305  L = 1576  A(EFF) =  3.3771  PROPORTION = 0.6281  TRAFFIC = 64.28

ROUTES FROM ORIGIN 165  TO DESTINATION 82  CRITICAL ROUTE LENGTH = 1784  TOTAL TRAFFIC = 31
-----------------------------------------------------------------------------------------------

ROUTE  1  IS :     -82   -81   -80   -79   -78  -166  -165
LENGTH(T) = 1622  LENGTH(D) = 1622.06  NO. OF SECTIONS =  7  MEAN A(L) = 0.4635  MEAN CAP =    11.88  SPEED = 60.00

ROUTE  2  IS :     -82  -169  -168  -167  -165
LENGTH(T) = 1661  LENGTH(D) = 1660.87  NO. OF SECTIONS =  5  MEAN A(L) = 0.4096  MEAN CAP =    11.00  SPEED = 60.00

NUMBER OF ROUTES =  2  L(S) = 1622  L(D) =  1622  A(S) = 0.4635  R(S) =  7  Q(S) =    11.88  SUM A(EFF) =  4.9550
ROUTE  1  MEAN A(L) = 0.4635  L = 1622  A(EFF) =  2.0000  PROPORTION = 0.4036  TRAFFIC = 12.68
ROUTE  2  MEAN A(L) = 0.4096  L = 1661  A(EFF) =  2.9550  PROPORTION = 0.5964  TRAFFIC = 18.74

ROUTES FROM ORIGIN 165  TO DESTINATION 104  CRITICAL ROUTE LENGTH = 3105  TOTAL TRAFFIC = 101
-----------------------------------------------------------------------------------------------

ROUTE  1  IS :     104    47    49    50    34   -90   -89   -88   -87    74   -86   -85   -84   165
LENGTH(T) = 2823  LENGTH(D) = 2823.92  NO. OF SECTIONS = 14  MEAN A(L) = 0.6186  MEAN CAP =    15.87  SPEED = 60.02

NUMBER OF ROUTES =  1  L(S) = 2823  L(D) =  2824  A(S) = 0.6186  R(S) = 14  Q(S) =    15.87  SUM A(EFF) =  2.0000
ROUTE  1  MEAN A(L) = 0.6186  L = 2823  A(EFF) =  2.0000  PROPORTION = 1.0000  TRAFFIC = 100.87
```

Example of one and two routes between a pair of O-D with 10% allowable deviation from shortest route.

TABLE 10.6

```
ROUTES FROM ORIGIN 30  TO DESTINATION 82  CRITICAL ROUTE LENGTH = 2351  TOTAL TRAFFIC = 46
------------------------------------------------------------------------------------------

ROUTE  1  IS :     -82   -81   -80   -79   173   174    25    26    30
LENGTH(T) = 2137  LENGTH(D) = 2137.68  NO. OF SECTIONS =  9  MEAN A(L) = 0.5061  MEAN CAP =    12.72  SPEED = 60.02

ROUTE  2  IS :     -82   -81   -80   -79   173   178   179    26    30
LENGTH(T) = 2169  LENGTH(D) = 2170.22  NO. OF SECTIONS =  9  MEAN A(L) = 0.5052  MEAN CAP =    11.85  SPEED = 60.03

ROUTE  3  IS :     -82   -81   -80   -79   173   178   180  -156   185  -155    30
LENGTH(T) = 2264  LENGTH(D) = 2264.61  NO. OF SECTIONS = 11  MEAN A(L) = 0.5140  MEAN CAP =    11.32  SPEED = 60.02

NUMBER OF ROUTES =  3  L(S) = 2137  L(D) =  2138  A(S) = 0.5061  R(S) =  9  Q(S) =    12.72  SUM A(EFF) =  4.8094
ROUTE  1  MEAN A(L) = 0.5061  L = 2137  A(EFF) =  2.0000  PROPORTION = 0.4159  TRAFFIC = 18.96
ROUTE  2  MEAN A(L) = 0.5052  L = 2169  A(EFF) =  1.7118  PROPORTION = 0.3559  TRAFFIC = 16.23
ROUTE  3  MEAN A(L) = 0.5140  L = 2264  A(EFF) =  1.0975  PROPORTION = 0.2282  TRAFFIC = 10.41


ROUTES FROM ORIGIN 137  TO DESTINATION 170  CRITICAL ROUTE LENGTH = 4344  TOTAL TRAFFIC = 98
------------------------------------------------------------------------------------------

ROUTE  1  IS :   -170   -80   -79   -78   -77   -76   -75   -74   -73   -72   -71   -70   -69   -68   -64   137
LENGTH(T) = 3949  LENGTH(D) = 3949.81  NO. OF SECTIONS = 16  MEAN A(L) = 0.5000  MEAN CAP =    16.31  SPEED = 60.01

ROUTE  2  IS :   -170   -80   -79   -78   -77   163    86   -74   -73   -72   -71   -70   -69   -68   -64   137
LENGTH(T) = 4225  LENGTH(D) = 4225.74  NO. OF SECTIONS = 16  MEAN A(L) = 0.4986  MEAN CAP =    14.81  SPEED = 60.01

ROUTE  3  IS :   -170   -80   -79   -78   -77   -76   -75   -74    87    88    89  -149   132   135   -64   137
LENGTH(T) = 4329  LENGTH(D) = 4328.43  NO. OF SECTIONS = 16  MEAN A(L) = 0.5401  MEAN CAP =    13.60  SPEED = 59.99

ROUTE  4  IS :   -170   -80   -79   -78   -77   -76   -75   -74   -73   148   132   135   -64   137
LENGTH(T) = 4089  LENGTH(D) = 4089.00  NO. OF SECTIONS = 14  MEAN A(L) = 0.5211  MEAN CAP =    13.46  SPEED = 60.00

NUMBER OF ROUTES =  4  L(S) = 3949  L(D) =  3950  A(S) = 0.5000  R(S) = 16  Q(S) =    16.31  SUM A(EFF) =  6.3406
ROUTE  1  MEAN A(L) = 0.5000  L = 3949  A(EFF) =  2.0000  PROPORTION = 0.3154  TRAFFIC = 30.98
ROUTE  2  MEAN A(L) = 0.4986  L = 4225  A(EFF) =  1.5442  PROPORTION = 0.2435  TRAFFIC = 23.92
ROUTE  3  MEAN A(L) = 0.5401  L = 4329  A(EFF) =  1.2213  PROPORTION = 0.1926  TRAFFIC = 18.92
ROUTE  4  MEAN A(L) = 0.5211  L = 4089  A(EFF) =  1.5751  PROPORTION = 0.2484  TRAFFIC = 24.40
```

Example of three and four routes between a pair of O-D with 10% allowable deviation from shortest route.

TABLE 10.7

```
ROUTES FROM ORIGIN 177  TO DESTINATION 139  CRITICAL ROUTE LENGTH = 4830  TOTAL TRAFFIC = 29
------------------------------------------------------------------------------------------

ROUTE  1  IS :    -139   -65  -135  -132   149    90   -48    49    50   -33   -32   -31   -30    27   177
LENGTH(T) = 4391  LENGTH(D) = 4390.45  NO. OF SECTIONS = 15  MEAN A(L) = 0.6043  MEAN CAP =   16.80  SPEED = 59.99

ROUTE  2  IS :    -139   -65    68    69    70    71    72    73    74    75    76    77    78   173   174   175   -28
 177
LENGTH(T) = 4766  LENGTH(D) = 4768.25  NO. OF SECTIONS = 18  MEAN A(L) = 0.5100  MEAN CAP =   15.55  SPEED = 60.03

ROUTE  3  IS :    -139   -65   -64   -63   -62   -61   -60   -59   -58  -199   202   189   -38   -37   -36   -35   -48
  49    50   -33   -32   -31   -30    27   177
LENGTH(T) = 4771  LENGTH(D) = 4771.73  NO. OF SECTIONS = 25  MEAN A(L) = 0.5667  MEAN CAP =   19.[illegible]2  SPEED = 6[illegible]

ROUTE  4  IS :    -139   -65   -64   -63   -62   -61   -60   126   128   129   -36   -35   -48    49    50   -33   -32
 -31   -30    27   177
LENGTH(T) = 4812  LENGTH(D) = 4811.37  NO. OF SECTIONS = 21  MEAN A(L) = 0.6058  MEAN CAP =   18.41  SPEED = 59.99

ROUTE  5  IS :    -139   -65  -135  -132   149    90   -48    49    50   -33   -32   153  -186  -155    27   177
LENGTH(T) = 4677  LENGTH(D) = 4678.42  NO. OF SECTIONS = 16  MEAN A(L) = 0.5997  MEAN CAP =   16.77  SPEED = 60.02

NUMBER OF ROUTES =  5  L(S) = 4391  L(D) =  4390  A(S) = 0.6043  R(S) = 15  Q(S) =   16.80  SUM A(EFF) =  7.3729
ROUTE  1  MEAN A(L) = 0.6043  L = 4391  A(EFF) =  2.0000  PROPORTION = 0.2713  TRAFFIC =  7.87
ROUTE  2  MEAN A(L) = 0.5100  L = 4766  A(EFF) =  1.3124  PROPORTION = 0.1780  TRAFFIC =  5.17
ROUTE  3  MEAN A(L) = 0.5667  L = 4771  A(EFF) =  1.1339  PROPORTION = 0.1538  TRAFFIC =  4.46
ROUTE  4  MEAN A(L) = 0.6058  L = 4812  A(EFF) =  1.3214  PROPORTION = 0.1792  TRAFFIC =  5.20
ROUTE  5  MEAN A(L) = 0.5997  L = 4677  A(EFF) =  1.6052  PROPORTION = 0.2177  TRAFFIC =  6.32
```

Example of five routes between a pair of O-D
with 10% allowable deviation from shortest route.

TABLE 10.8

ROUTES FROM ORIGIN 7 TO DESTINATION 169 CRITICAL ROUTE LENGTH = 5392 TOTAL TRAFFIC = 48

NUMBER OF ROUTES = 53 L(S) = 4902 L(D) = 4901 A(S) = 0.5121 R(S) = 21 Q(S) = 15.58 SUM A(EFF) = 36.9486

ROUTE 1	MEAN A(L) = 0.5121	L = 4902	A(EFF) = 2.0000	PROPORTION = 0.0231	TRAFFIC = 1.19
ROUTE 2	MEAN A(L) = 0.5139	L = 4978	A(EFF) = 1.9867	PROPORTION = 0.0228	TRAFFIC = 1.09
ROUTE 3	MEAN A(L) = 0.5136	L = 5010	A(EFF) = 1.8762	PROPORTION = 0.0216	TRAFFIC = 1.03
ROUTE 4	MEAN A(L) = 0.5170	L = 5105	A(EFF) = 1.5388	PROPORTION = 0.0177	TRAFFIC = 0.84
ROUTE 5	MEAN A(L) = 0.5122	L = 5111	A(EFF) = 1.5911	PROPORTION = 0.0183	TRAFFIC = 0.87
ROUTE 6	MEAN A(L) = 0.5486	L = 5126	A(EFF) = 1.6347	PROPORTION = 0.0188	TRAFFIC = 0.90
ROUTE 7	MEAN A(L) = 0.5571	L = 5392	A(EFF) = 1.5505	PROPORTION = 0.0178	TRAFFIC = 0.85
ROUTE 8	MEAN A(L) = 0.5479	L = 5161	A(EFF) = 1.5407	PROPORTION = 0.0177	TRAFFIC = 0.84
ROUTE 9	MEAN A(L) = 0.5513	L = 5120	A(EFF) = 1.5947	PROPORTION = 0.0183	TRAFFIC = 0.87
ROUTE 10	MEAN A(L) = 0.5593	L = 5386	A(EFF) = 1.5143	PROPORTION = 0.0174	TRAFFIC = 0.83
ROUTE 11	MEAN A(L) = 0.5505	L = 5155	A(EFF) = 1.5038	PROPORTION = 0.0173	TRAFFIC = 0.82
ROUTE 12	MEAN A(L) = 0.5143	L = 5297	A(EFF) = 1.5718	PROPORTION = 0.0181	TRAFFIC = 0.86
ROUTE 13	MEAN A(L) = 0.5503	L = 5312	A(EFF) = 1.5900	PROPORTION = 0.0183	TRAFFIC = 0.87
ROUTE 14	MEAN A(L) = 0.5496	L = 5347	A(EFF) = 1.5020	PROPORTION = 0.0173	TRAFFIC = 0.82
ROUTE 15	MEAN A(L) = 0.5511	L = 5025	A(EFF) = 1.8887	PROPORTION = 0.0217	TRAFFIC = 1.03
ROUTE 16	MEAN A(L) = 0.5597	L = 5291	A(EFF) = 1.7735	PROPORTION = 0.0204	TRAFFIC = 0.97
ROUTE 17	MEAN A(L) = 0.5590	L = 5326	A(EFF) = 1.6801	PROPORTION = 0.0193	TRAFFIC = 0.92
ROUTE 18	MEAN A(L) = 0.5503	L = 5060	A(EFF) = 1.7305	PROPORTION = 0.0205	TRAFFIC = 0.97
ROUTE 19	MEAN A(L) = 0.5589	L = 5362	A(EFF) = 1.5702	PROPORTION = 0.0181	TRAFFIC = 0.86
ROUTE 20	MEAN A(L) = 0.5422	L = 5363	A(EFF) = 1.3082	PROPORTION = 0.0150	TRAFFIC = 0.72
ROUTE 21	MEAN A(L) = 0.5136	L = 5236	A(EFF) = 1.6595	PROPORTION = 0.0191	TRAFFIC = 0.91
ROUTE 22	MEAN A(L) = 0.5497	L = 5251	A(EFF) = 1.6732	PROPORTION = 0.0192	TRAFFIC = 0.92
ROUTE 23	MEAN A(L) = 0.5490	L = 5286	A(EFF) = 1.5807	PROPORTION = 0.0182	TRAFFIC = 0.87
ROUTE 24	MEAN A(L) = 0.5197	L = 5296	A(EFF) = 1.3414	PROPORTION = 0.0154	TRAFFIC = 0.73
ROUTE 25	MEAN A(L) = 0.5154	L = 5302	A(EFF) = 1.3813	PROPORTION = 0.0159	TRAFFIC = 0.75
ROUTE 26	MEAN A(L) = 0.5487	L = 5317	A(EFF) = 1.4327	PROPORTION = 0.0165	TRAFFIC = 0.73
ROUTE 27	MEAN A(L) = 0.5480	L = 5352	A(EFF) = 1.3534	PROPORTION = 0.0156	TRAFFIC = 0.74
ROUTE 28	MEAN A(L) = 0.5512	L = 5311	A(EFF) = 1.4012	PROPORTION = 0.0161	TRAFFIC = 0.77
ROUTE 29	MEAN A(L) = 0.5505	L = 5346	A(EFF) = 1.3243	PROPORTION = 0.0152	TRAFFIC = 0.73
ROUTE 30	MEAN A(L) = 0.5147	L = 5265	A(EFF) = 1.6608	PROPORTION = 0.0191	TRAFFIC = 0.91
ROUTE 31	MEAN A(L) = 0.5596	L = 5289	A(EFF) = 1.6730	PROPORTION = 0.0192	TRAFFIC = 0.91
ROUTE 32	MEAN A(L) = 0.5498	L = 5315	A(EFF) = 1.5783	PROPORTION = 0.0182	TRAFFIC = 0.86
ROUTE 33	MEAN A(L) = 0.5514	L = 4993	A(EFF) = 1.9873	PROPORTION = 0.0229	TRAFFIC = 1.09
ROUTE 34	MEAN A(L) = 0.5500	L = 5259	A(EFF) = 1.8585	PROPORTION = 0.0214	TRAFFIC = 1.02
ROUTE 35	MEAN A(L) = 0.5593	L = 5294	A(EFF) = 1.7612	PROPORTION = 0.0203	TRAFFIC = 0.96
ROUTE 36	MEAN A(L) = 0.5506	L = 5078	A(EFF) = 1.8743	PROPORTION = 0.0216	TRAFFIC = 1.03
ROUTE 37	MEAN A(L) = 0.5592	L = 5330	A(EFF) = 1.6470	PROPORTION = 0.0189	TRAFFIC = 0.90
ROUTE 38	MEAN A(L) = 0.5425	L = 5331	A(EFF) = 1.3802	PROPORTION = 0.0159	TRAFFIC = 0.76
ROUTE 39	MEAN A(L) = 0.5110	L = 5178	A(EFF) = 1.6185	PROPORTION = 0.0186	TRAFFIC = 0.89
ROUTE 40	MEAN A(L) = 0.5491	L = 5193	A(EFF) = 1.6431	PROPORTION = 0.0189	TRAFFIC = 0.90
ROUTE 41	MEAN A(L) = 0.5433	L = 5228	A(EFF) = 1.5487	PROPORTION = 0.0178	TRAFFIC = 0.85
ROUTE 42	MEAN A(L) = 0.5628	L = 5374	A(EFF) = 1.6283	PROPORTION = 0.0187	TRAFFIC = 0.89
ROUTE 43	MEAN A(L) = 0.5499	L = 4917	A(EFF) = 2.0131	PROPORTION = 0.0232	TRAFFIC = 1.10
ROUTE 44	MEAN A(L) = 0.5586	L = 5183	A(EFF) = 1.8844	PROPORTION = 0.0217	TRAFFIC = 1.03
ROUTE 45	MEAN A(L) = 0.5579	L = 5218	A(EFF) = 1.7843	PROPORTION = 0.0205	TRAFFIC = 0.98
ROUTE 46	MEAN A(L) = 0.5471	L = 4952	A(EFF) = 1.8768	PROPORTION = 0.0218	TRAFFIC = 1.04
ROUTE 47	MEAN A(L) = 0.5578	L = 5254	A(EFF) = 1.6669	PROPORTION = 0.0192	TRAFFIC = 0.91
ROUTE 48	MEAN A(L) = 0.5409	L = 5235	A(EFF) = 1.3882	PROPORTION = 0.0160	TRAFFIC = 0.76
ROUTE 49	MEAN A(L) = 0.5031	L = 5270	A(EFF) = 1.5986	PROPORTION = 0.0184	TRAFFIC = 0.88
ROUTE 50	MEAN A(L) = 0.5066	L = 5348	A(EFF) = 1.8213	PROPORTION = 0.0209	TRAFFIC = 1.00
ROUTE 51	MEAN A(L) = 0.5470	L = 5363	A(EFF) = 1.7768	PROPORTION = 0.0204	TRAFFIC = 0.97
ROUTE 52	MEAN A(L) = 0.5442	L = 5285	A(EFF) = 1.6154	PROPORTION = 0.0185	TRAFFIC = 0.88
ROUTE 53	MEAN A(L) = 0.5434	L = 5320	A(EFF) = 1.5127	PROPORTION = 0.0174	TRAFFIC = 0.83

Maximum number of routes between a pair of O-D with 10% allowable deviation from shortest route.

TABLE 10.9

GEDIAS SYSTEM - PART3 TRAFFIC ASSIGNMENT
RELATIVE ATTRACTIVENESS METHOD

TEST SARRAJ
SARRAJ

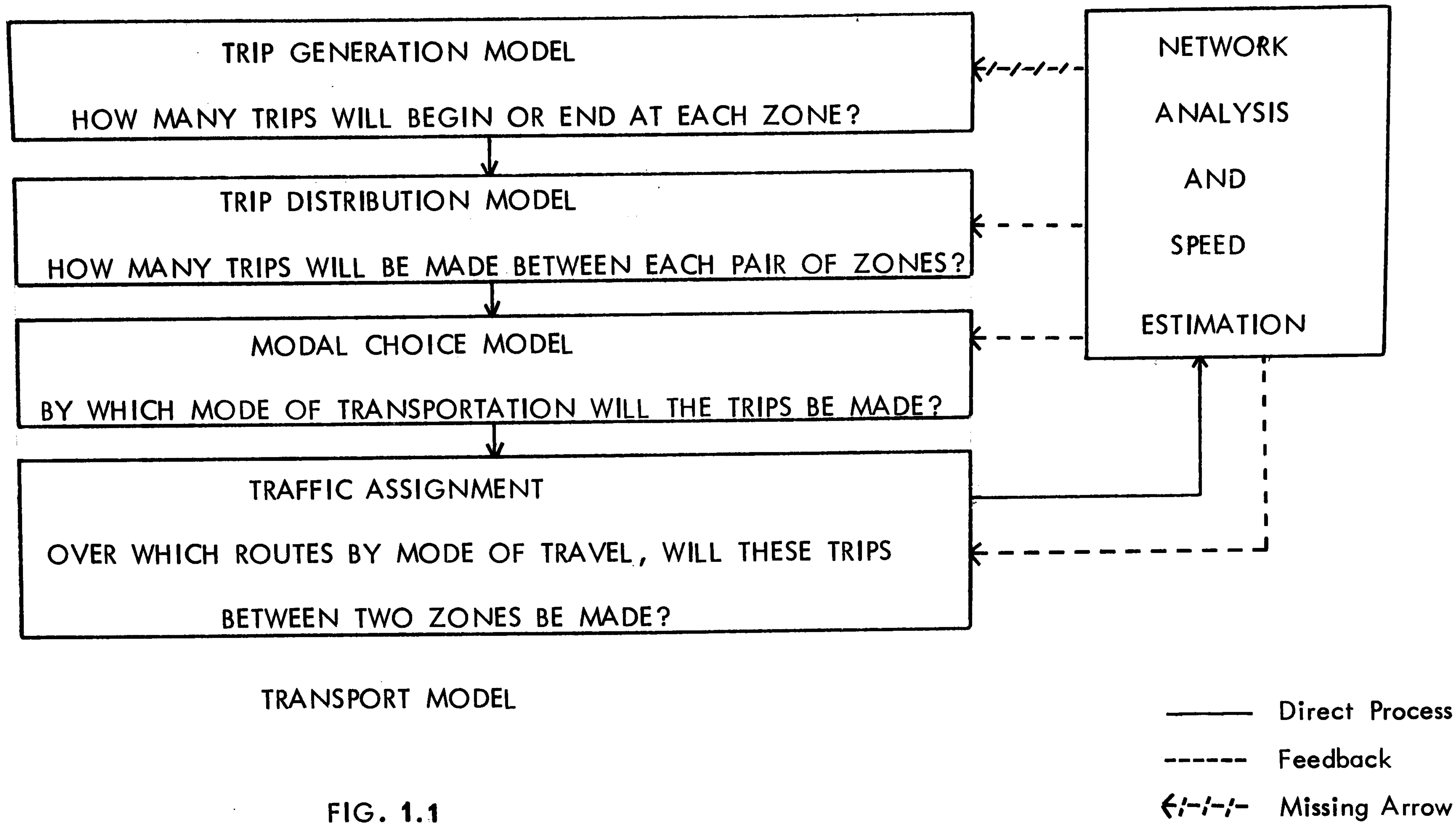
NETWORK 50015 ODTABLE 499993 LOADLIST 49030

FROM SECTION NUMBER	TURNING MOVEMENTS — TO SECTION NUMBERS: NUMBER	TRAFFIC	NUMBER	TRAFFIC	NUMBER	TRAFFIC	TRAFFIC ON SECTION: LEAVING	ENTERING	TOTAL	
25	175	796	24	1547	174	513	2856	2368	5224	TYPE 5
	26	1854	179	484	0	0	2368	2857	5225	
26	25	2263	179	567	0	0	2830	2434	5264	TYPE 3
	27	0	30	2122	155	313	2435	2829	5264	
27	3	2547	155	377	26	0	2724	3218	5942	TYPE 3
	28	2878	177	340	0	0	3218	2724	5942	
28	177	83	27	2403	0	0	2486	2981	5467	TYPE 3
	29	1842	176	642	175	496	2980	2485	5465	
29	176	199	28	1534	175	1445	3178	3867	7045	TYPE 3 ◆
	20	3163	19	704	0	0	3867	3178	7045	
30	27	2749	155	568	26	2555	5872	5010	11382	TYPE 4
	31	4453	154	649	0	0	5102	5943	11045	
31	154	122	30	5126	0	0	5248	4514	9762	TYPE 4
	32	4437	153	77	0	0	4514	5248	9762	
32	153	1195	31	5235	0	0	6430	5509	11939	TYPE 4
	33	5214	152	72	151	222	5508	6429	11937	
33	152	274	32	6211	151	88	6573	5672	12245	TYPE 4
	34	0	50	5673	0	0	5673	6574	12247	
34	33	6574	50	2217	0	0	8791	0	8791	TYPE 4
	35	0	48	0	90	0	0	8790	8790	ONE-WAY
35	34	3175	48	0	91	843	3918	3701	7619	TYPE 2 ◆
	36	2817	115	884	0	0	3701	3918	7619	
36	35	2594	115	127	0	0	2721	3340	6061	TYPE 2
	37	1834	129	1364	0	0	3198	2589	5787	

◆ SEE APP 9

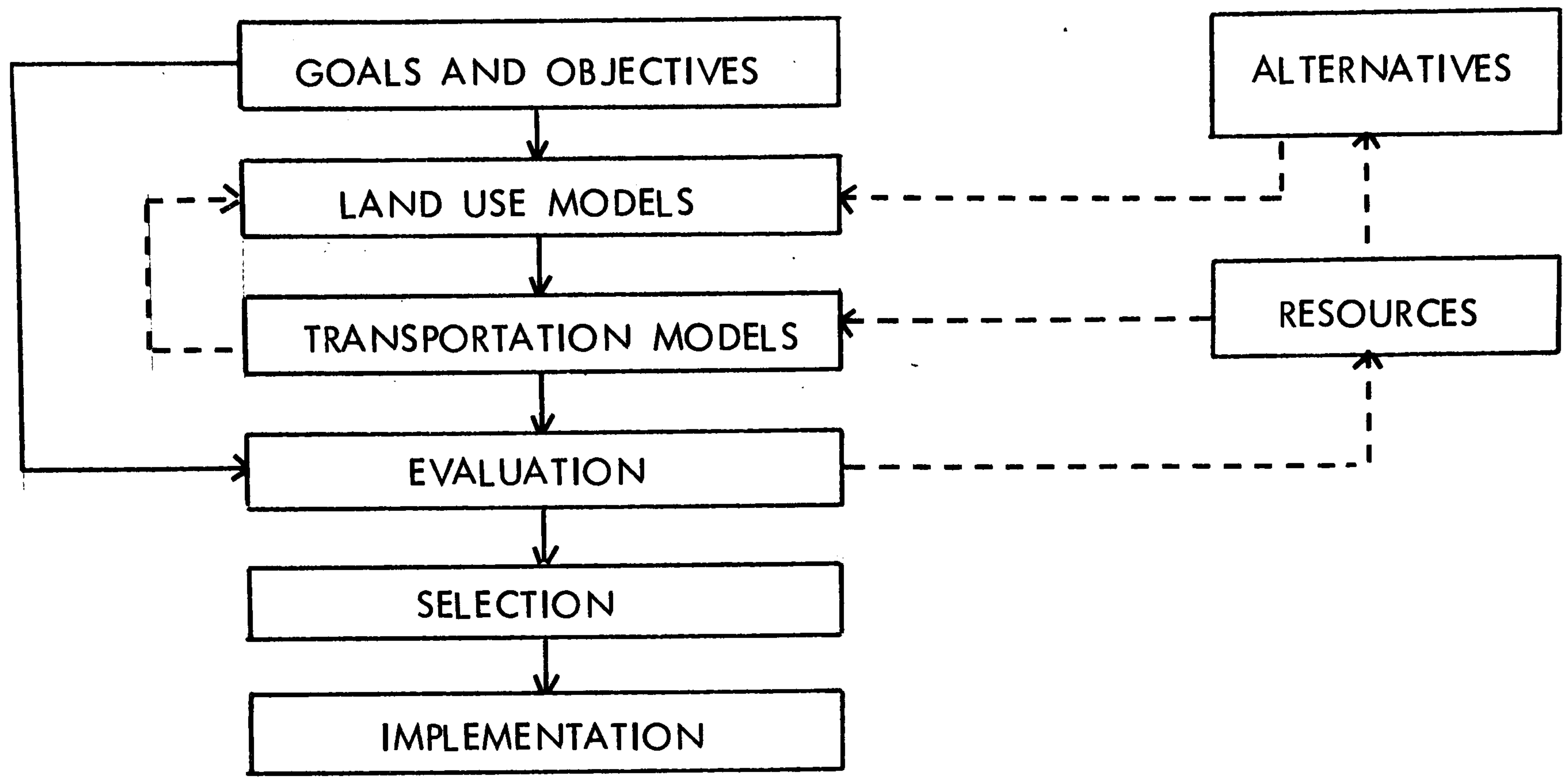
TABLE 10.10

FIGURES



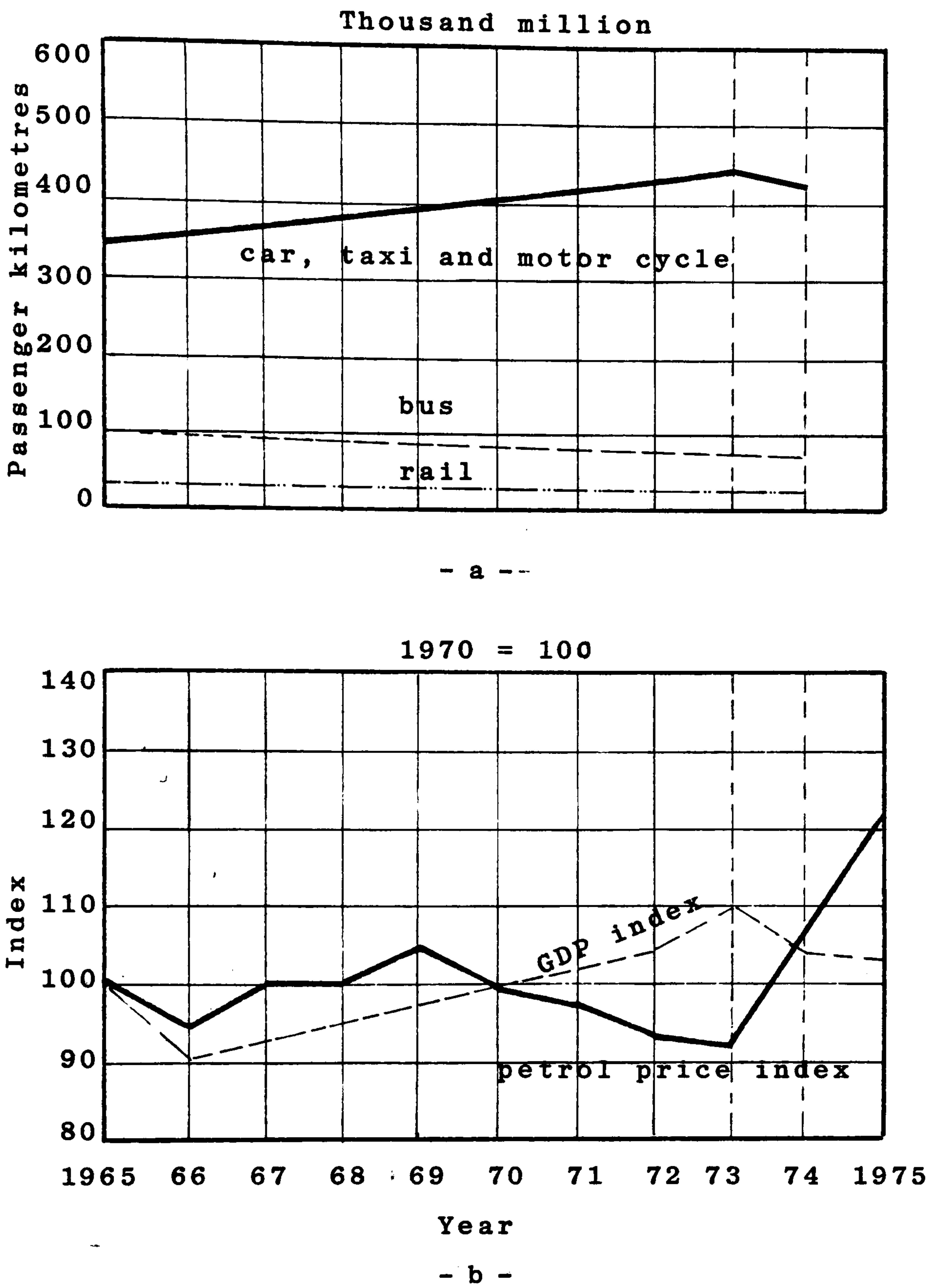
TRANSPORT MODEL

FIG. 1.1



ROLE OF MODELS IN PLANNING PROCESS

FIG. 1.2

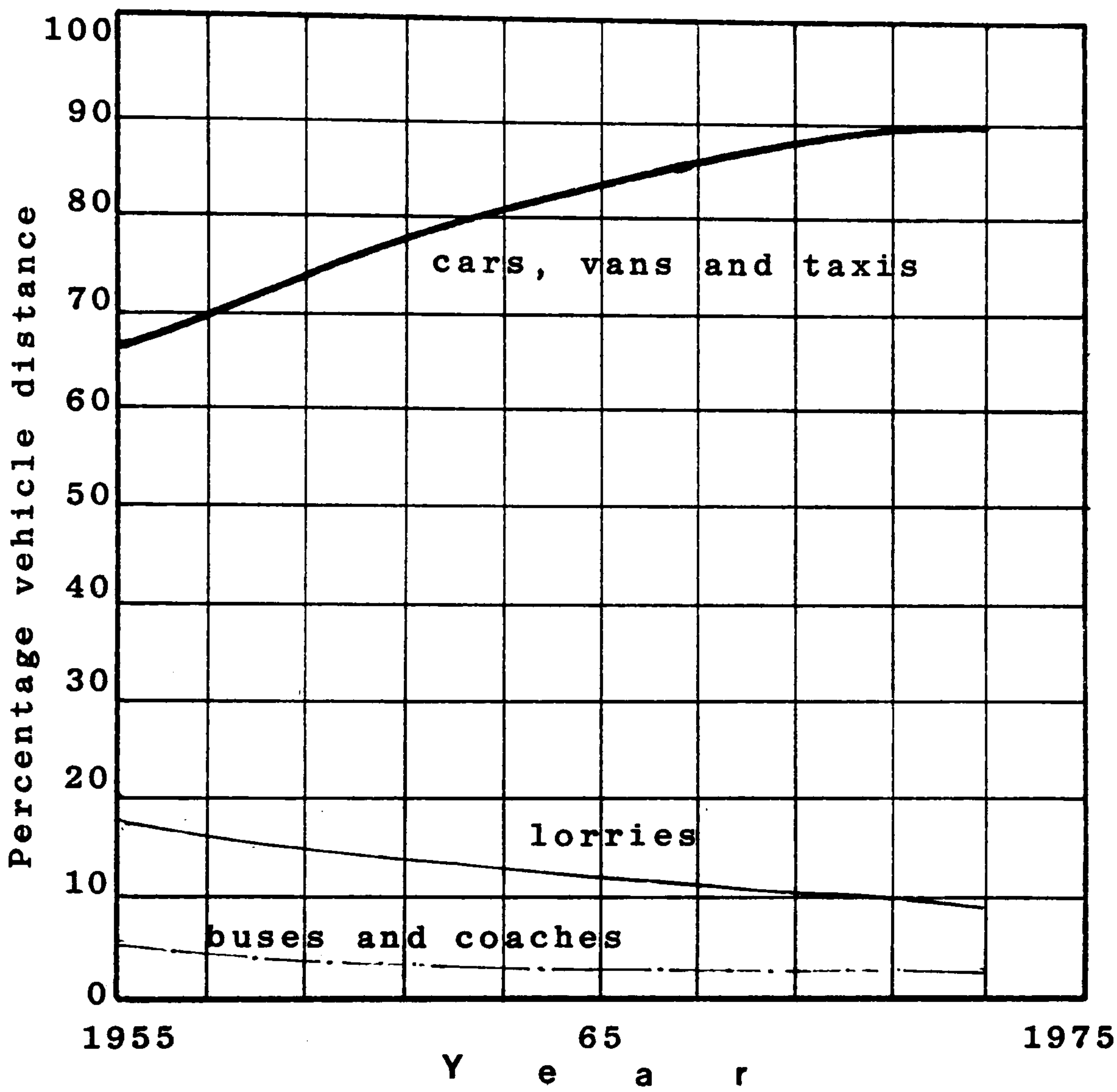


Passenger kilometres and petrol price index.

Note that only the period 1973-74 when petrol price index started to rise sharply, the car passenger kilometres fell down consequently.

Source : Transport Policy U.K.1976,Vol.2, pp.4-5
Transport statistics G.B.1965-1975
Economic Trends No.2, 1976,U.K.

FIG.,1.3



Vehicle distance travelled by different vehicles on all roads in U.K. as percentage of total travel.

Source : Transport Policy U.K. 1976
Vol. 2, pp.130

FIG. 1.4

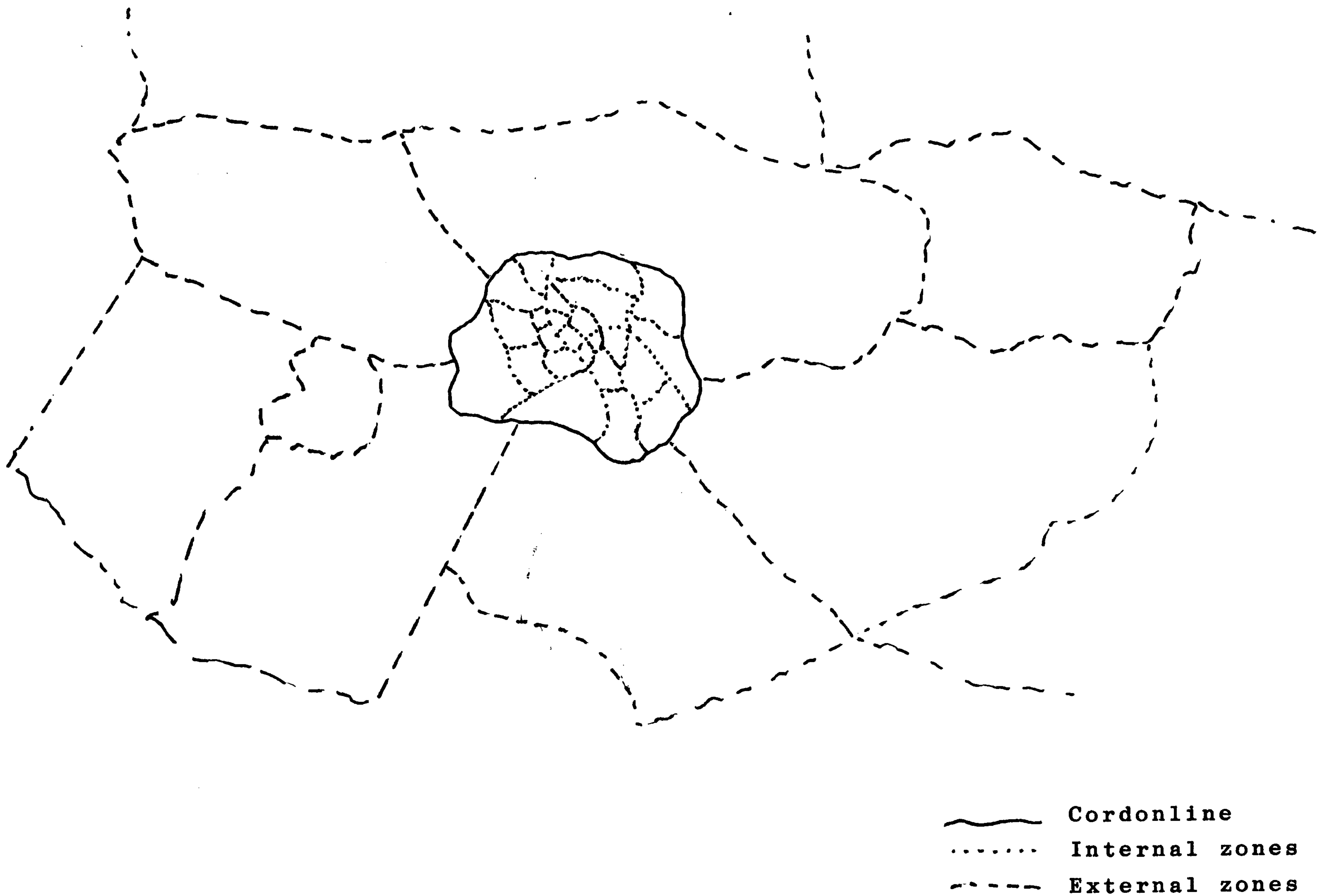


FIG. 1.5 Typical internal and external zoning system.

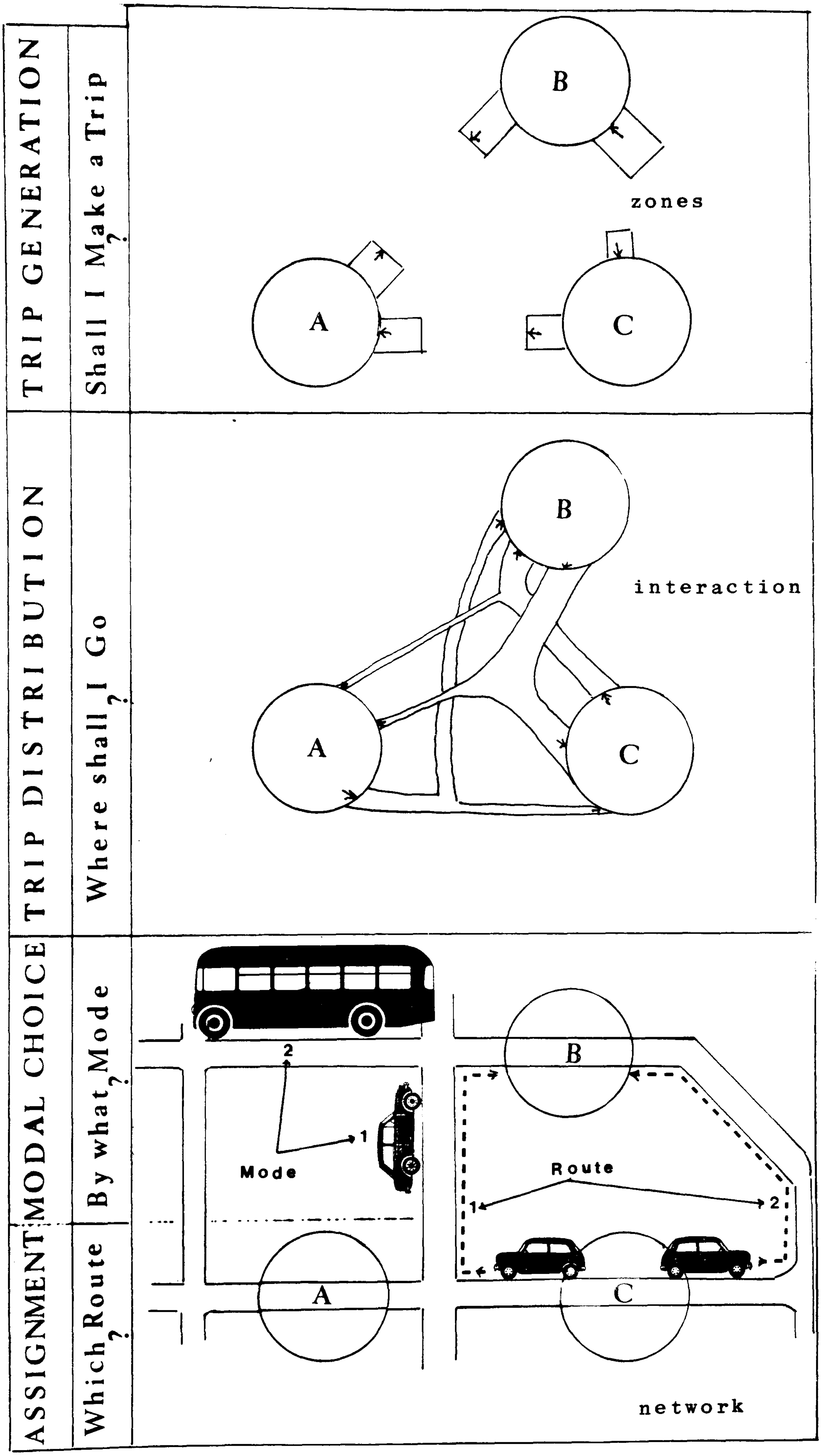
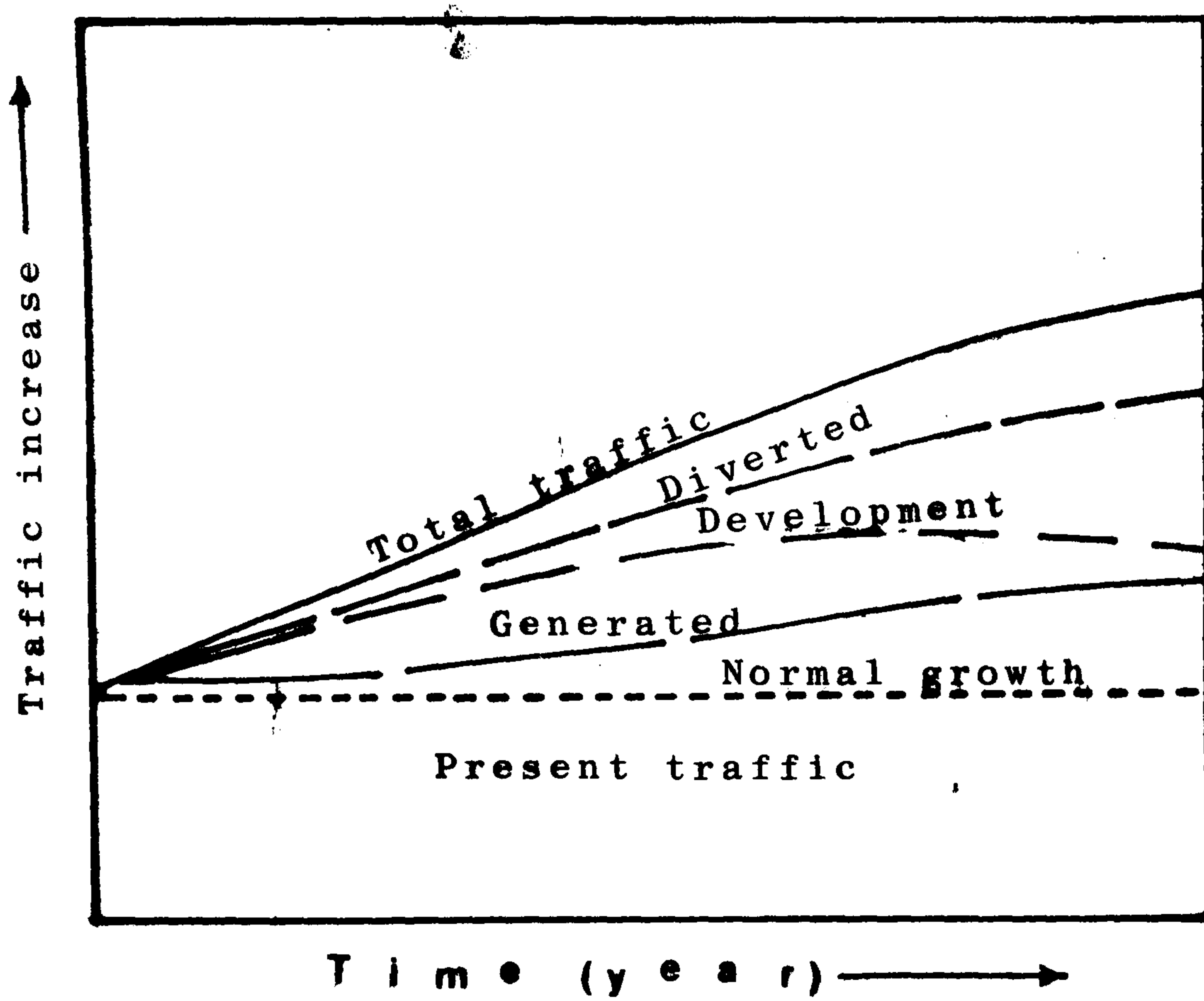
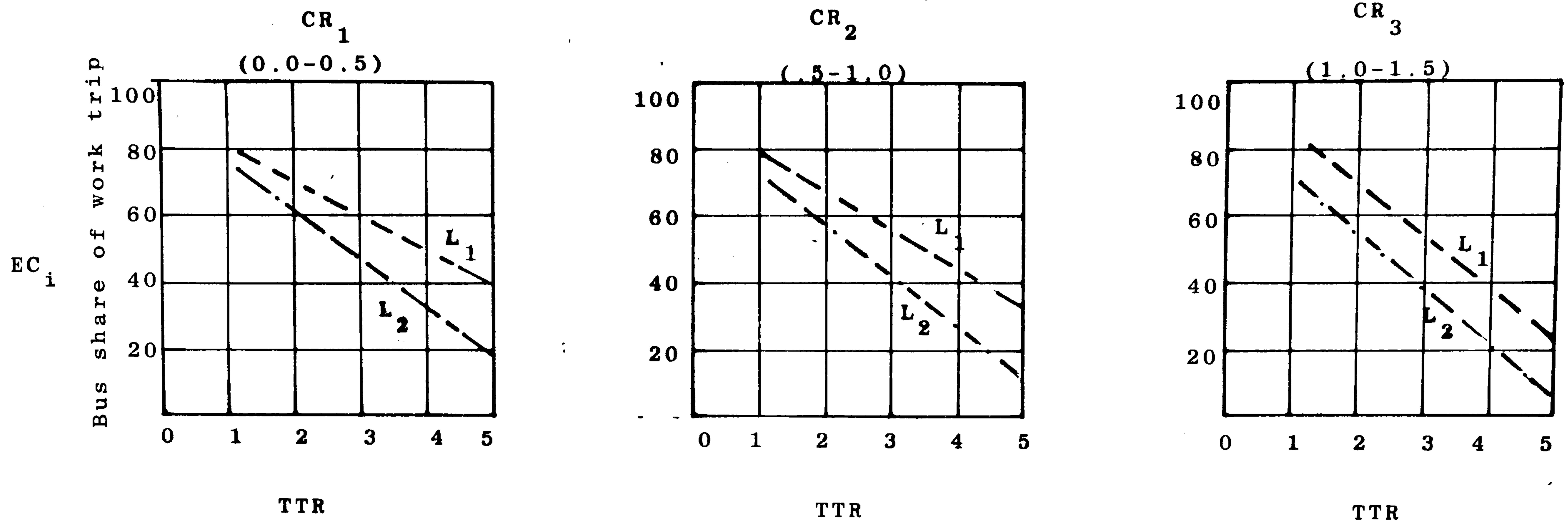


FIG. 2.1 Transportation planning process



Cause:	Obtained from:
Higher speed	Assignment
New development	Ignored in conventional methods
Higher level of service	Ignored in conventional methods
Growth and income	Generation models
Existing land use and growth	Survey data

FIG. 2.2 Traffic on a network



TTR : Ratio of bus to car time

CR : Ratio of bus to car cost

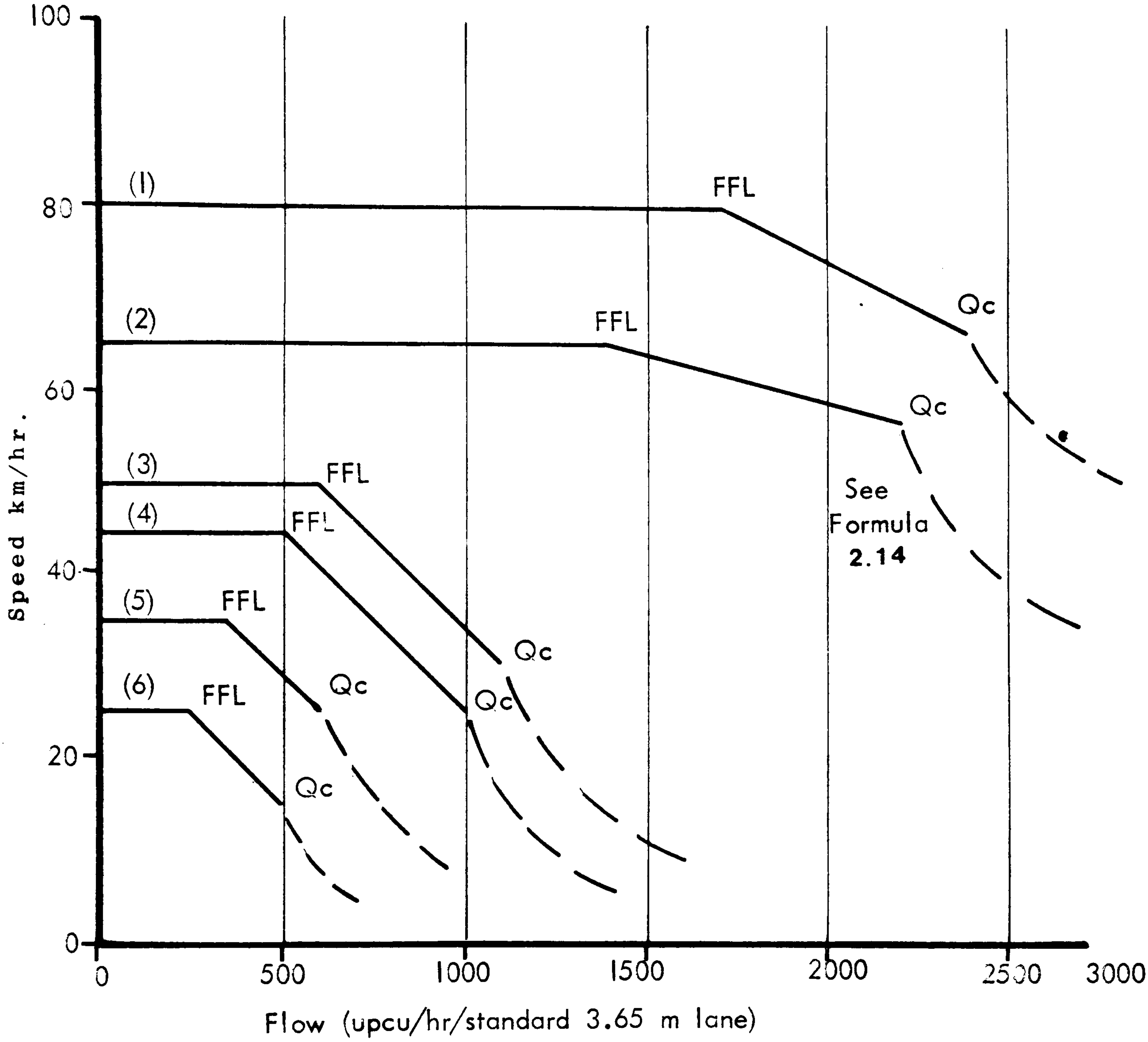
L : Ratio of bus to car service

EC_i : Average weekly income per worker for income group (i)

FIG. 2.3 Example of work-trip modal-split relationship.

SPEED/FLOW RELATIONSHIPS

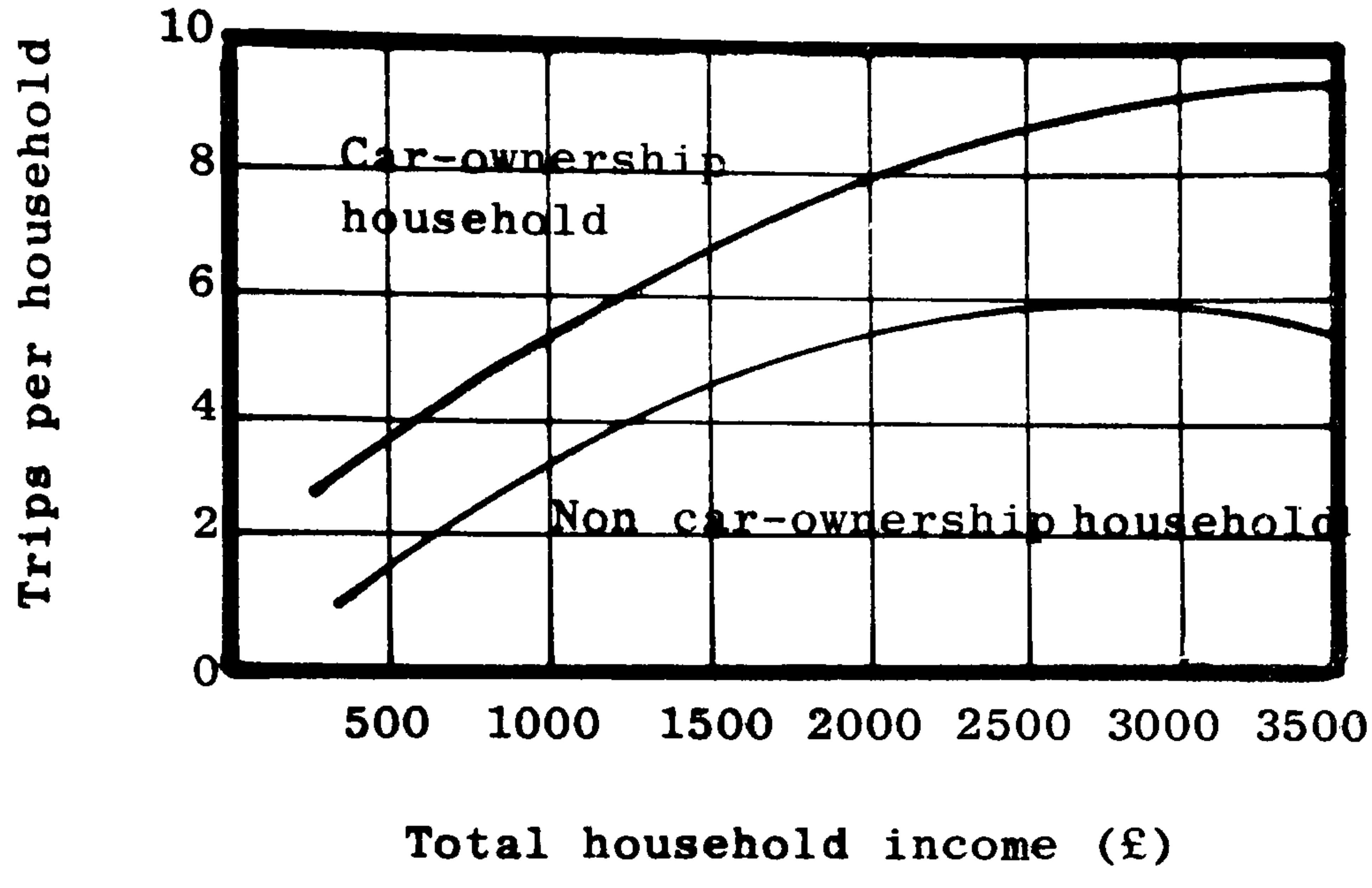
URBAN ROADS



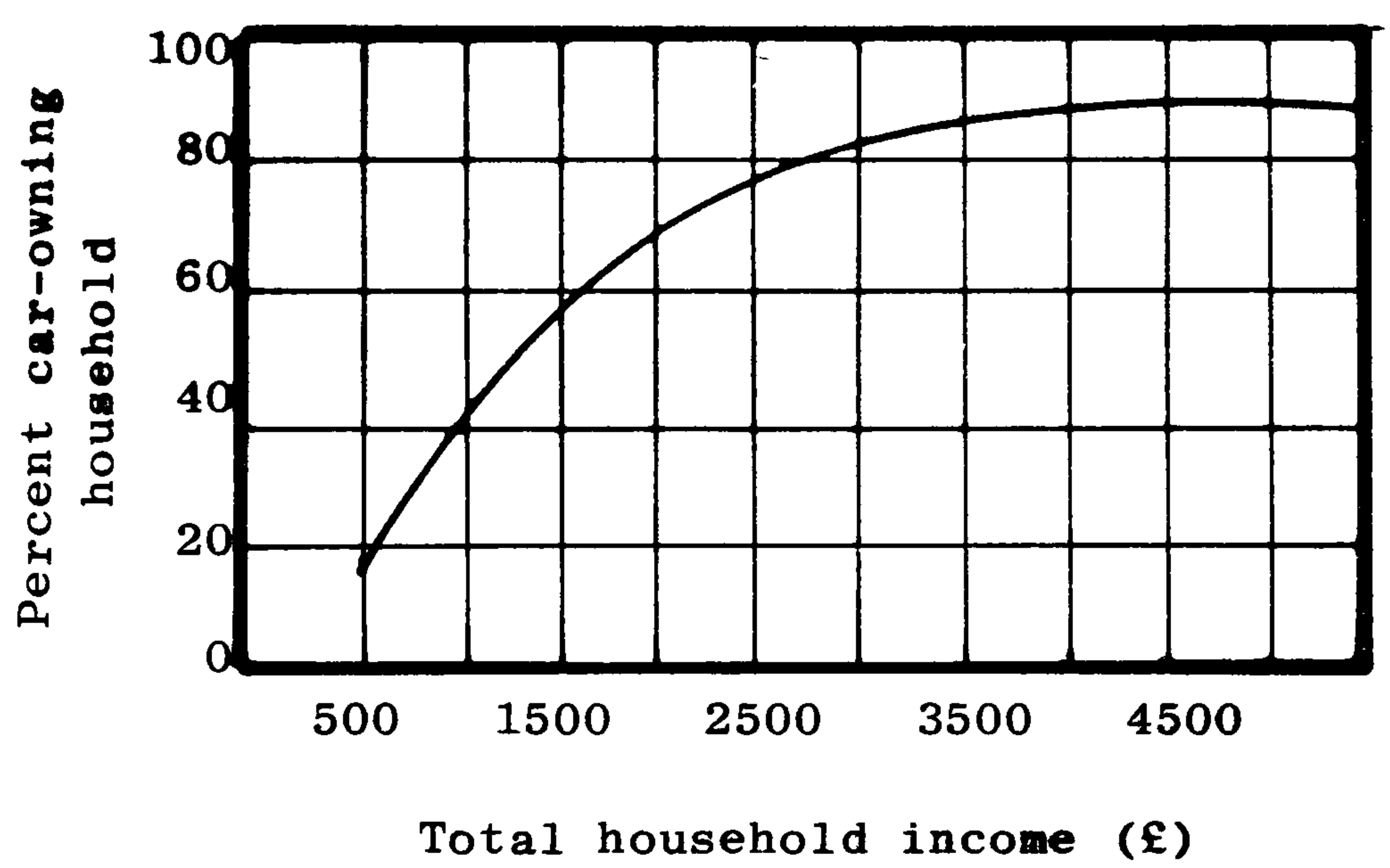
Key FFL = Free Flow Limit
Qc = "limiting capacity"
upcu = urban pcu
rpcu = rural pcu

Source: DoE. Advice Note No.IA

FIG. 2.4



(a)

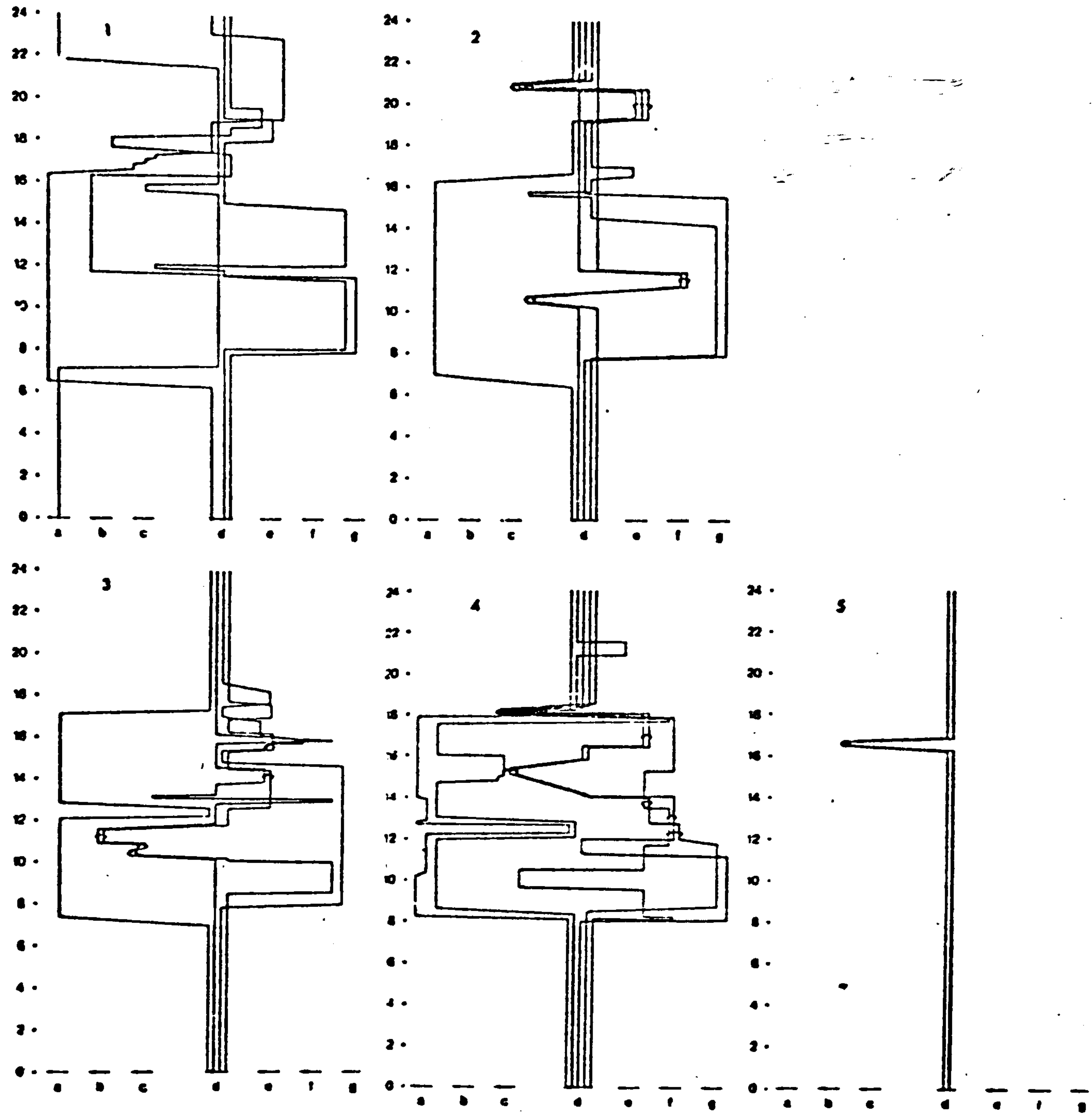


(b)

Effect of income on number of trips and car ownership

Source : Movement in London Ch.2.

FIG. 3.1



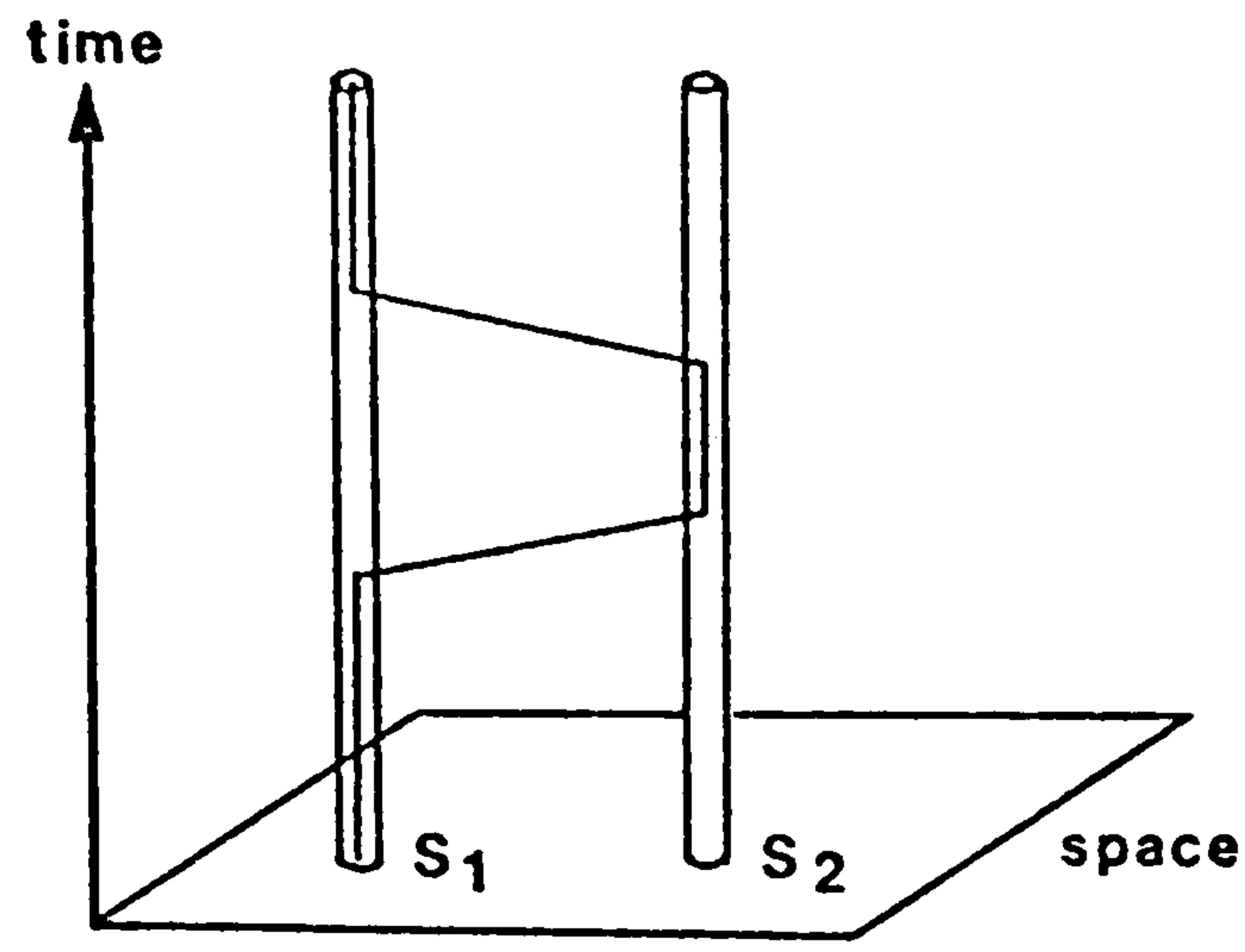
The daily path of each member of five households. Seven categories are recognised: a) place of work b) place of services other than commercial c) commercial services d) home e) recreational space f) other houses g) schools. Members of each household are considered by age with the oldest one to the left.

1. Man 43, car; wife 38; boy 10; boy 8
2. Man 36, car; wife 36; boy 12; girl 10; boy 3.
3. Man 44, car; wife 38, car; boy 11; boy 7.
4. Man 37, car; wife 34, car; boy 9; girl 7; boy 5.
5. Man 81; wife 76.

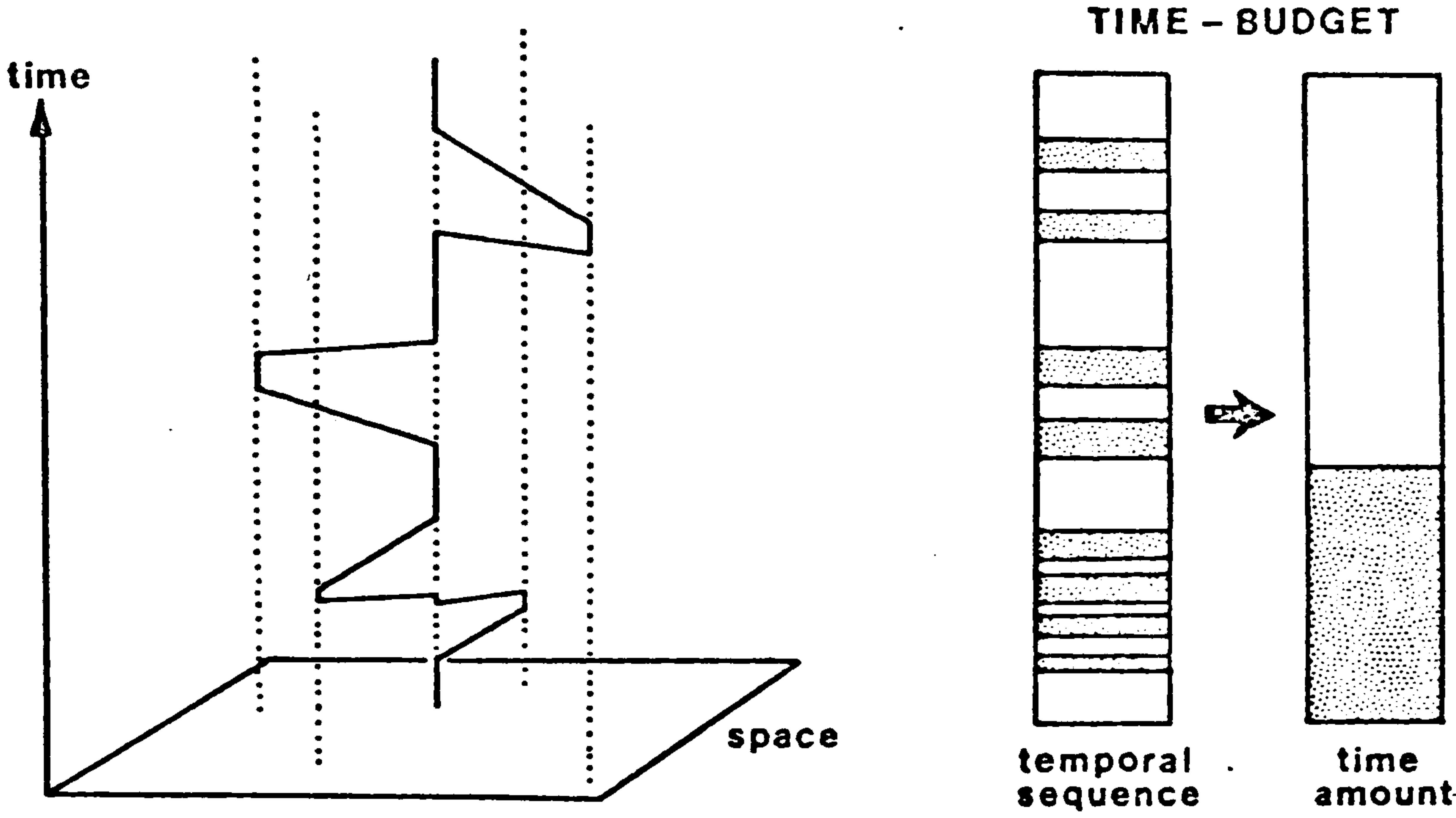
Category space as an analytical adjunct - after Martensen.

Source : Thrift, 1977.

FIG. 3.2



One individual (line) moving from one station (tube) to another and back again. The slope of the individual's path in relation to plane indicates the time it takes to travel.

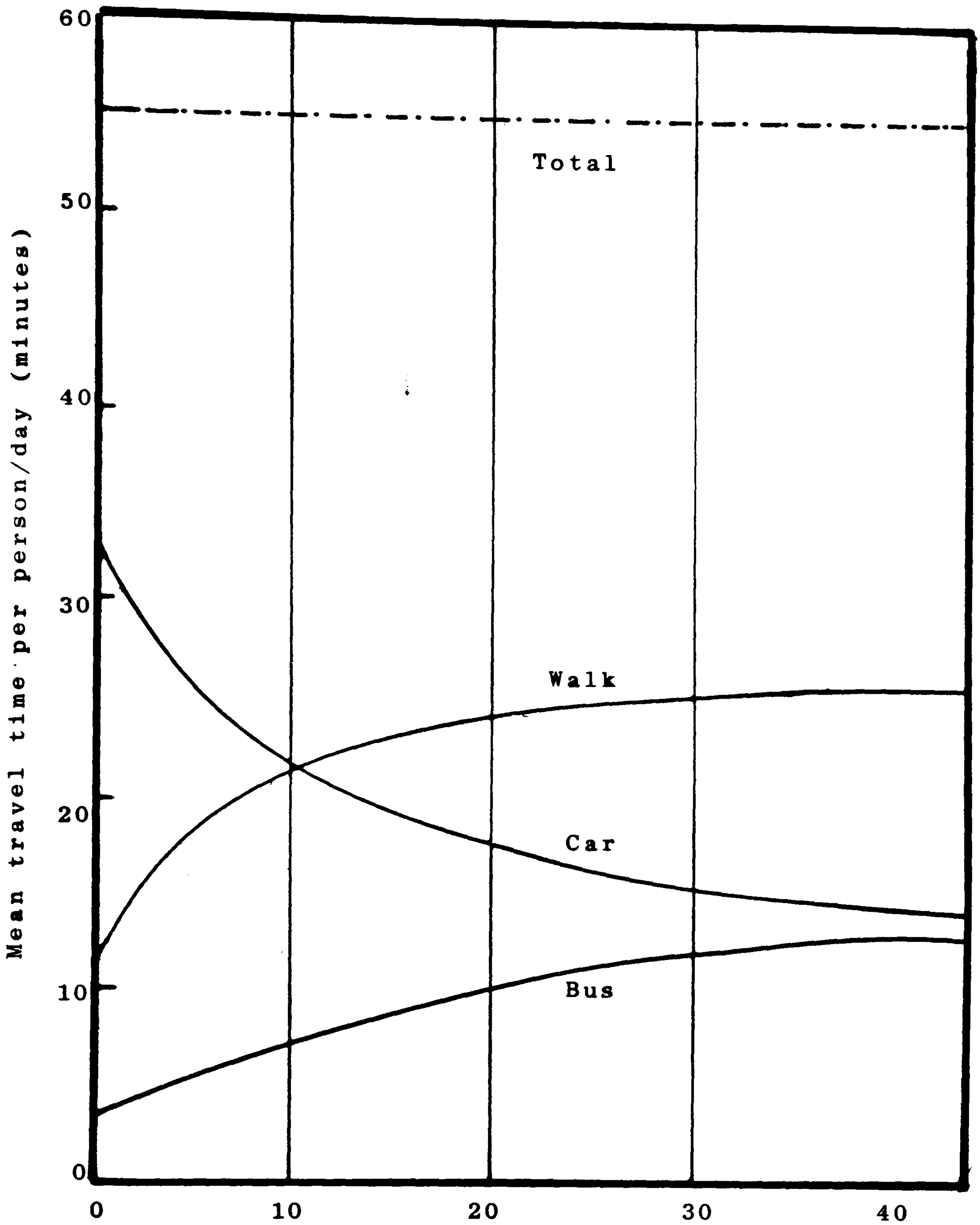


The relation between a) an individual's path moving among four stations, left, and b) time spent on stationary versus mobile activities in a 24 hour period, right. The figure thus shows the relation between time-space path and "time-budget".

Path and Budget because of Station
- After Carlstein

Source : Thrift, 1977

FIG. 3.3



Residential density (person/acre)

Travel time and residential density

Source : TRRL 771

FIG. 3.4

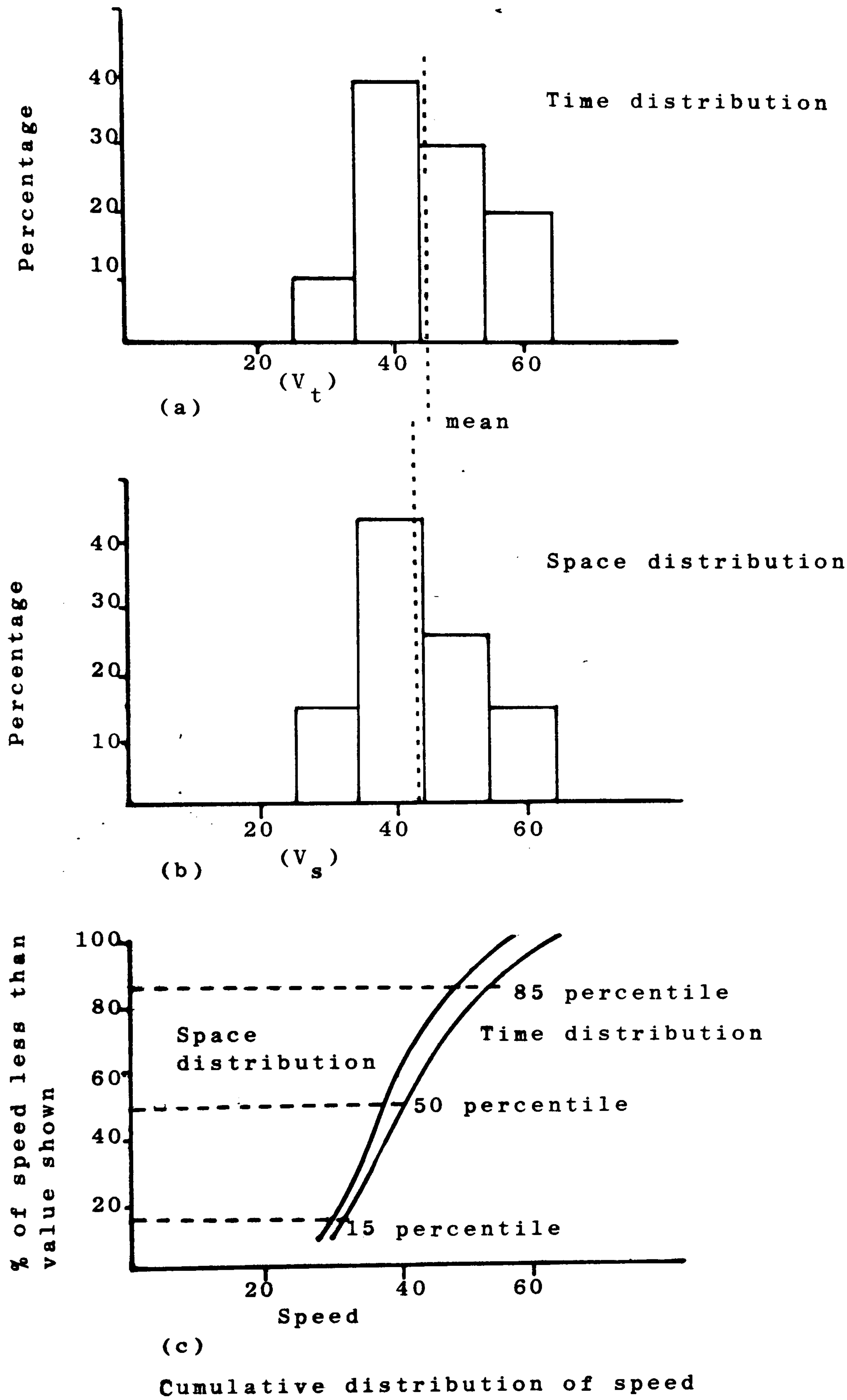
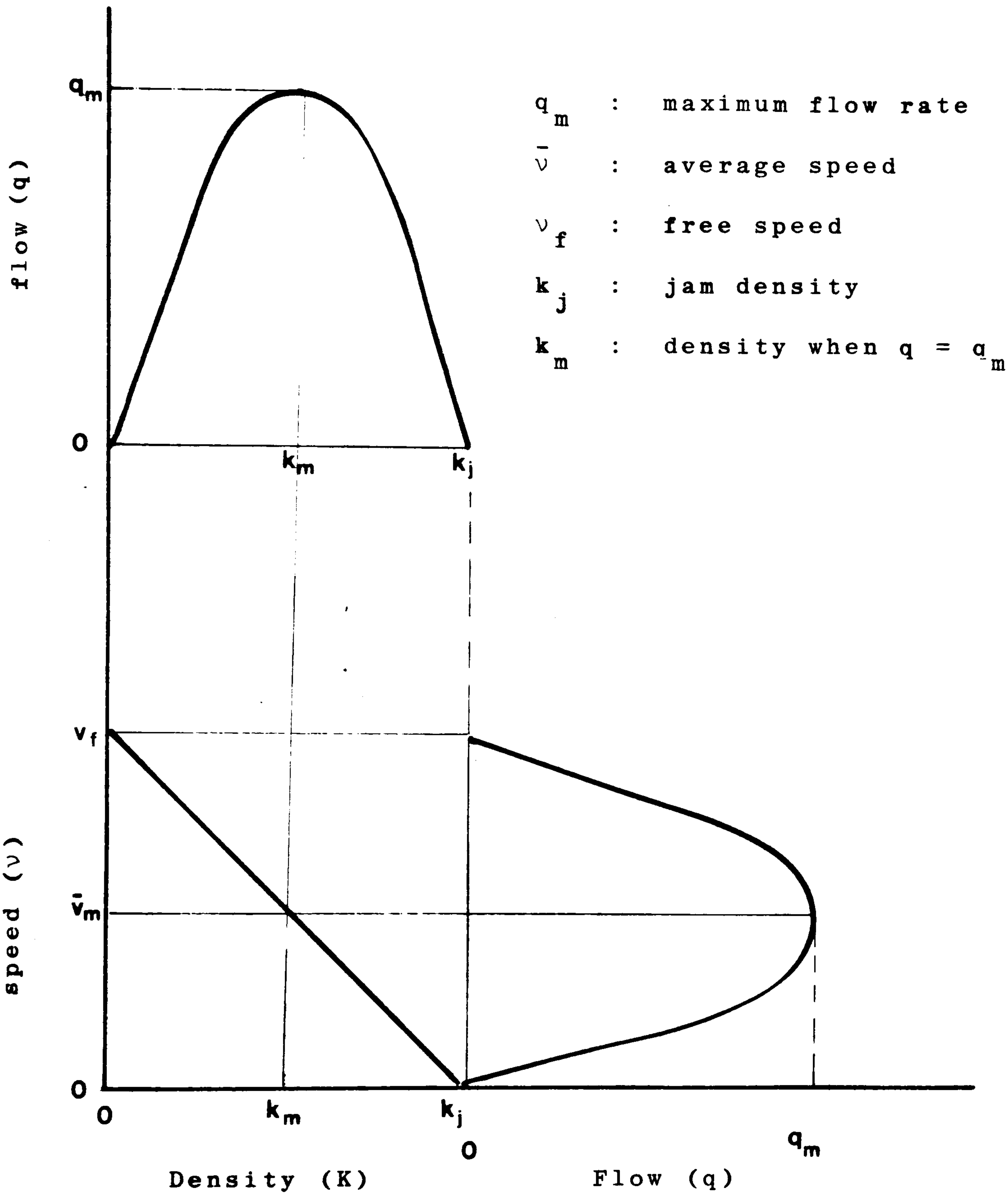

Percentage
40
30
20
10
20
40
60
(V_t)
(a)
Time distribution
mean
Percentage
40
30
20
10
20
40
60
(V_s)
(b)
Space distribution
% of speed less than value shown
100
80
60
40
20
85 percentile
Space distribution
Time distribution
50 percentile
15 percentile
20
40
60
Speed
(c)
Cumulative distribution of speed

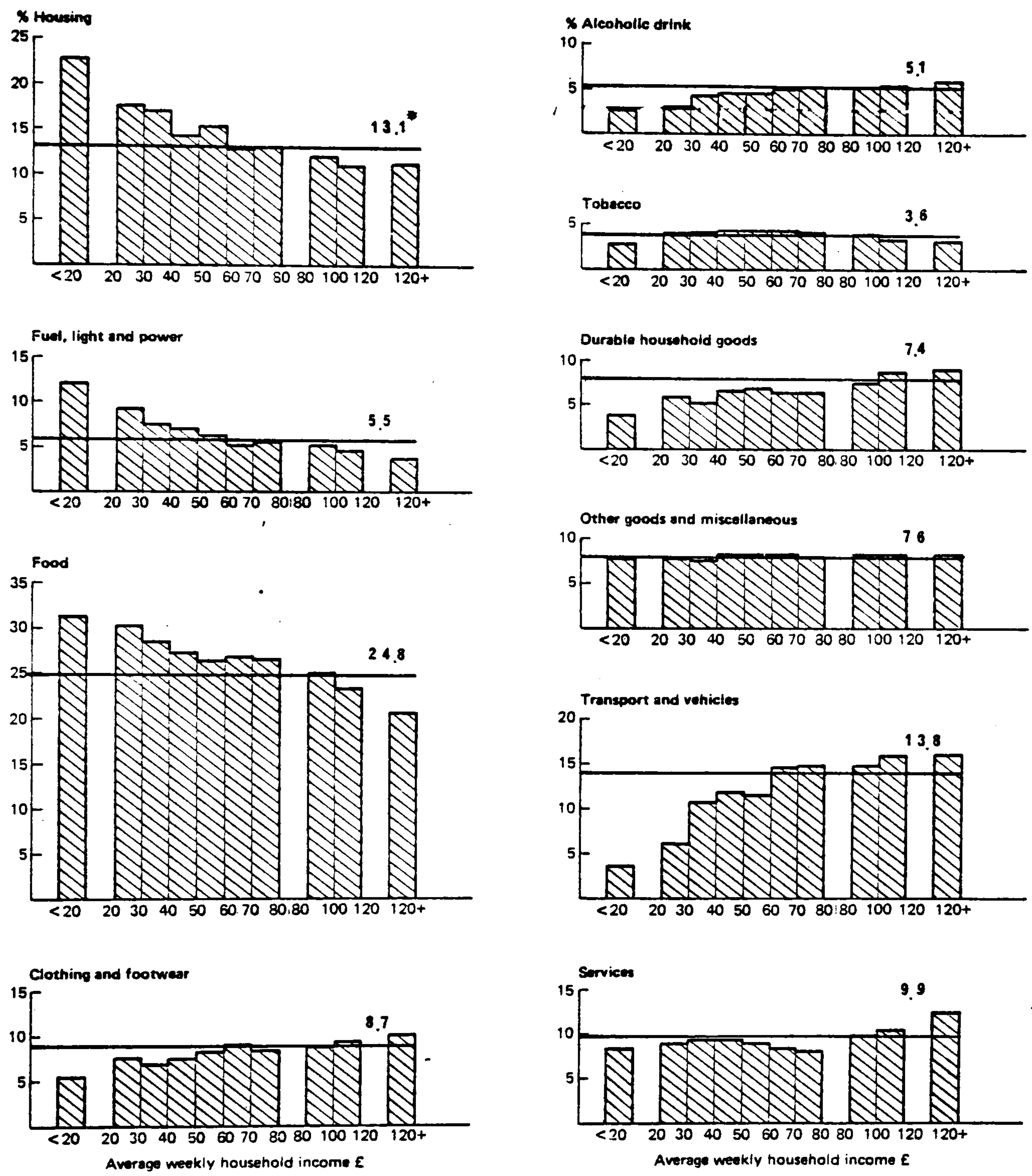
FIG. 4.1



Theoretical speed, flow and density relationship

FIG. 4.2

Variation of expenditure pattern with income of household 1975



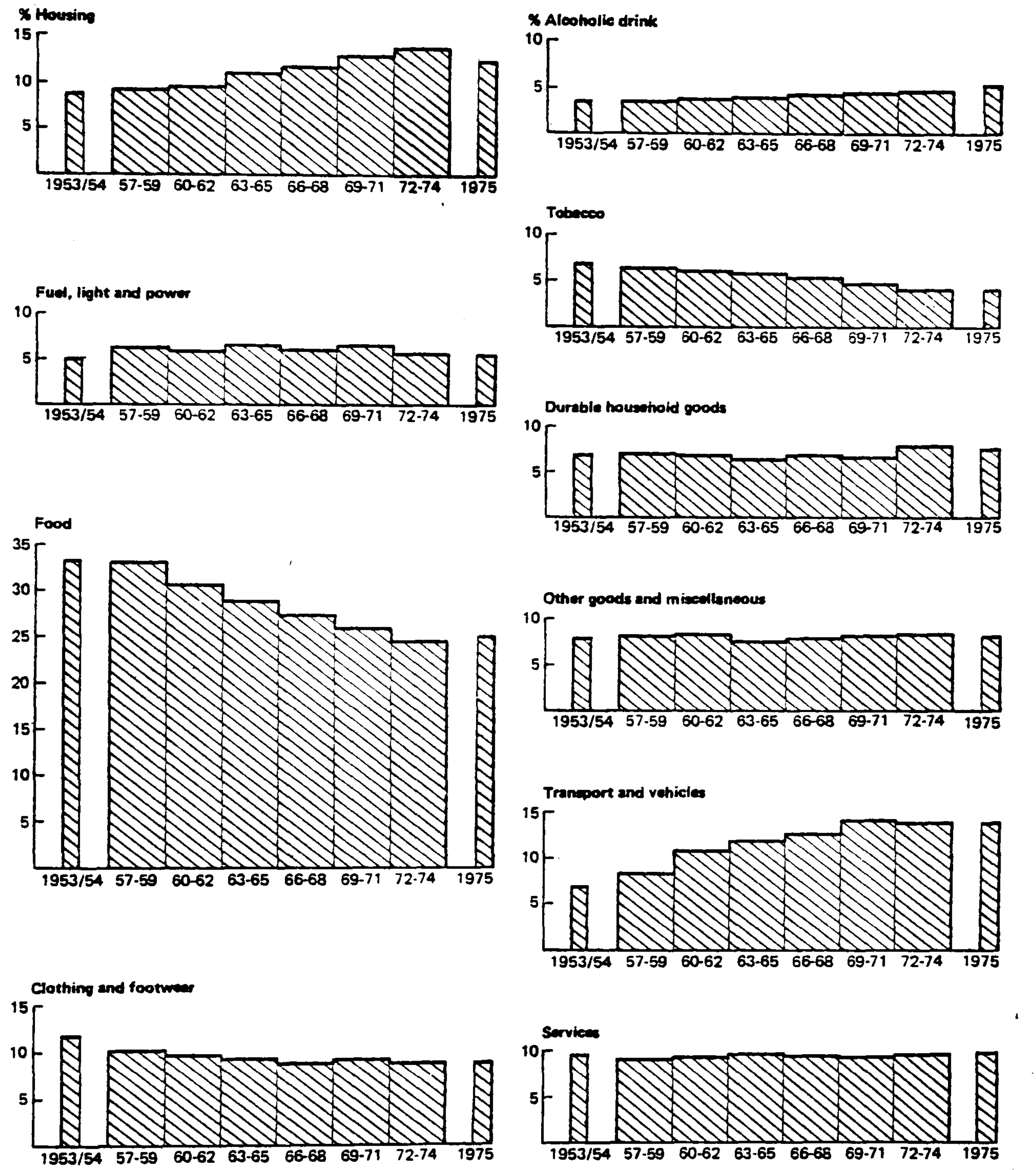
NOTE: *Percentages are expenditure on commodity or service group as a percentage of total household expenditure.*

* Average for all households.

Source : FES ; 1975

FIG. 5.1

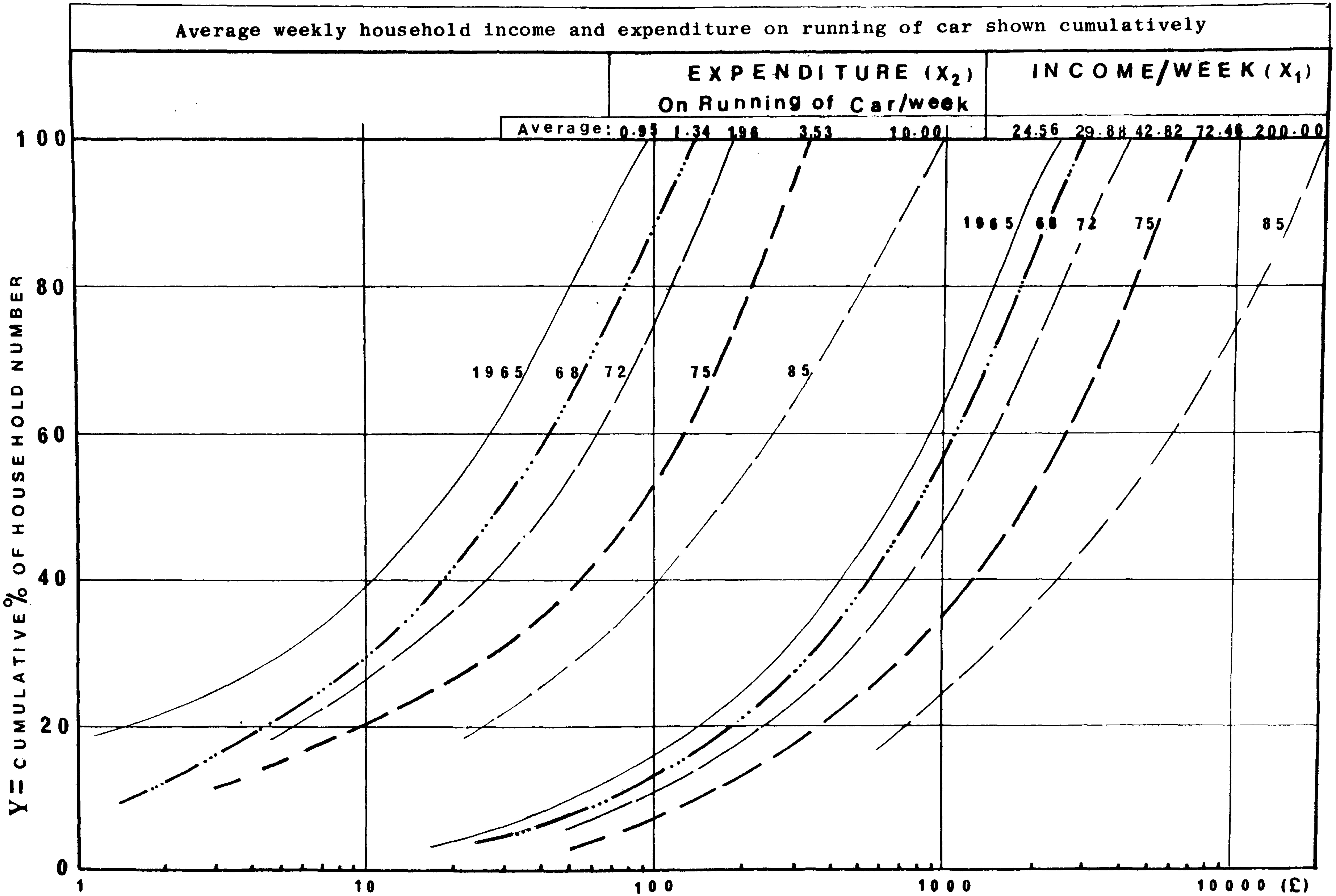
Variation of expenditure pattern over time **1953/54 and 1957-75**



NOTE: *Percentages are expenditure on commodity or service group as a percentage of total household expenditure.*

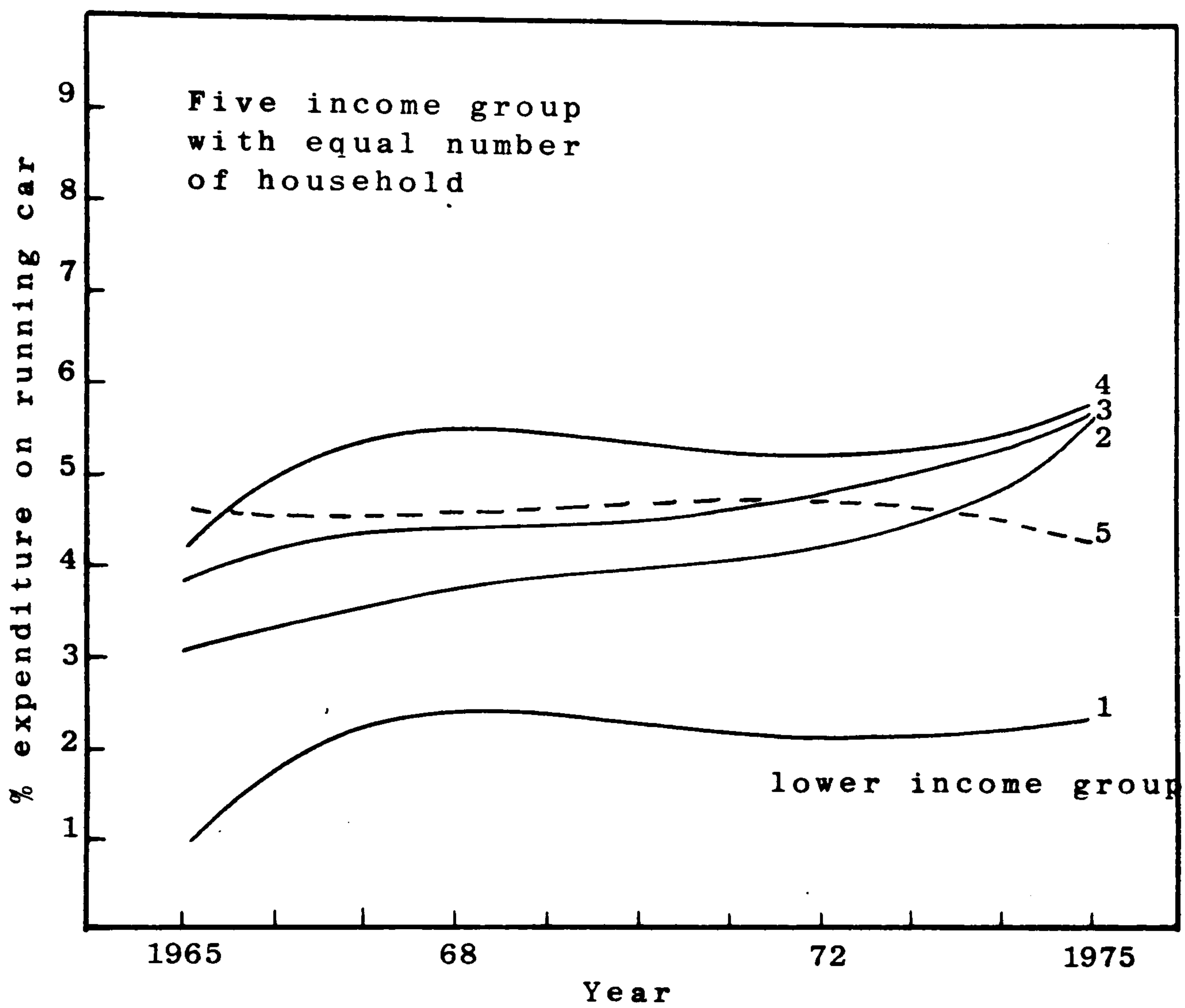
Sources: 1953/54 Report of an Enquiry into Household Expenditure
1957-75 Family Expenditure Survey reports

FIG. 5.2



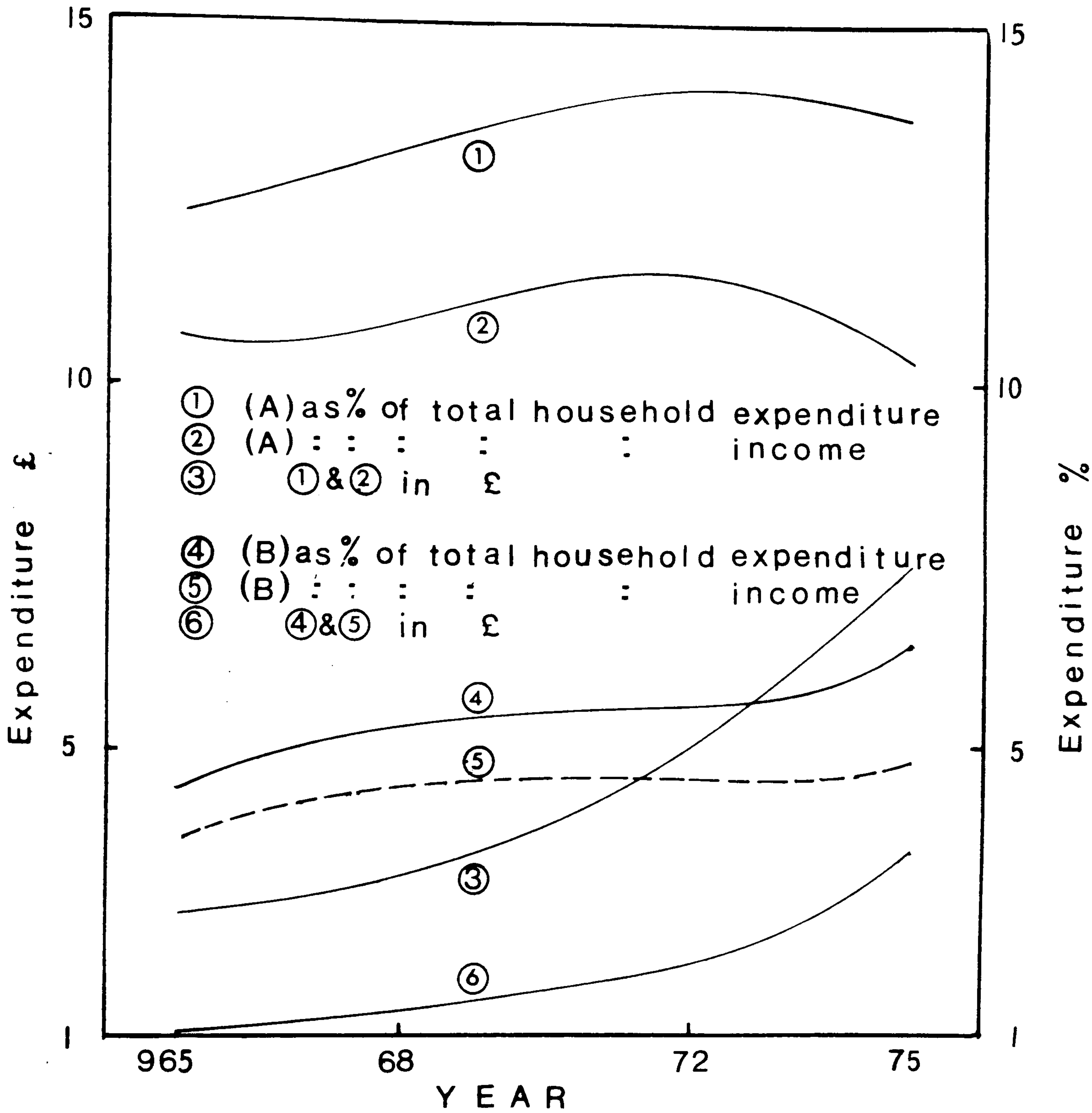
See Table 5.1 for value of Y, X_1 and X_2.

FIG. 5.3



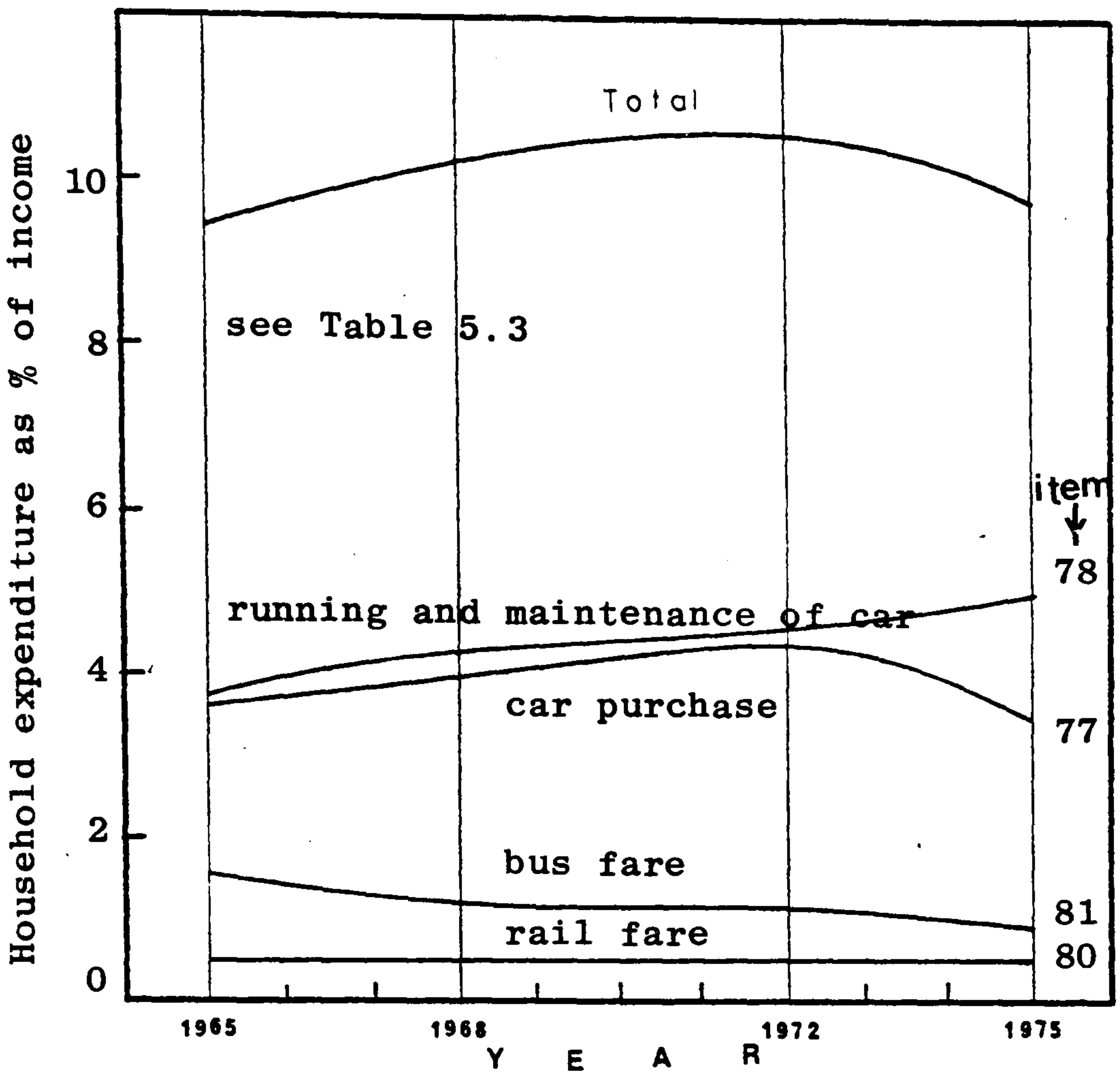
Expenditure on maintenance and running of motor vehicle as % of average household income.

FIG. 5.4a



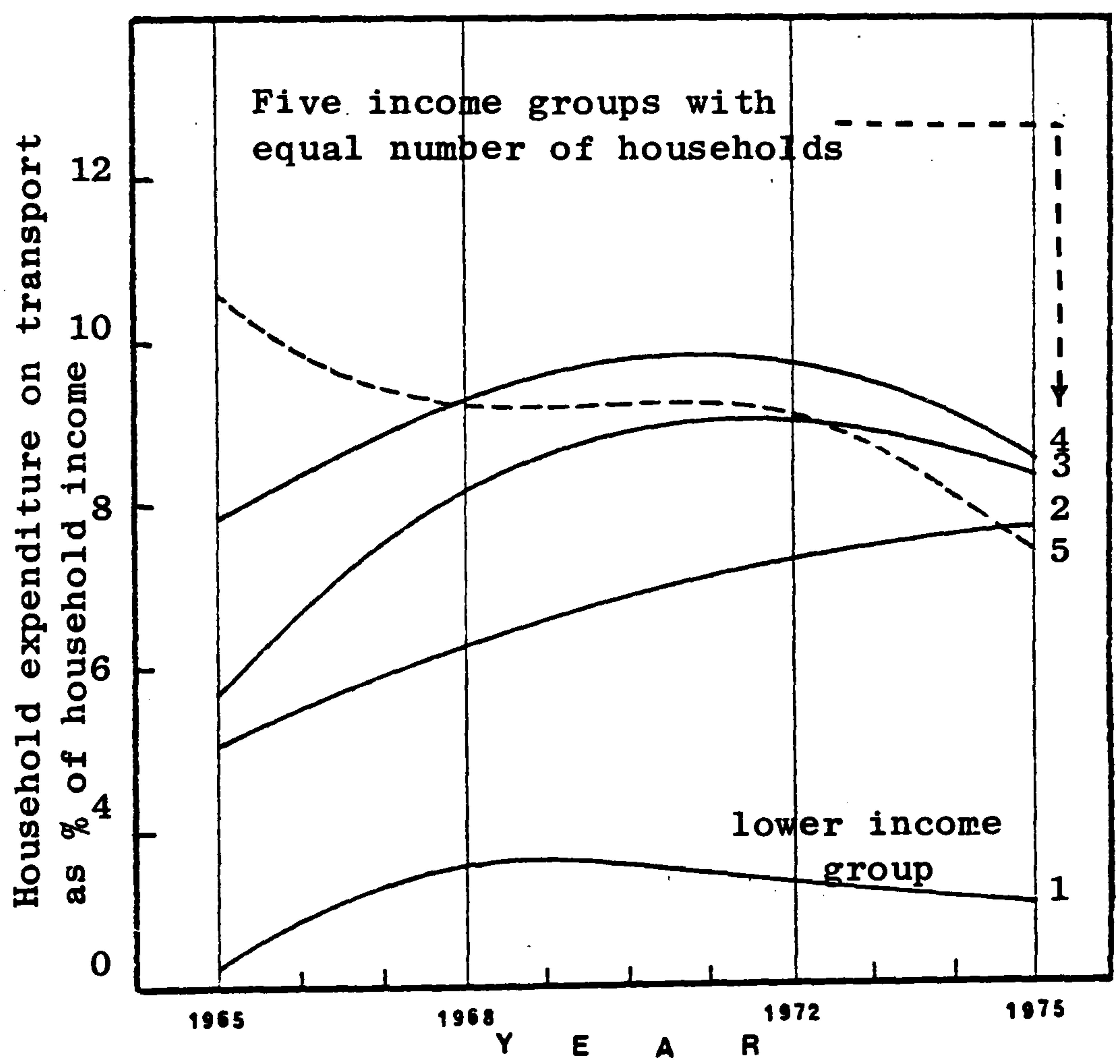
TOTAL HOUSEHOLD EXPENDITURE ON TRANSPORT (A)
&ON MAINTENANCE & RUNNING MOTOR VEHICLE (B)

FIG.5-4b



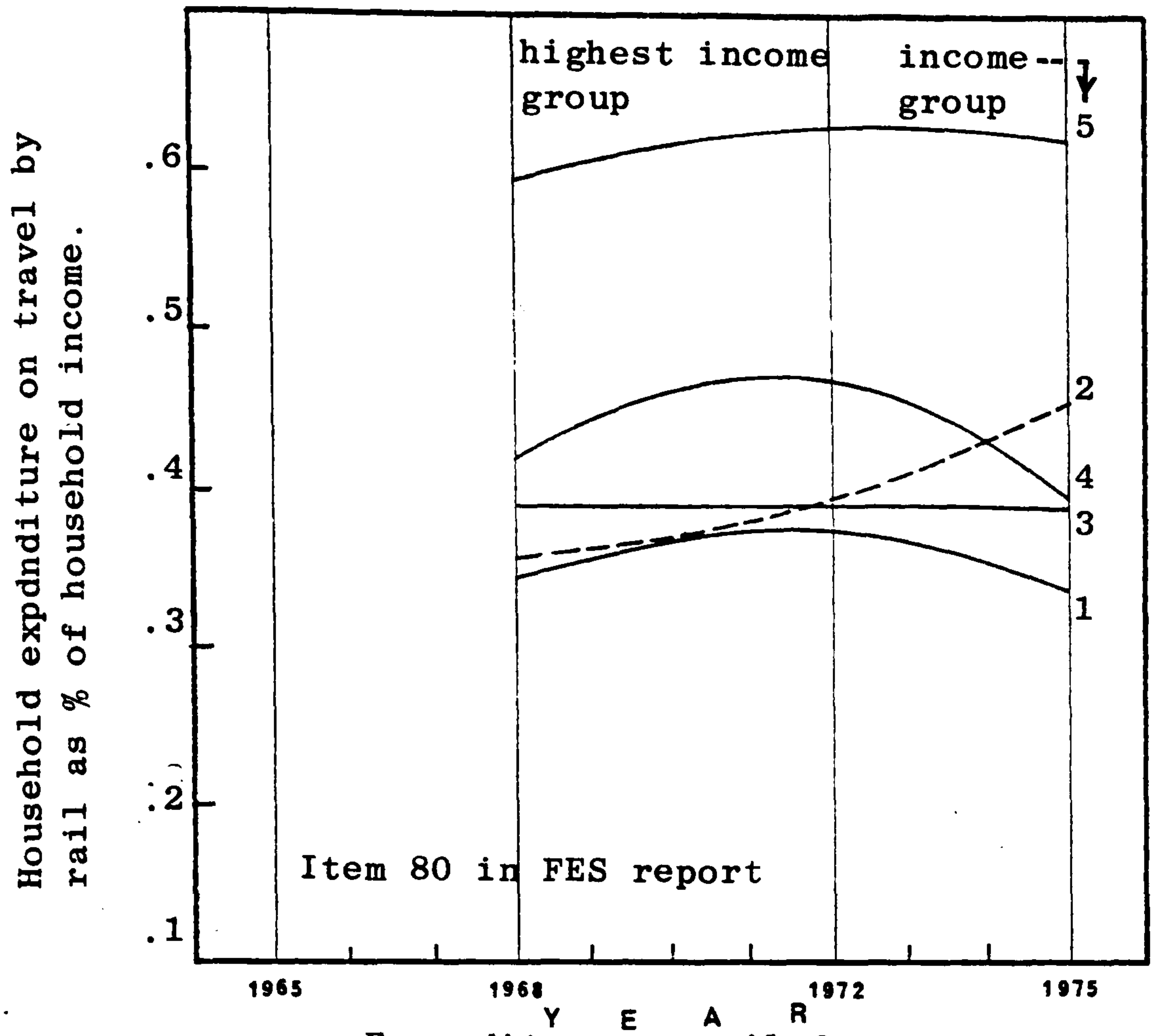
Average household expenditure on
four main items of transport.

FIG. 5.5

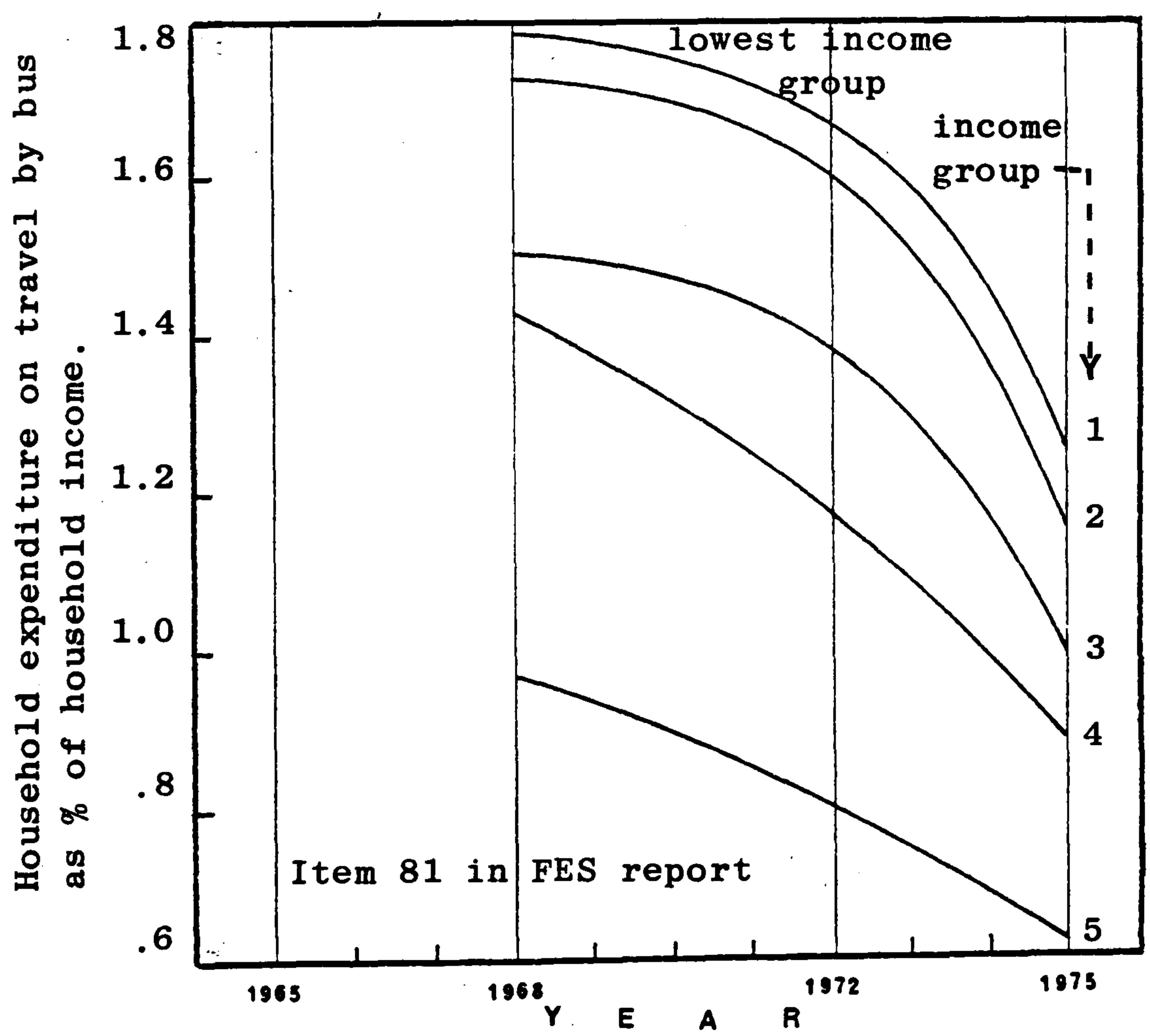


Trend of income groups in expenditure
on four items on transport.

FIG. 5.6

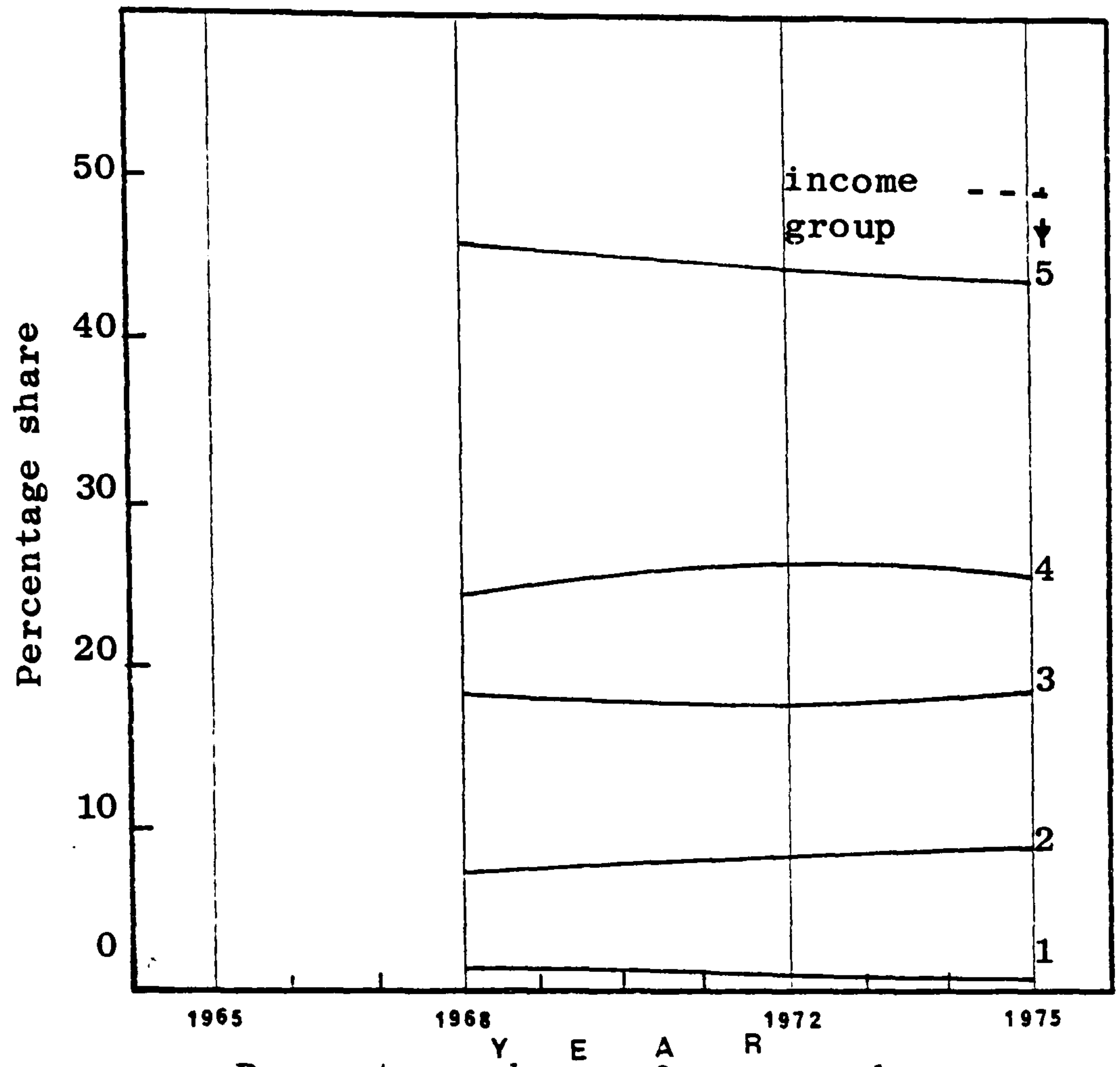


Expenditure on rail fares
by household income group
FIG. 5.7



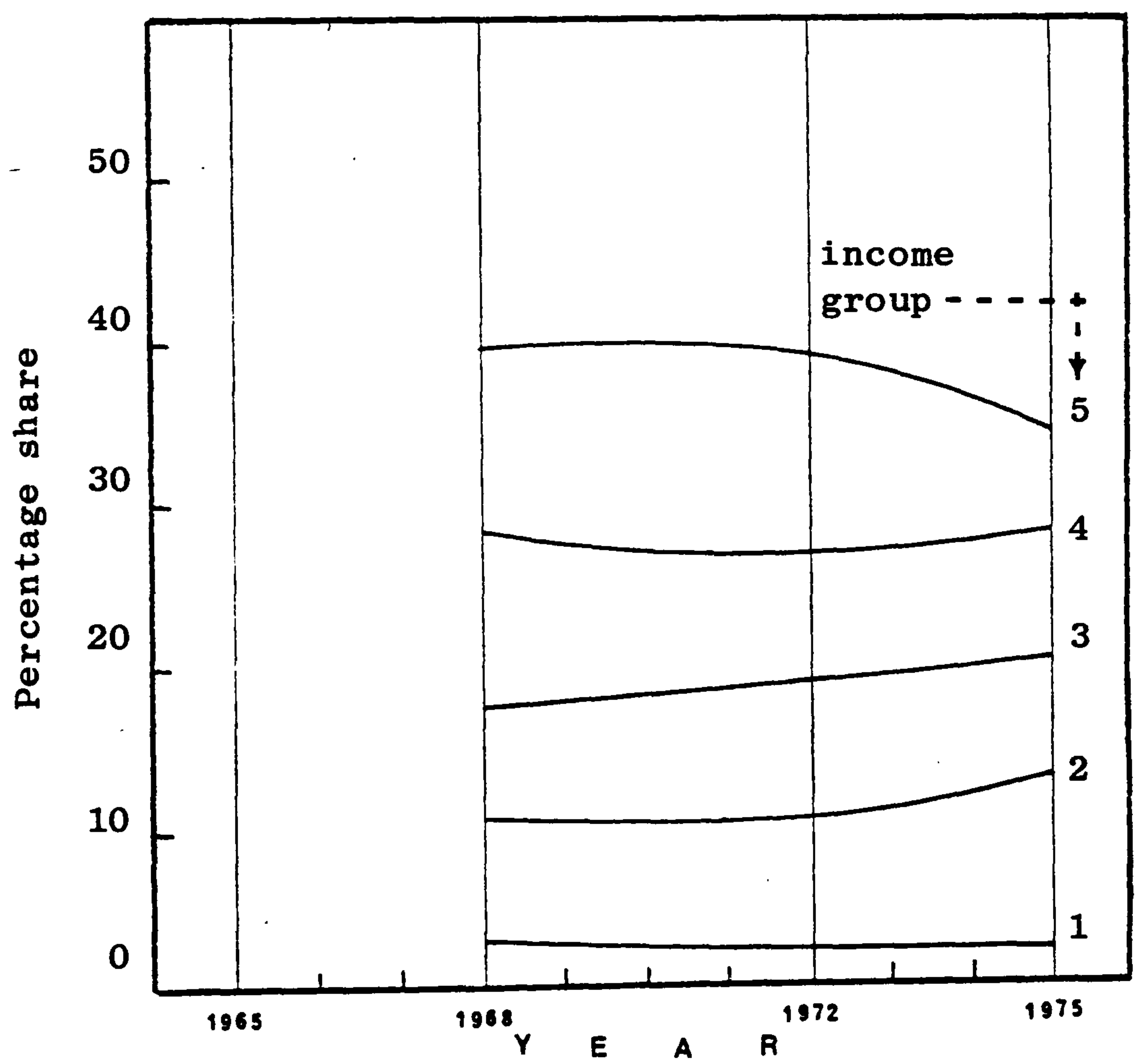
Expenditure on bus fares
by household income group

FIG. 5.8



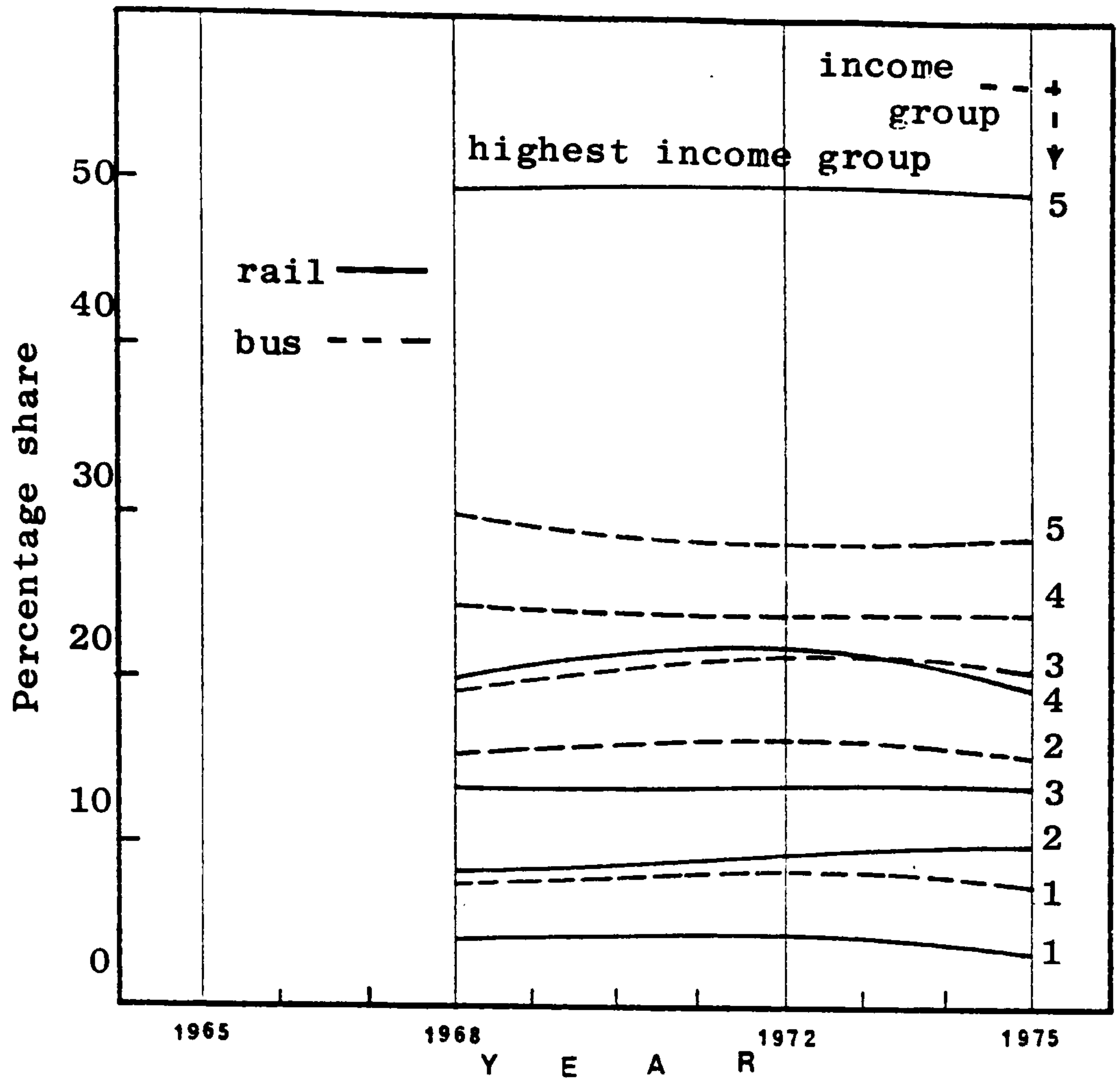
Percentage share of car purchase by household income group.

FIG. 5.9a



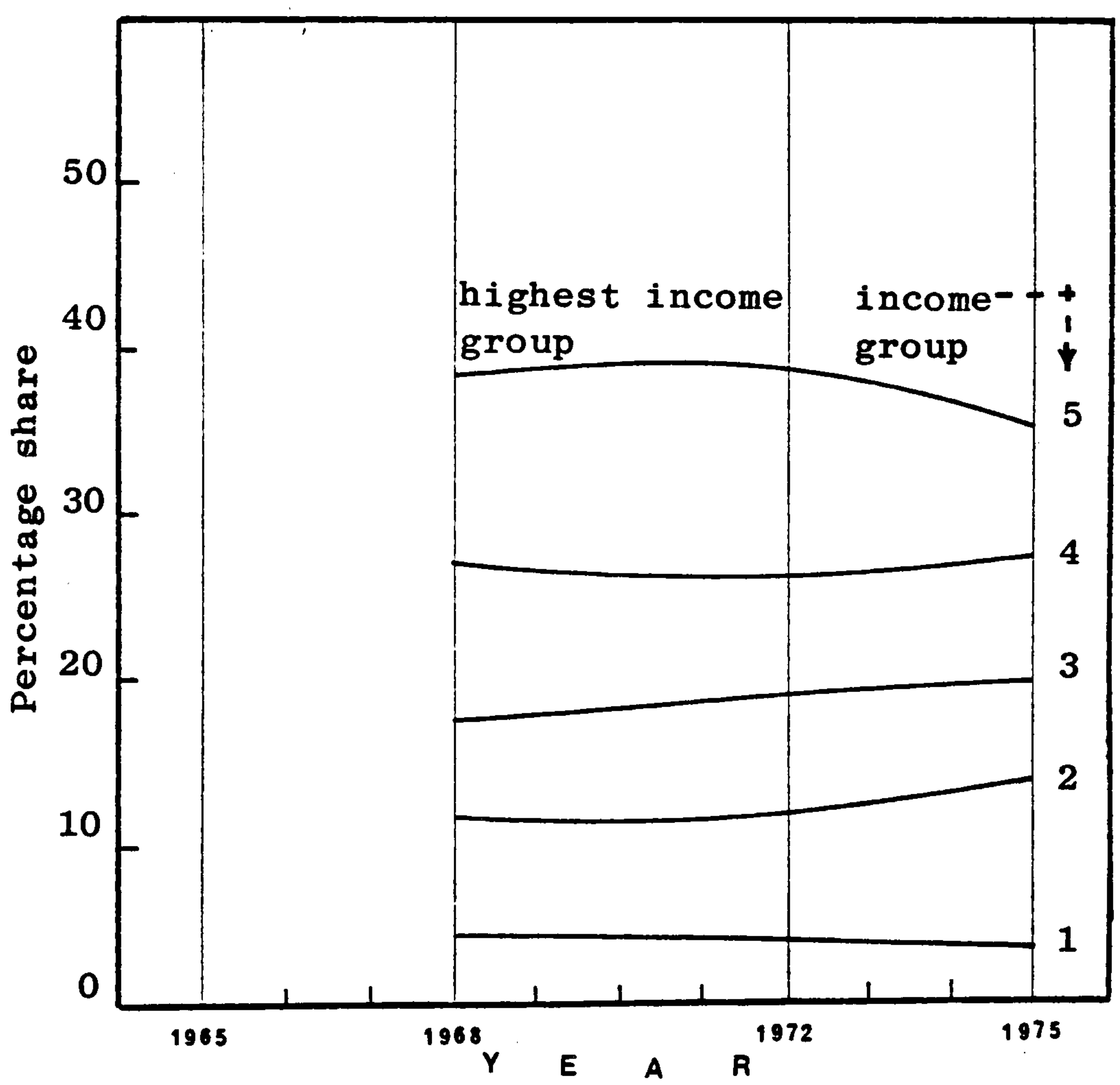
Percentage share of travel by car by household income group.

FIG. 5.9b



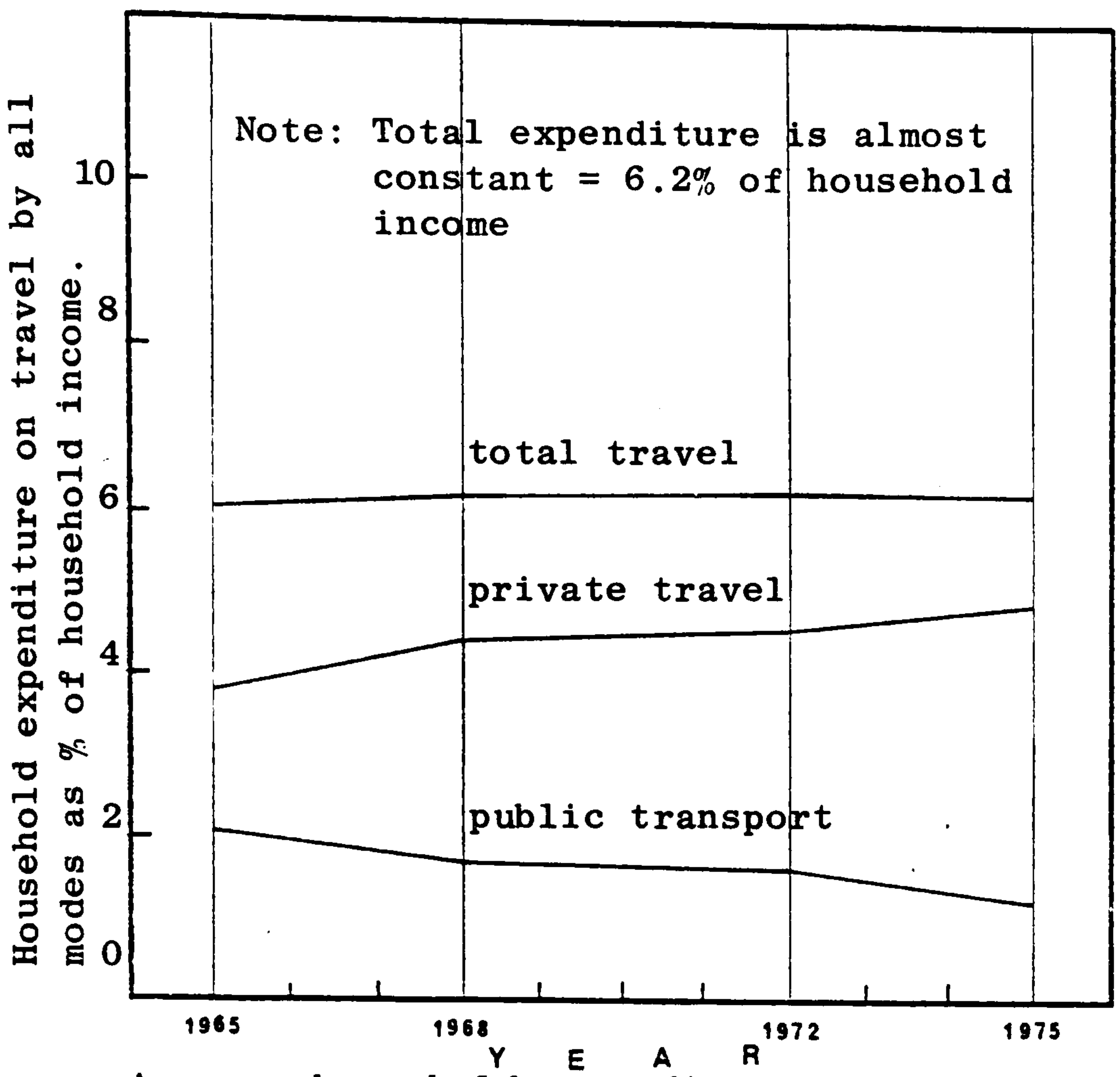
Percentage share on travel by public tramsport by household income group.

FIG. 5.9c



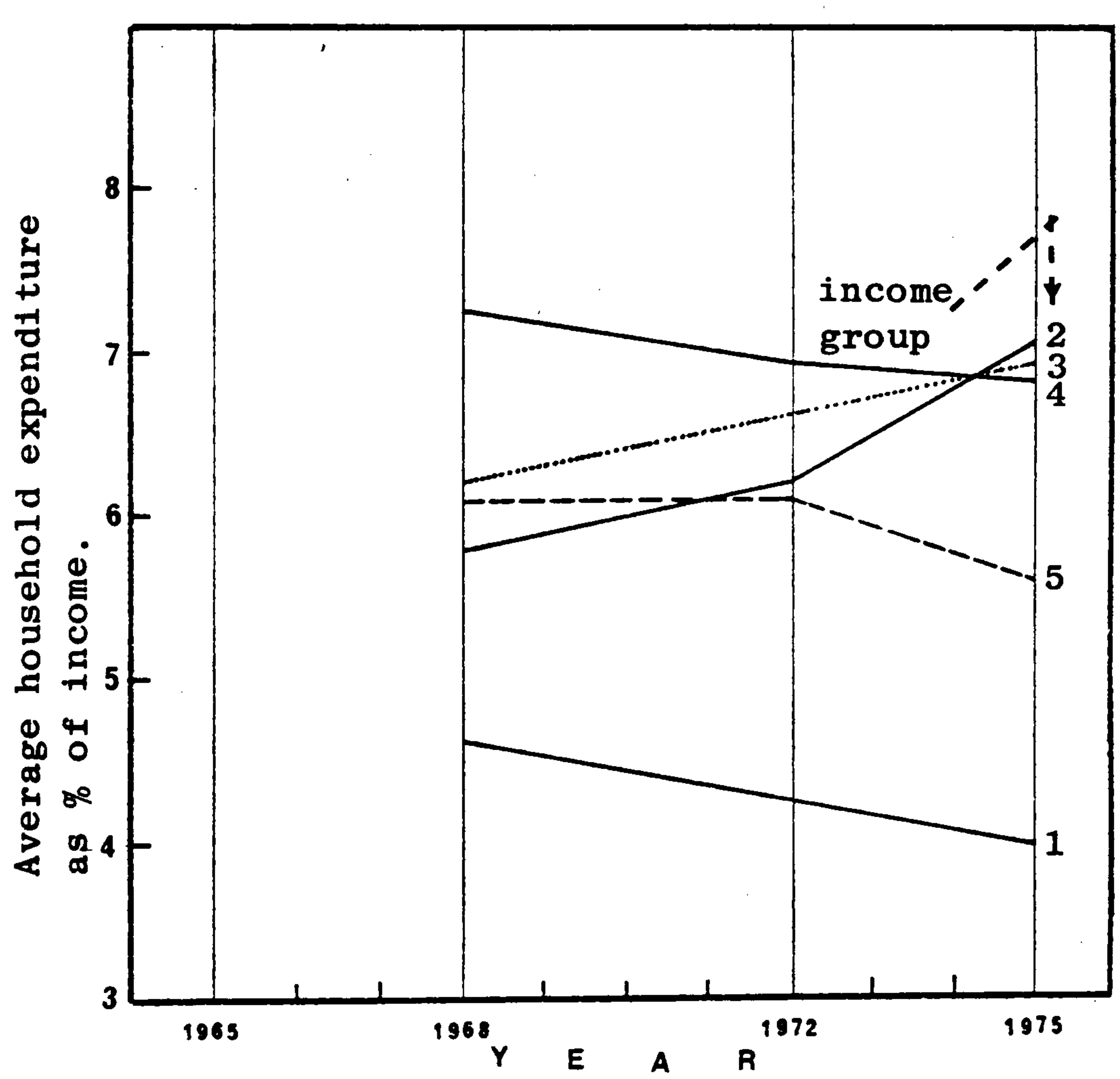
Percentage share on all travel (private and public transport)by household income group.

FIG. 5.9d



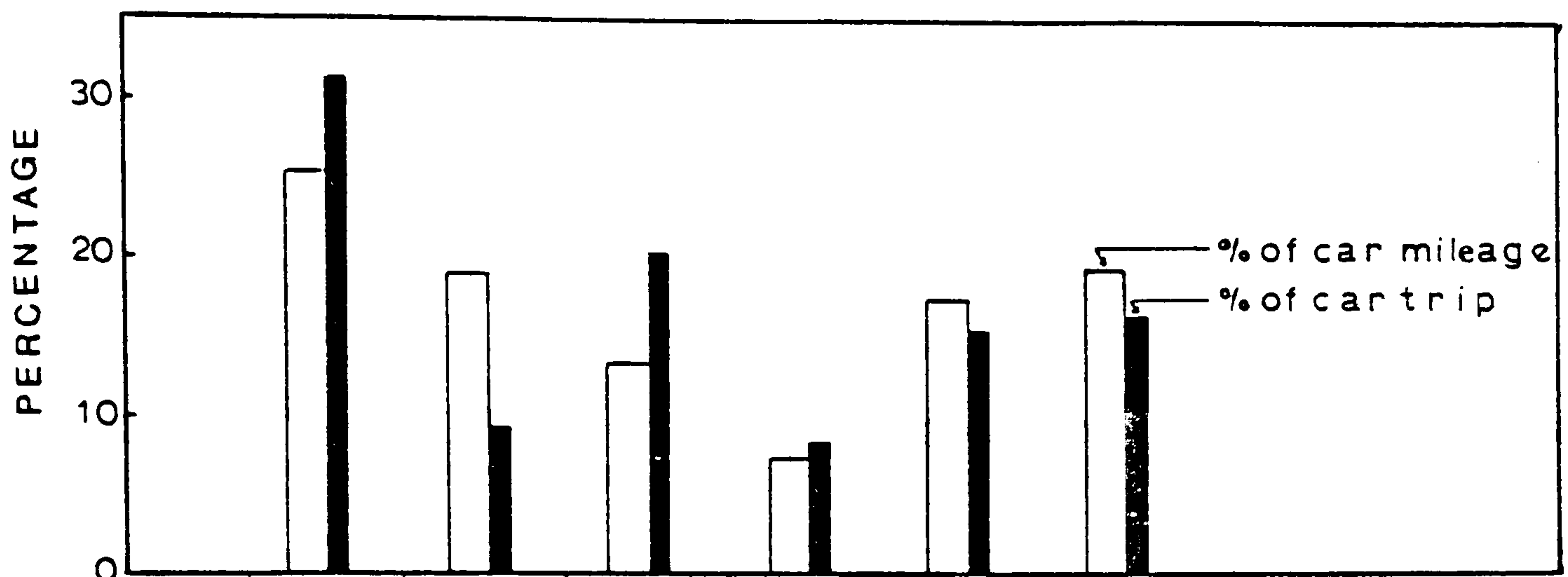
Average household expenditure on travel by private(car) and public (rail and bus).

FIG. 5.10



Average household expenditure on travel by car,and public transport (bus and rail) by household income group.

FIG. 5.11



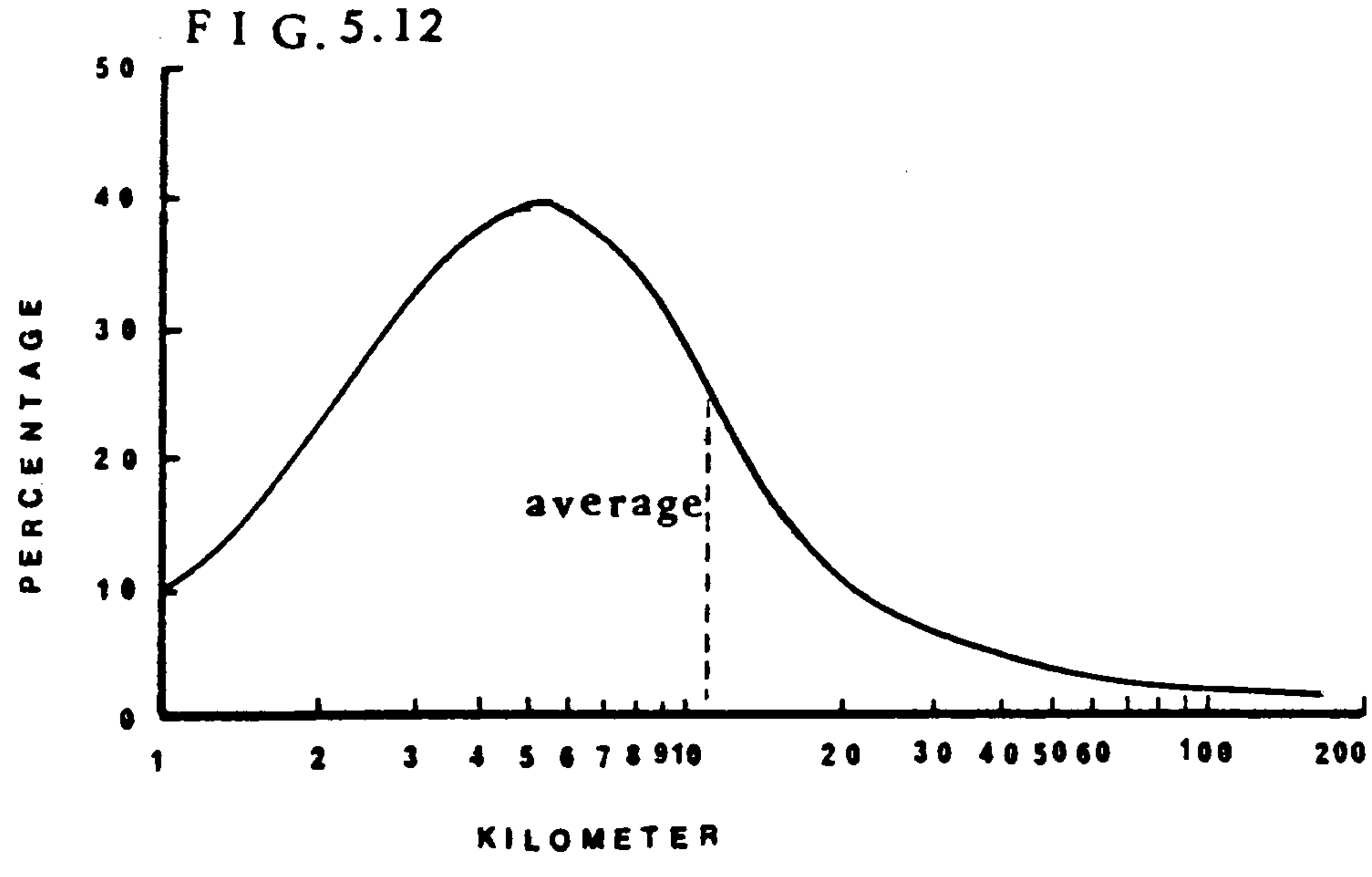
	To & from work	In course of work	Shopping	Entertain_ment, sport	Personal social	Holidays, pleasure
Average Car Occupancy 1.75	1.30	1.12	1.88	2.21	2.31	2.33
Average Trip Distance km. 12.0	9.7	25-3	7.8	10.5	13.3	14.3

Car journey characteristics

(All households)

sourse NTS 1972/73

FIG.5.12



CAR TRIP LENGTH DISTRIBUTION

Source: NTS 1972/73

FIG.5.13

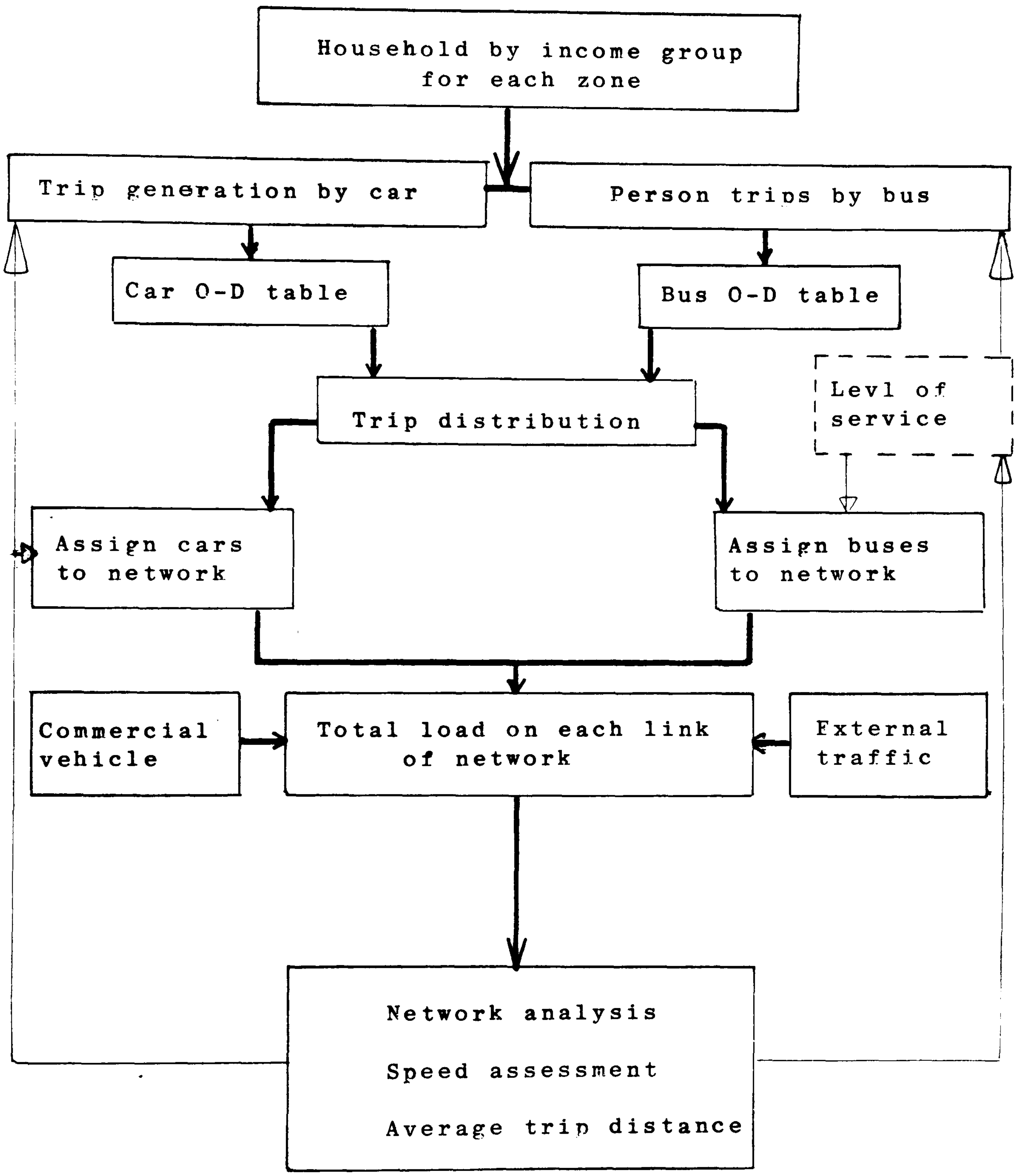
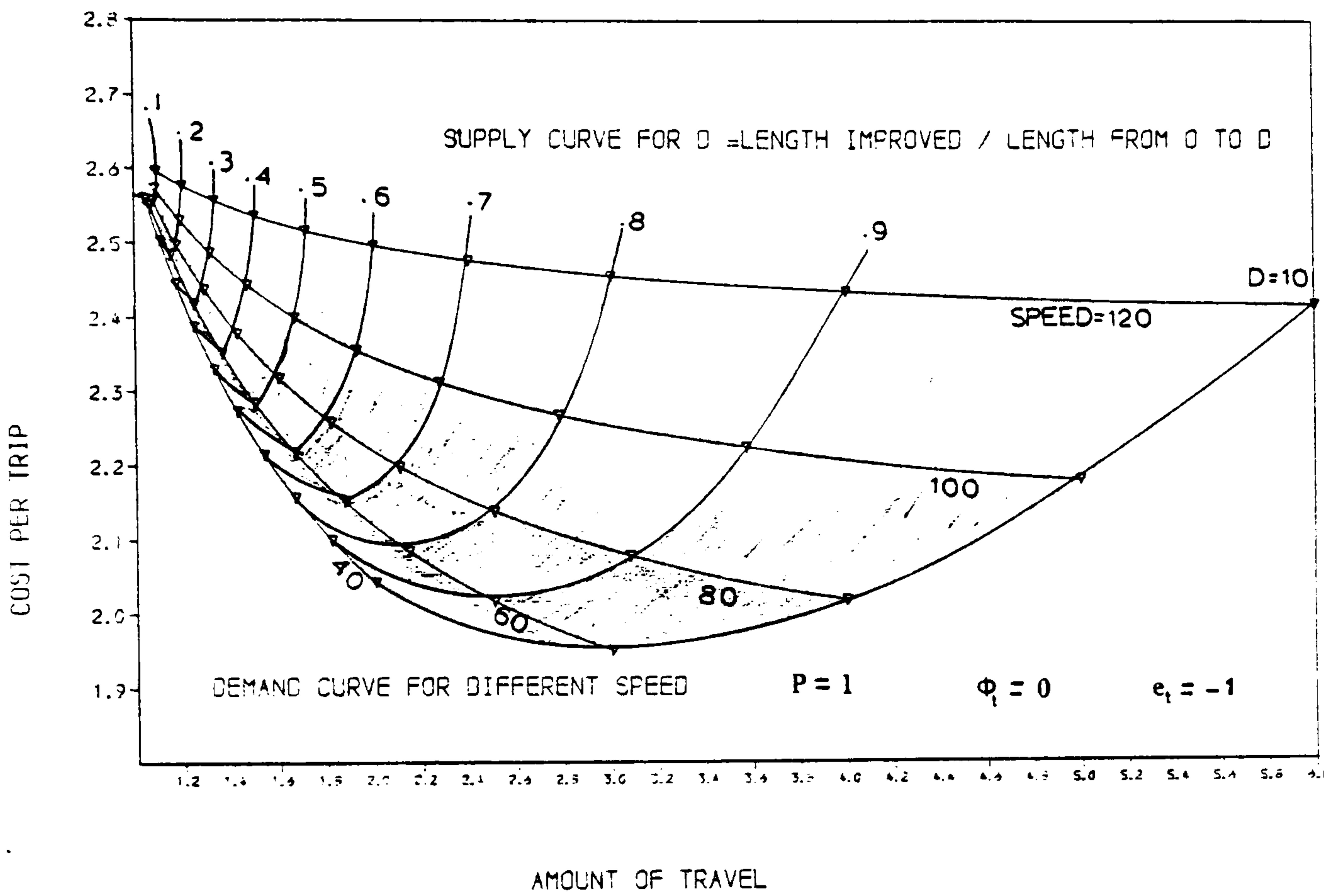
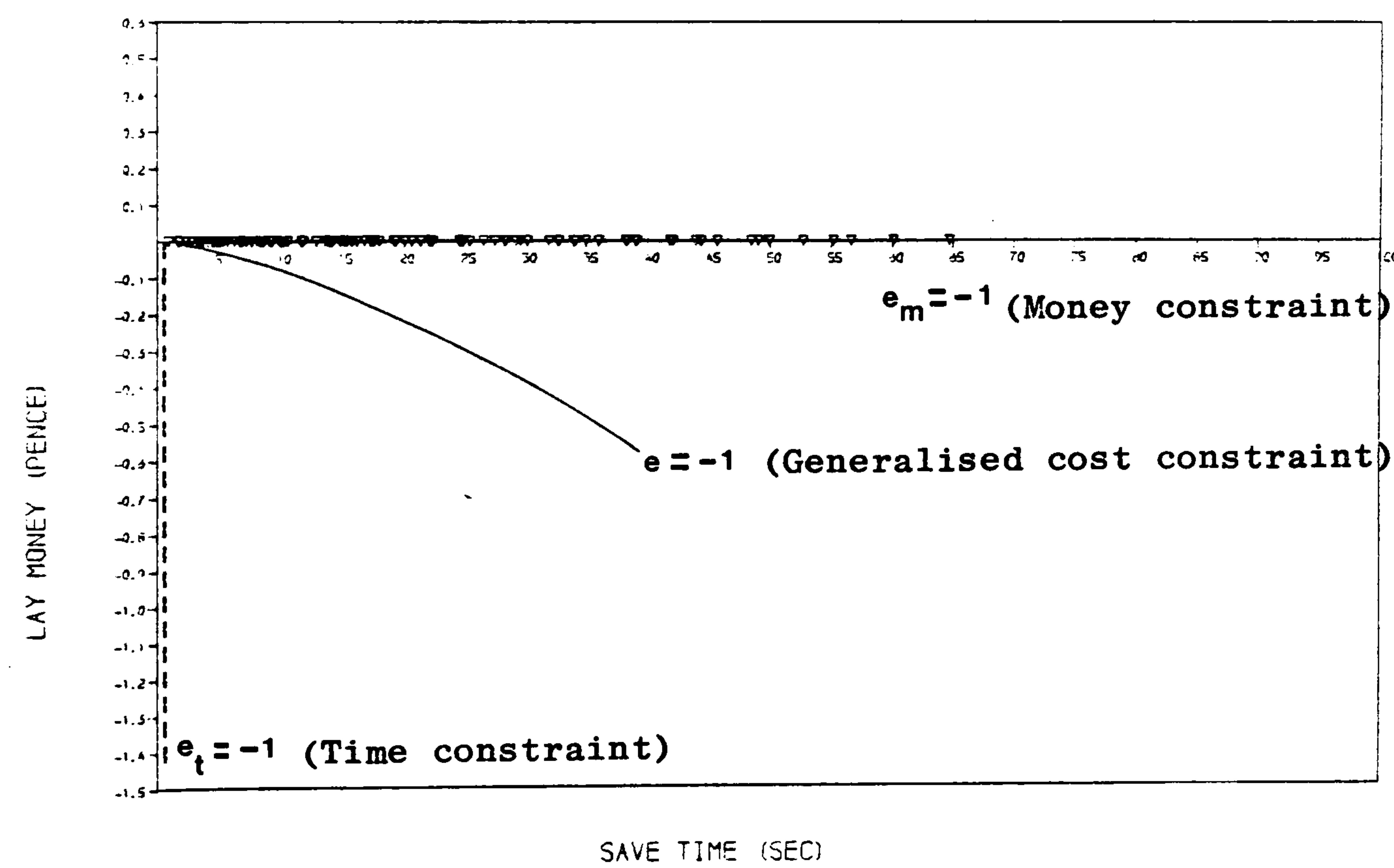


FIG. 6.1 MODIFIED TRANSPORT MODEL



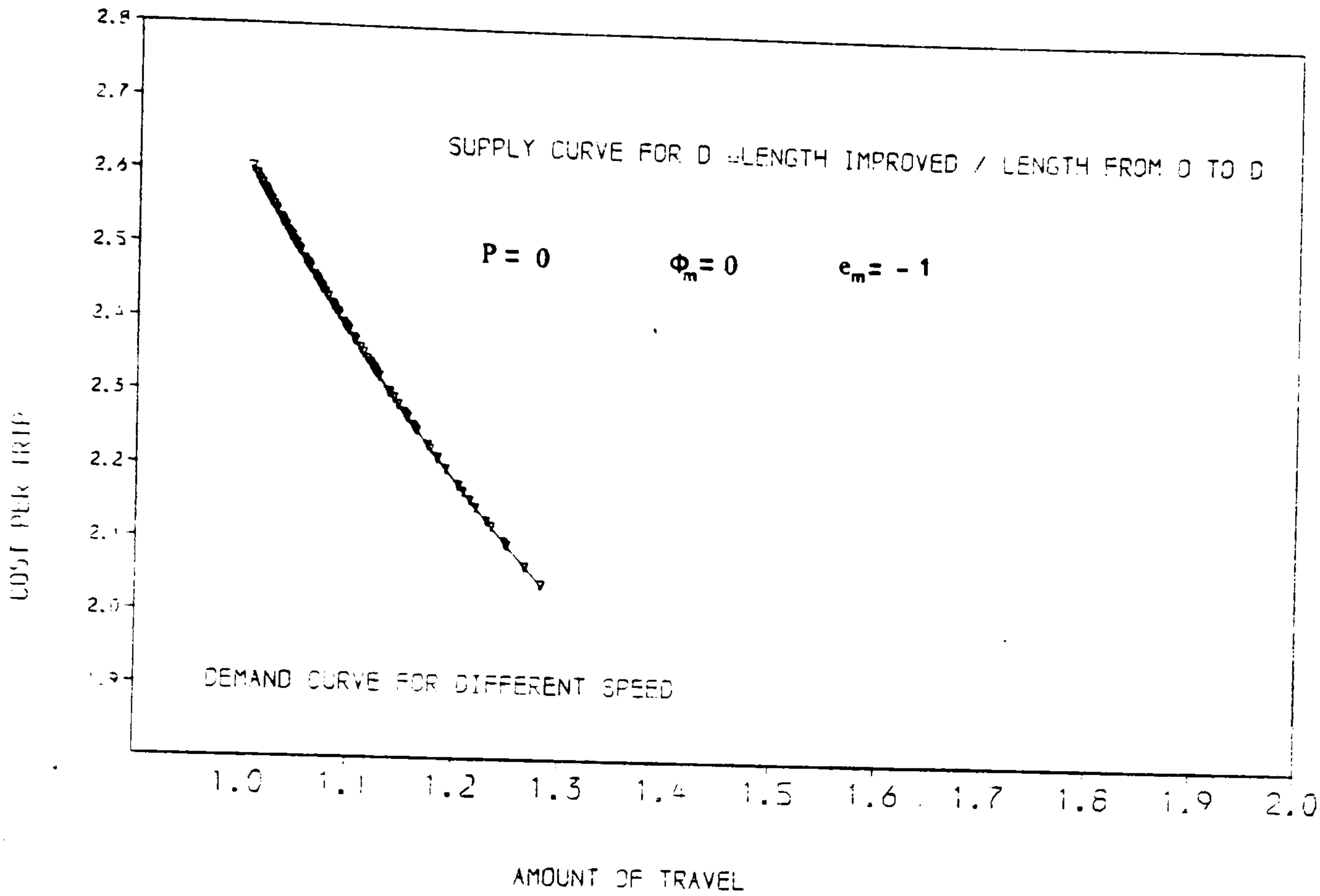
DEMAND AND SUPPLY CURVE
(Time constraint)

FIG. 7.1



TIME SAVED AND EXTRA MONEY SPENT
FOR DIFFERENT LEVELS OF IMROVEMENT

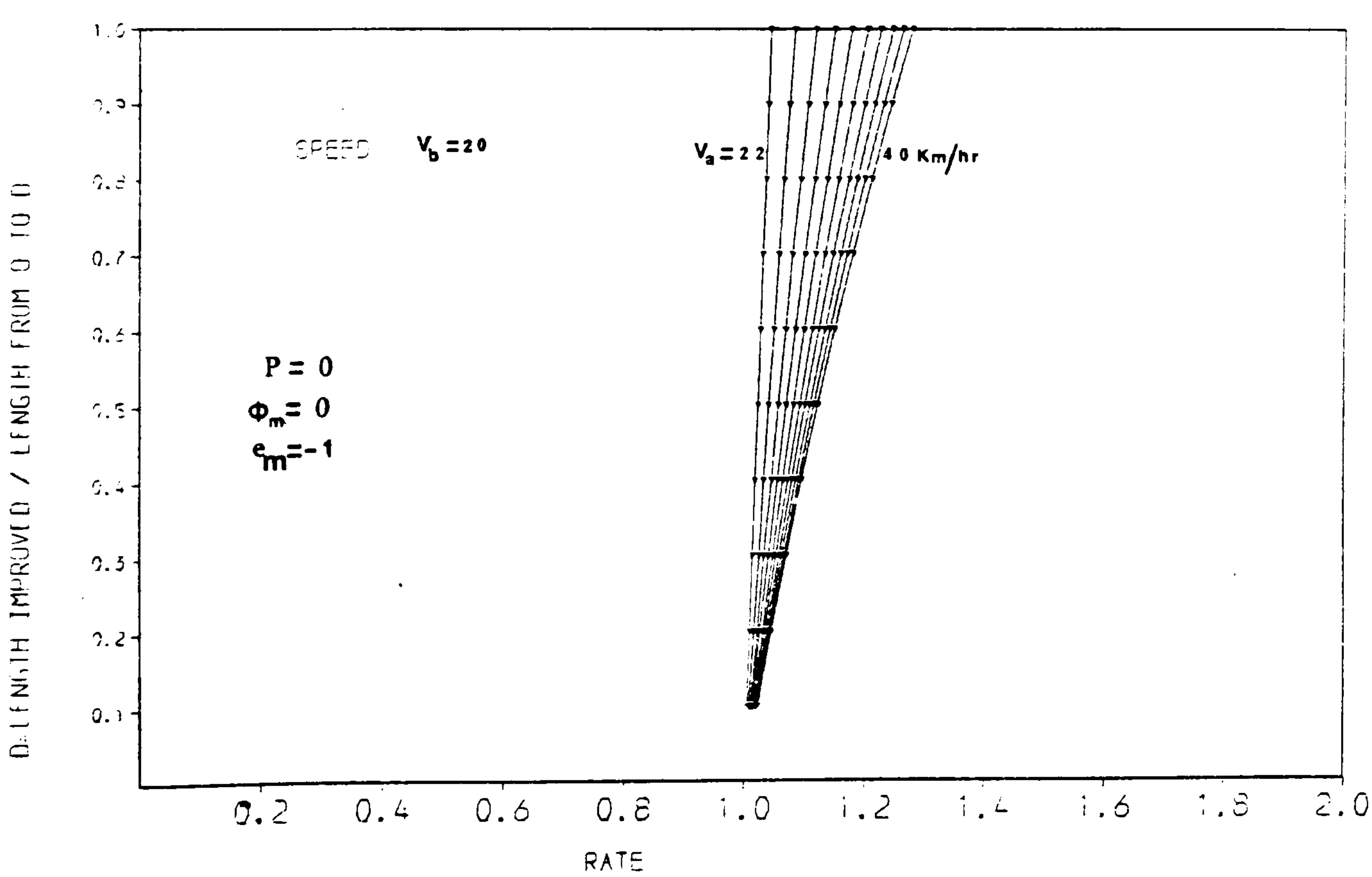
FIG. 7.2



DEMAND AND SUPPLY CURVE

(Money constraint)

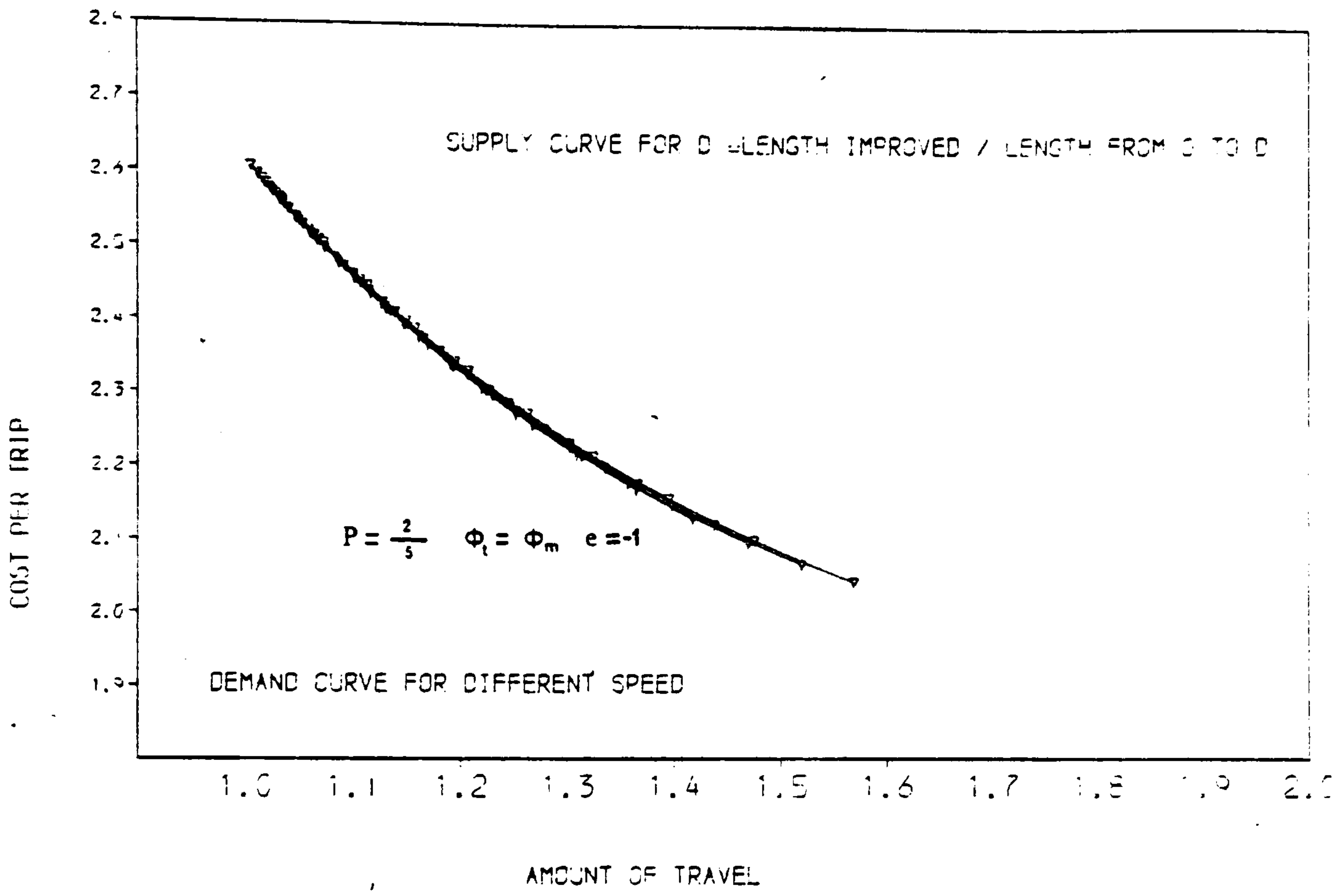
FIG. 7.3



RATE OF GENARATED TRIP
FOR DIFFERENT LEVELS OF IMPROVEMENT

(Money constraint)

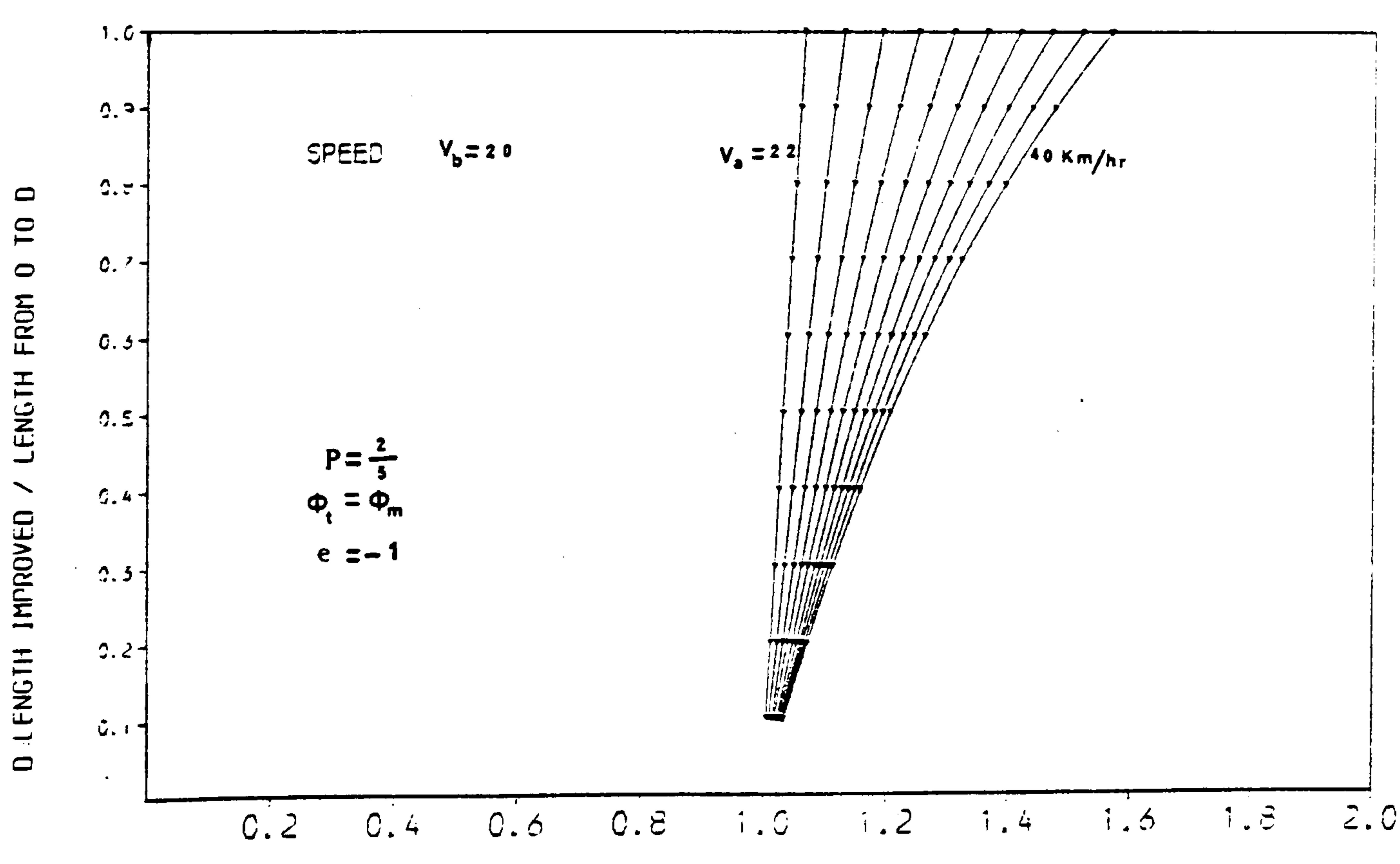
FIG. 7.4



DEMAND AND SUPPLY CURVE

(Generalised cost contraint)

FIG. 7.5

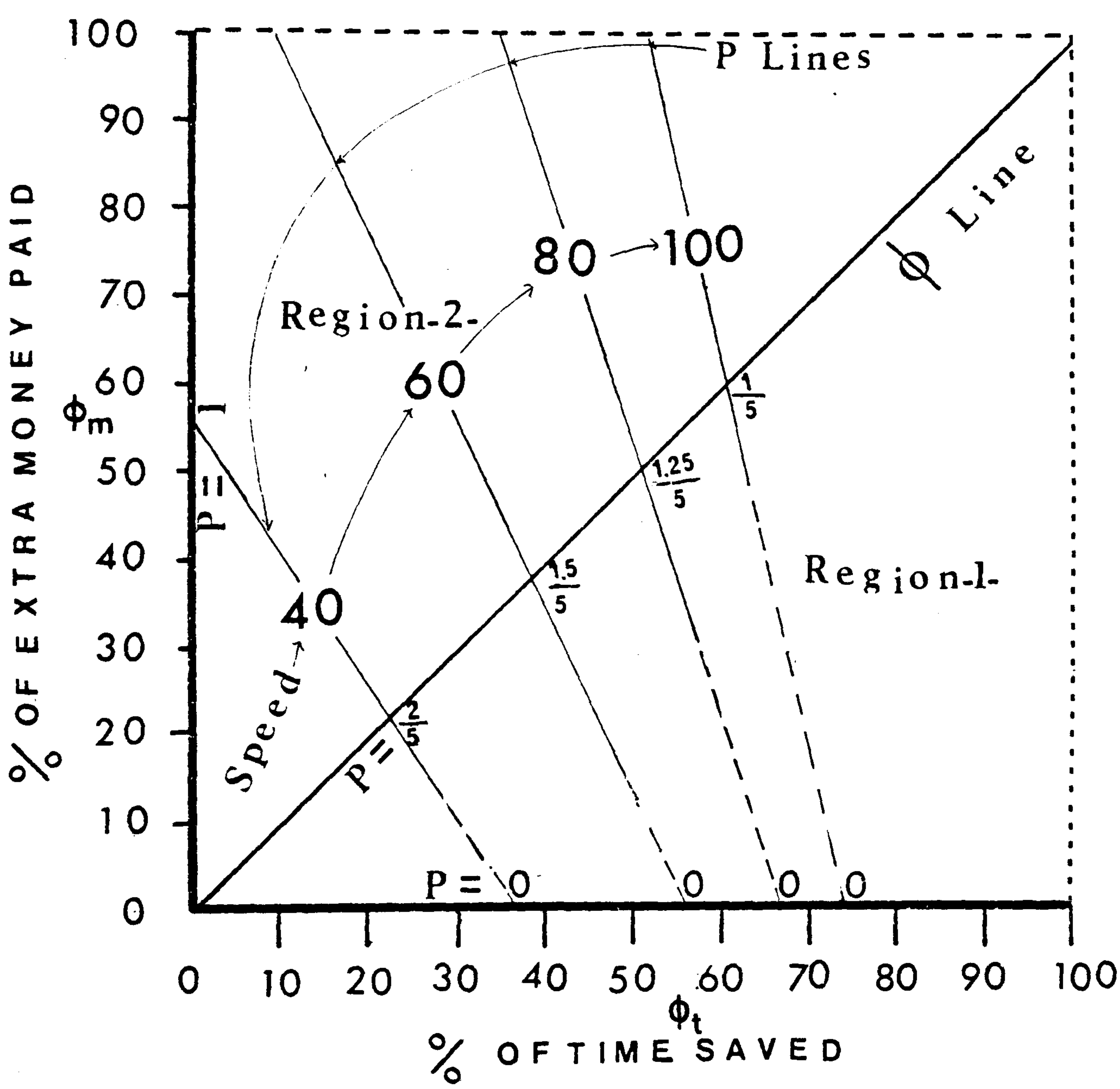


RATE OF GENARATED TRIP

FOR DIFFERENT LEVELS OF IMPROVEMENT

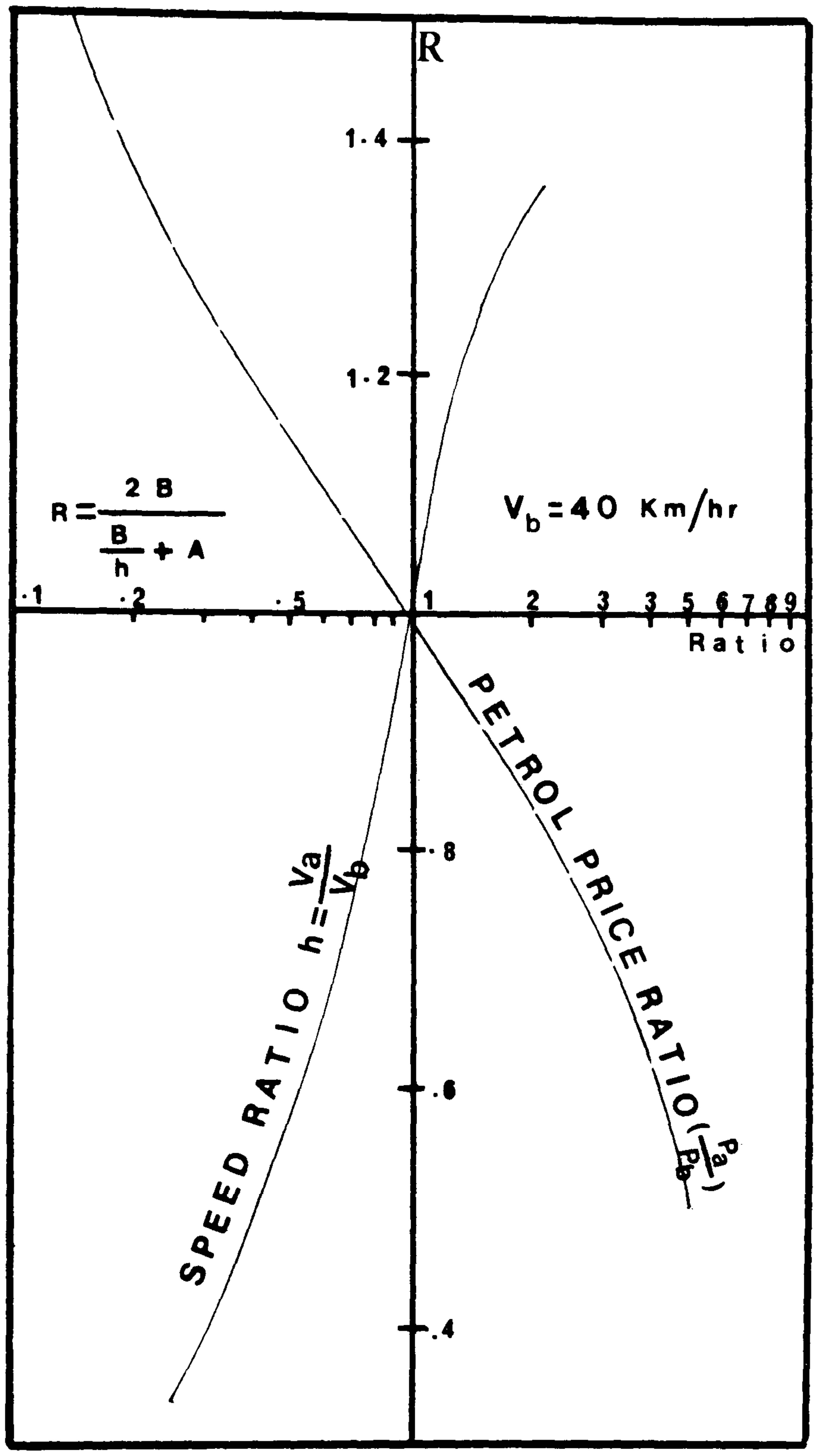
(Generalised cost constraint)

FIG. 7.6



P values with ϕ_m and ϕ_t

FIG. 7.7



EFFECT OF CHANGE IN PETROL PRICE

AND SPEED ON GENERATED TRIPRATE (R)

(Generalised Cost Constraint)

Values of A and B from 1973 Cost Formula ;

$$C = 1.29 + \frac{26}{V_b h} + .000063(V_b h)^2$$

FIG. 7.8

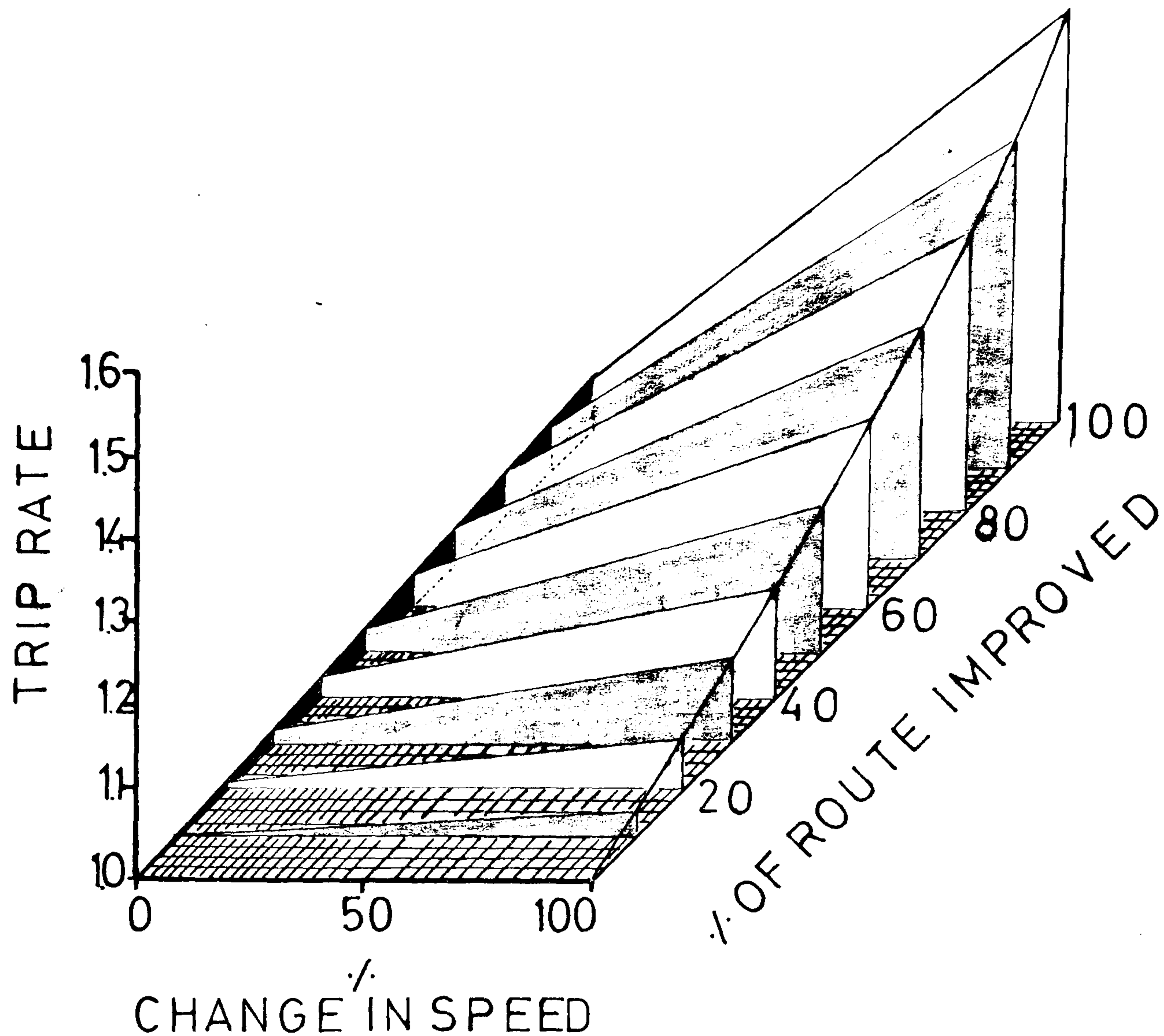
$$R = \frac{2B}{\frac{B}{h} + A}$$

Values of A and B

from 1973 Cost Formula

$$C = 1.29 + \frac{26}{V_b} + \cdot 0000 (V_b h)^2$$

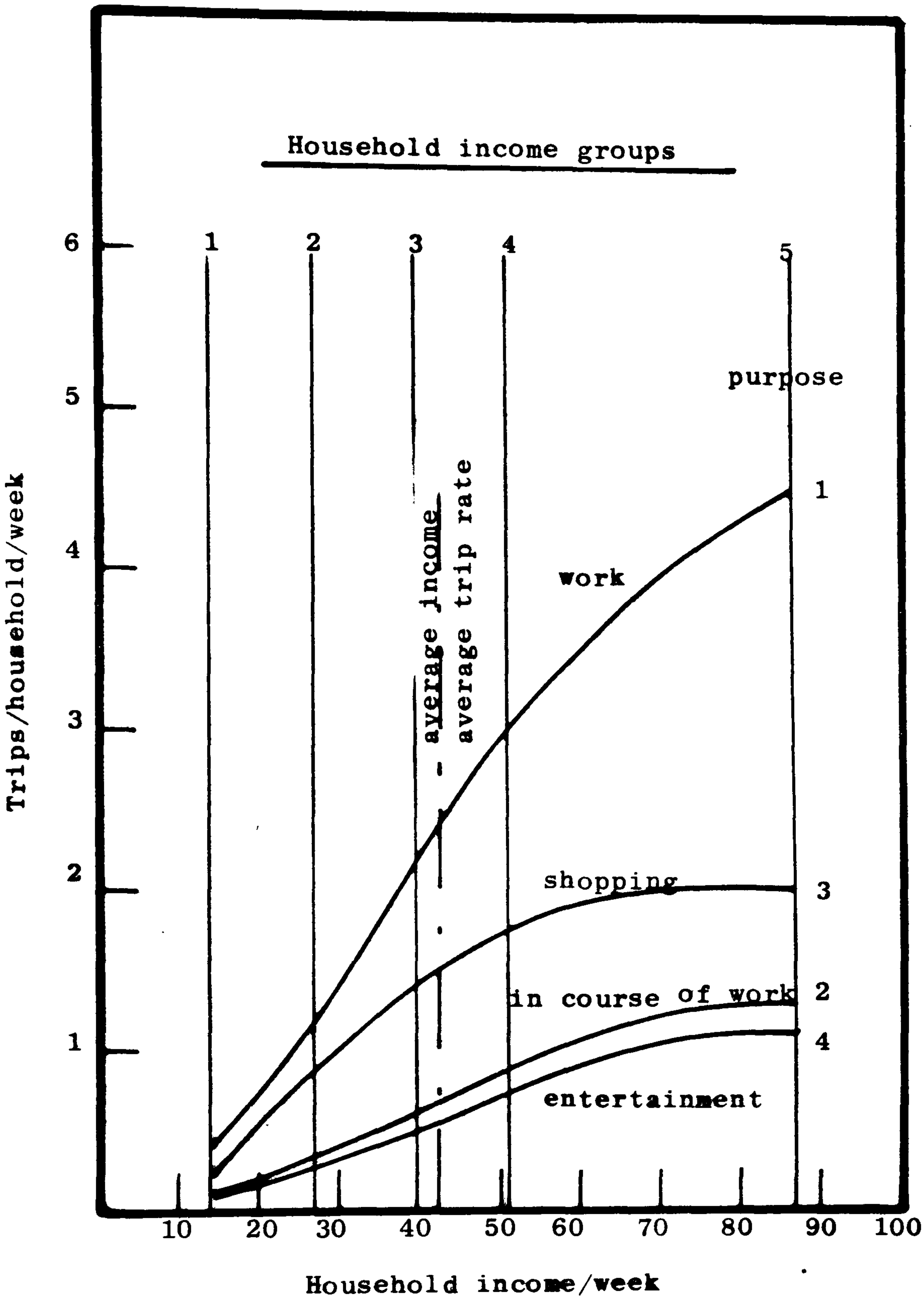
$V_b = 20\ Km/hr$



RESPONSE SURFACE FOR GENERATED TRIP

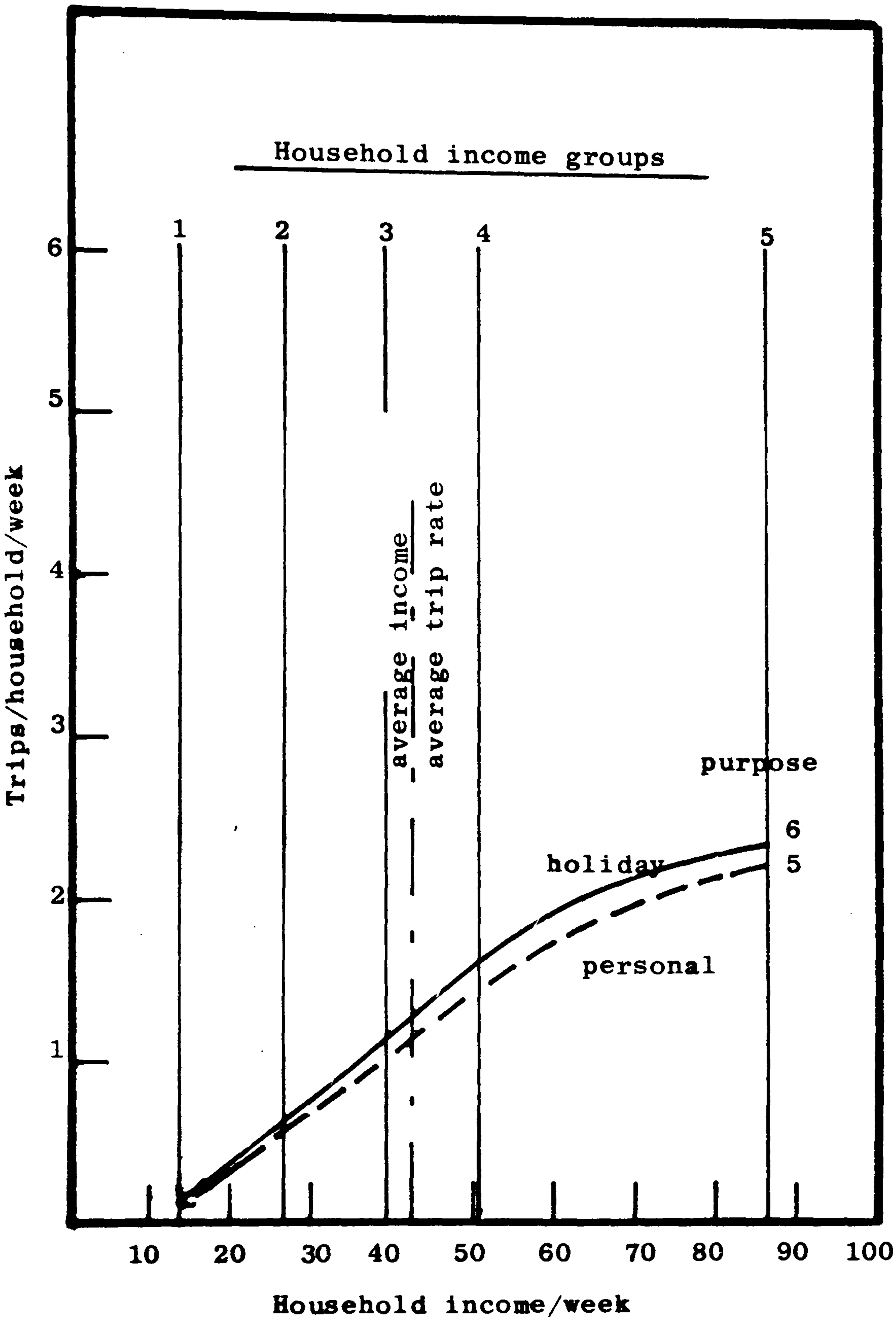
(Generalised Cost Model)

FIG. 7.9



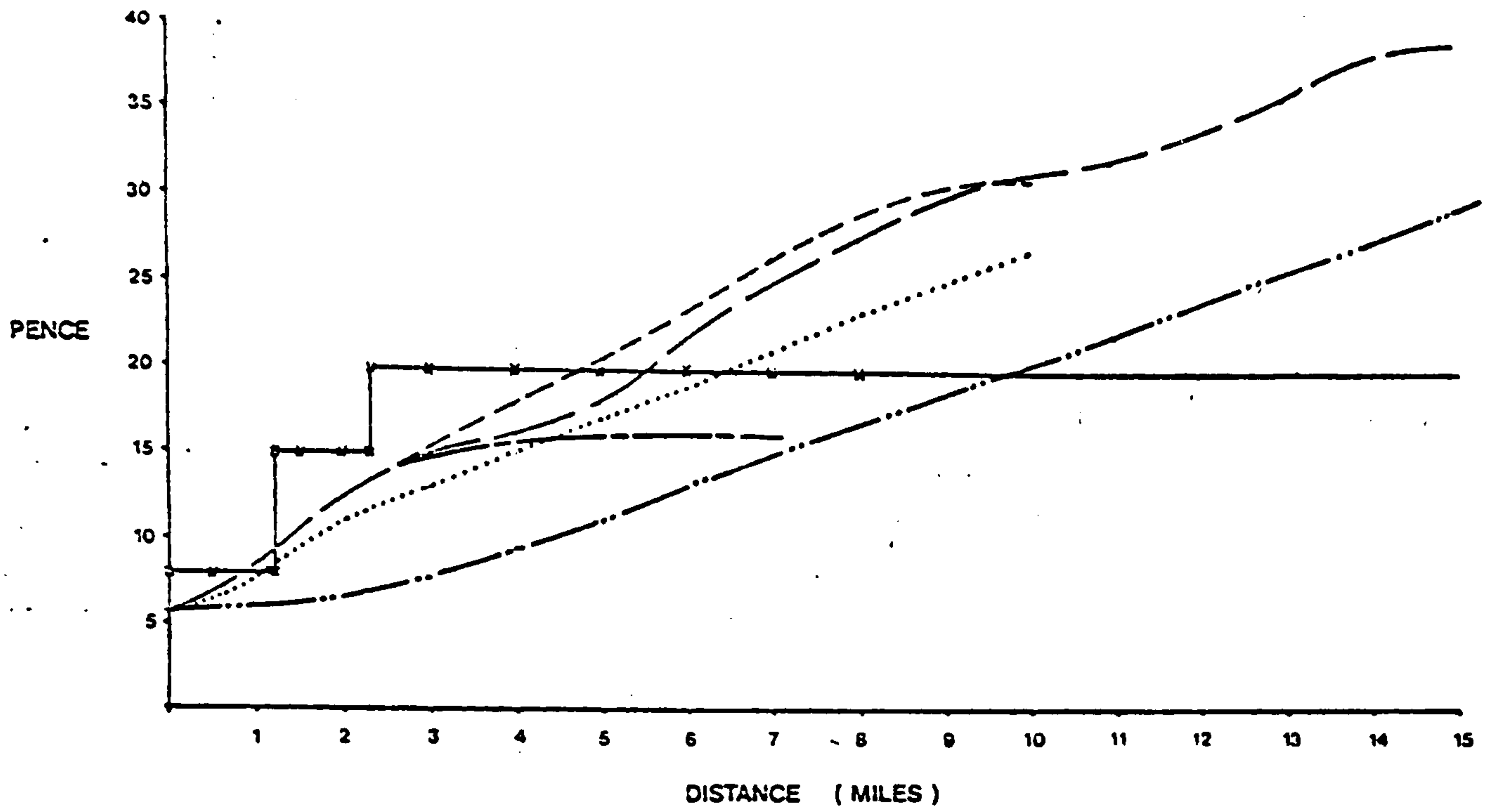
Car trip rate
1972/73

FIG. 8.1



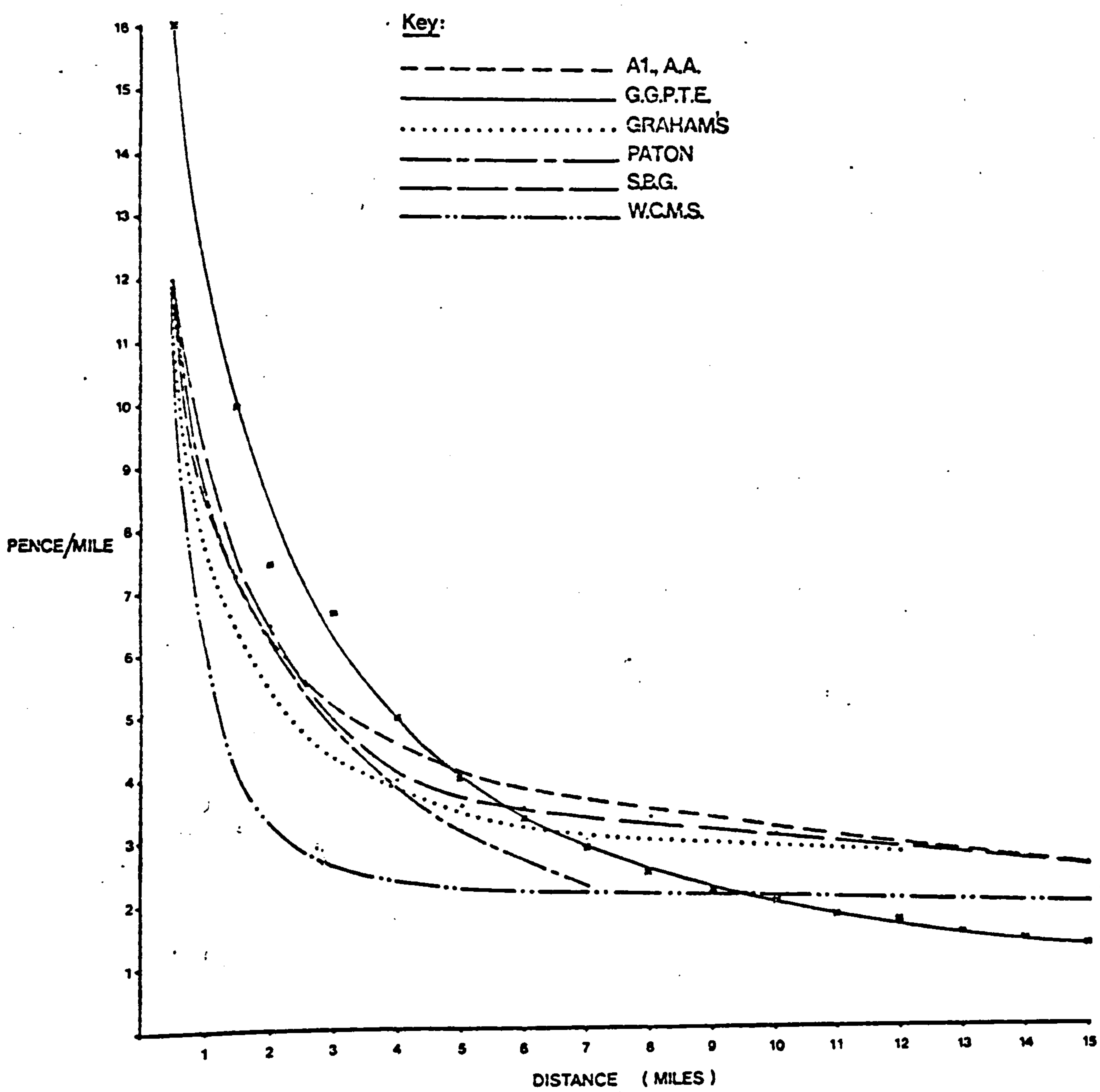
Car trip rate
1972/73

FIG. 8.2



GLASGOW FARE STRUCTURE FOR P.T.E.,S.B.G. & INDEPENDENT BUS OPERATORS (MID 1975).

FIG. 9.1a



GLASGOW FARE RATE PER MILE FOR P.T.E., S.B.G. & INDEPENDENT BUS OPERATORS (MID 1975).

FIG.9.1b

CUMULATIVE HOUSEHOLD EXPENDITURE ON TRAVEL AND INCOME - FOR 1965

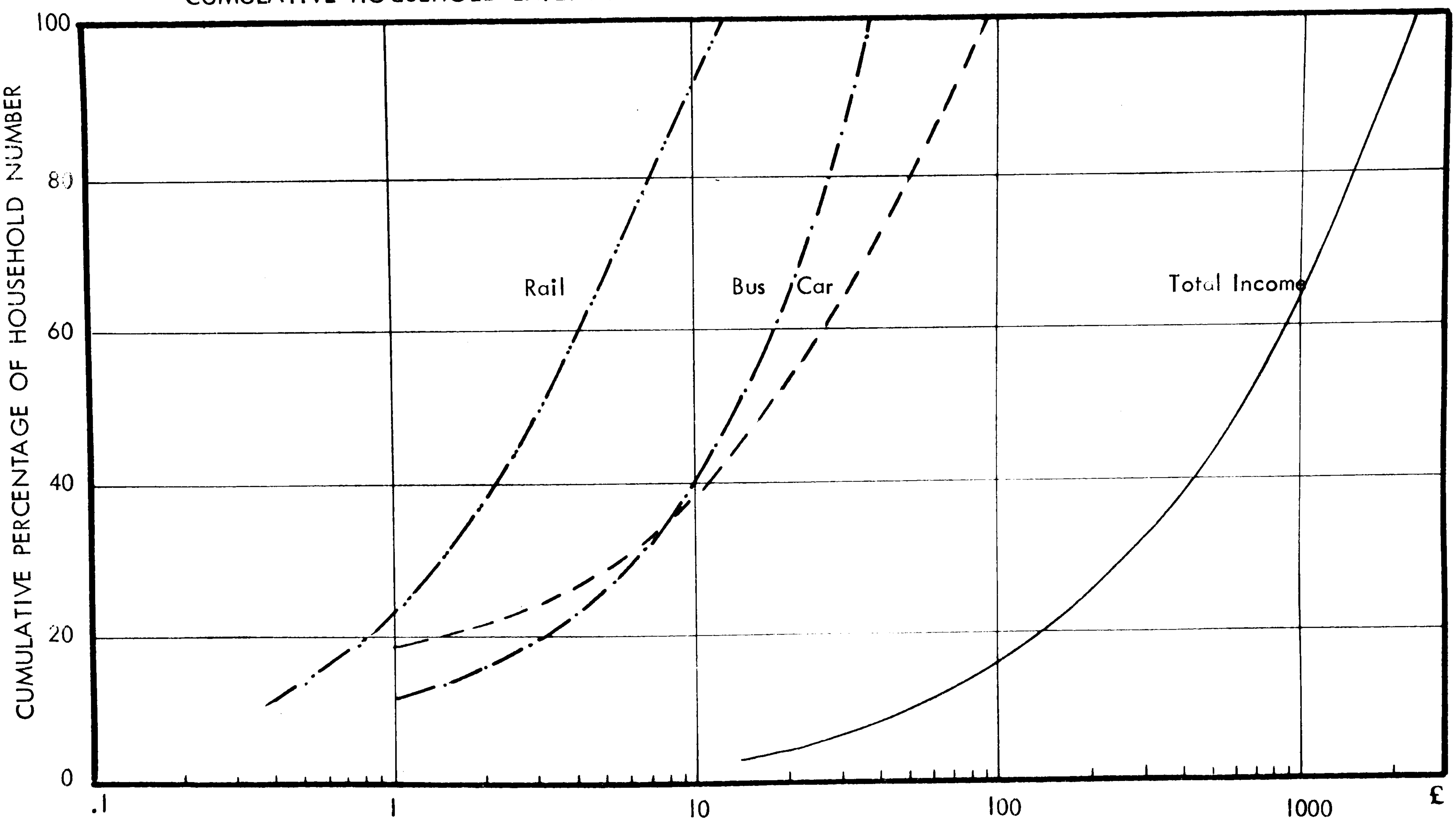


FIG. 9.1

CUMULATIVE HOUSEHOLD EXPENDITURE ON TRAVEL AND INCOME - FOR 1968

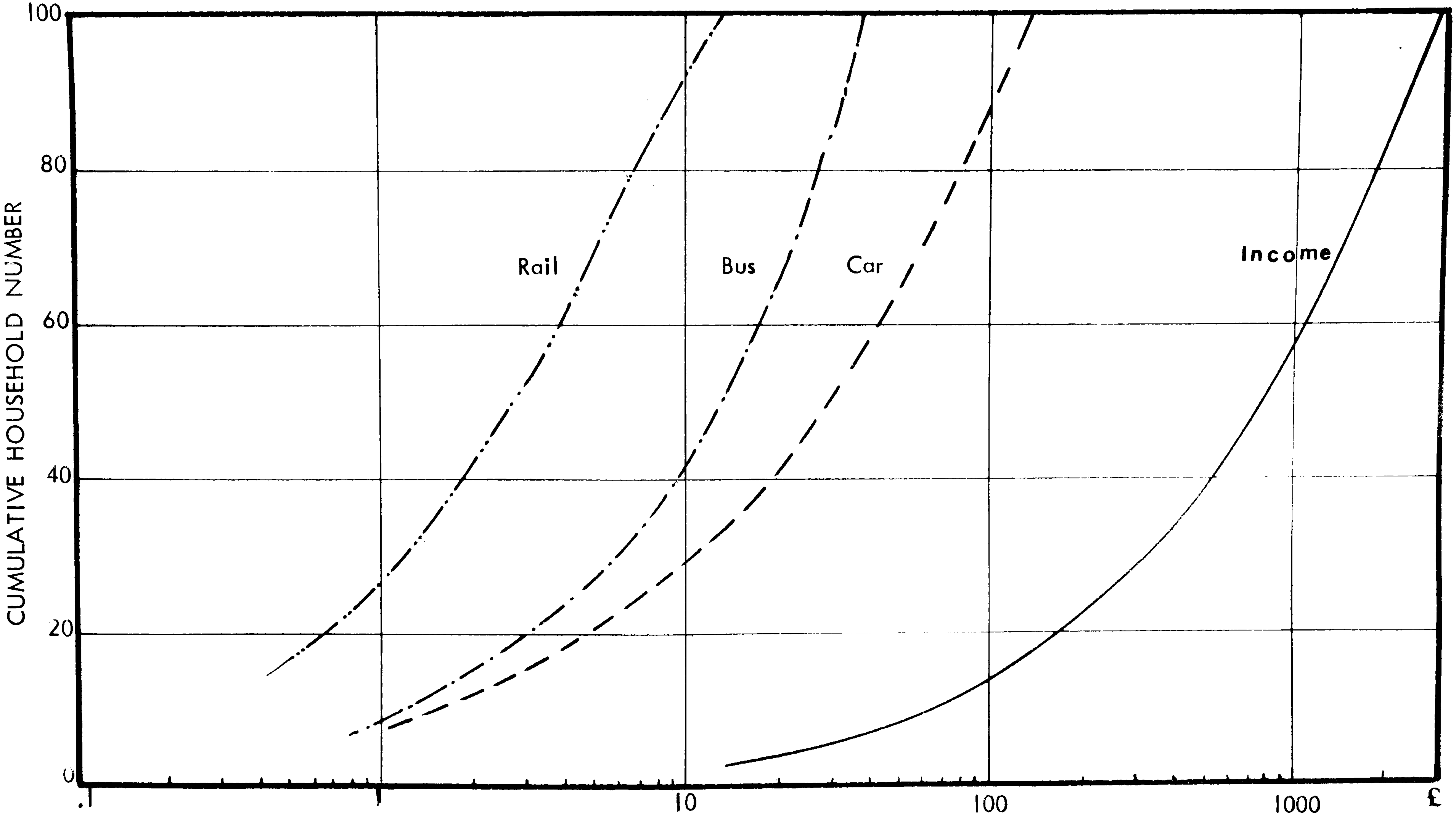


FIG. 9.2

CUMULATIVE HOUSEHOLD EXPENDITURE ON TRAVEL AND INCOME - FOR 1972

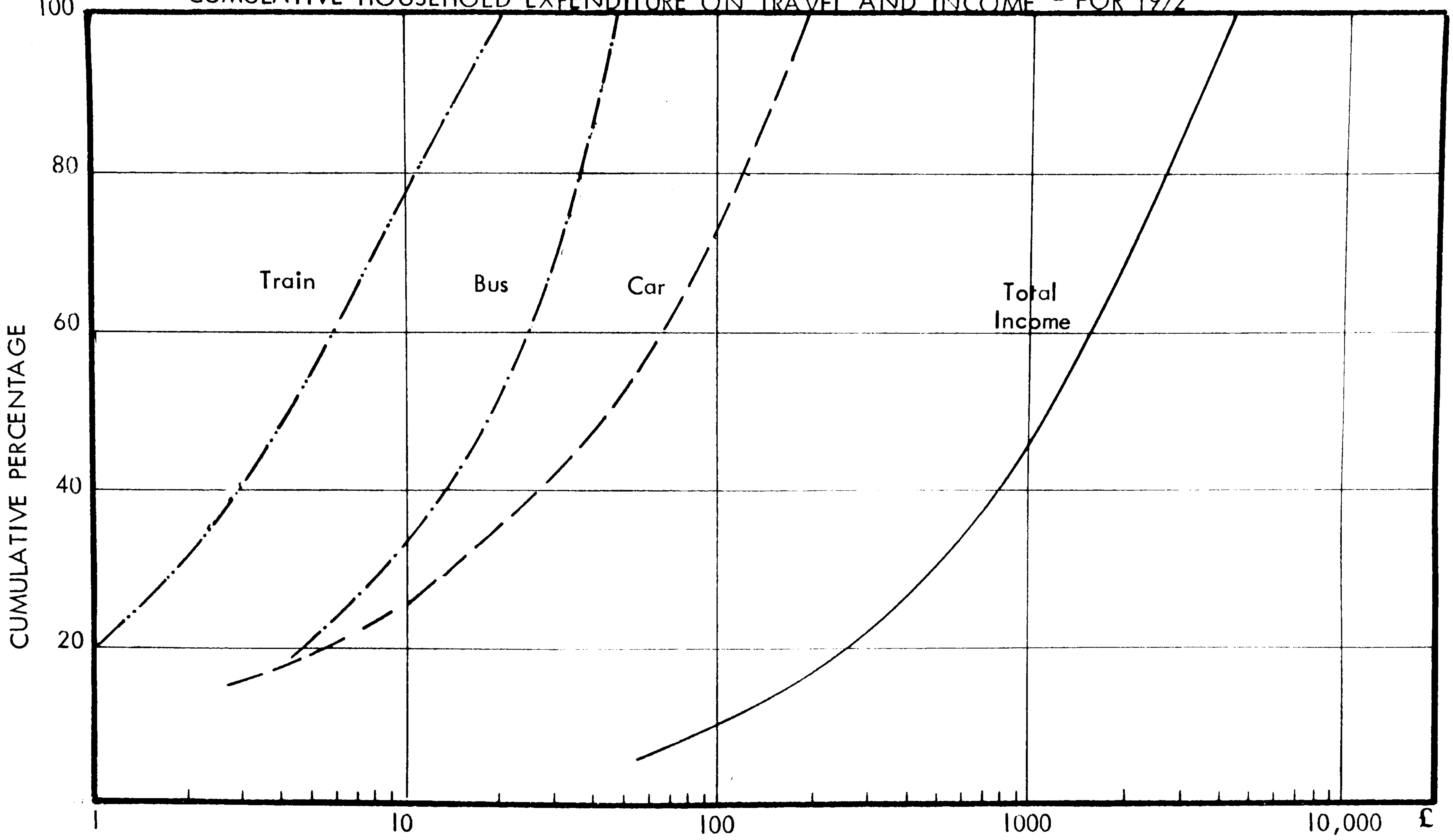


FIG. 9.3

CUMULATIVE HOUSEHOLD EXPENDITURE ON TRAVEL AND INCOME - FOR 1975

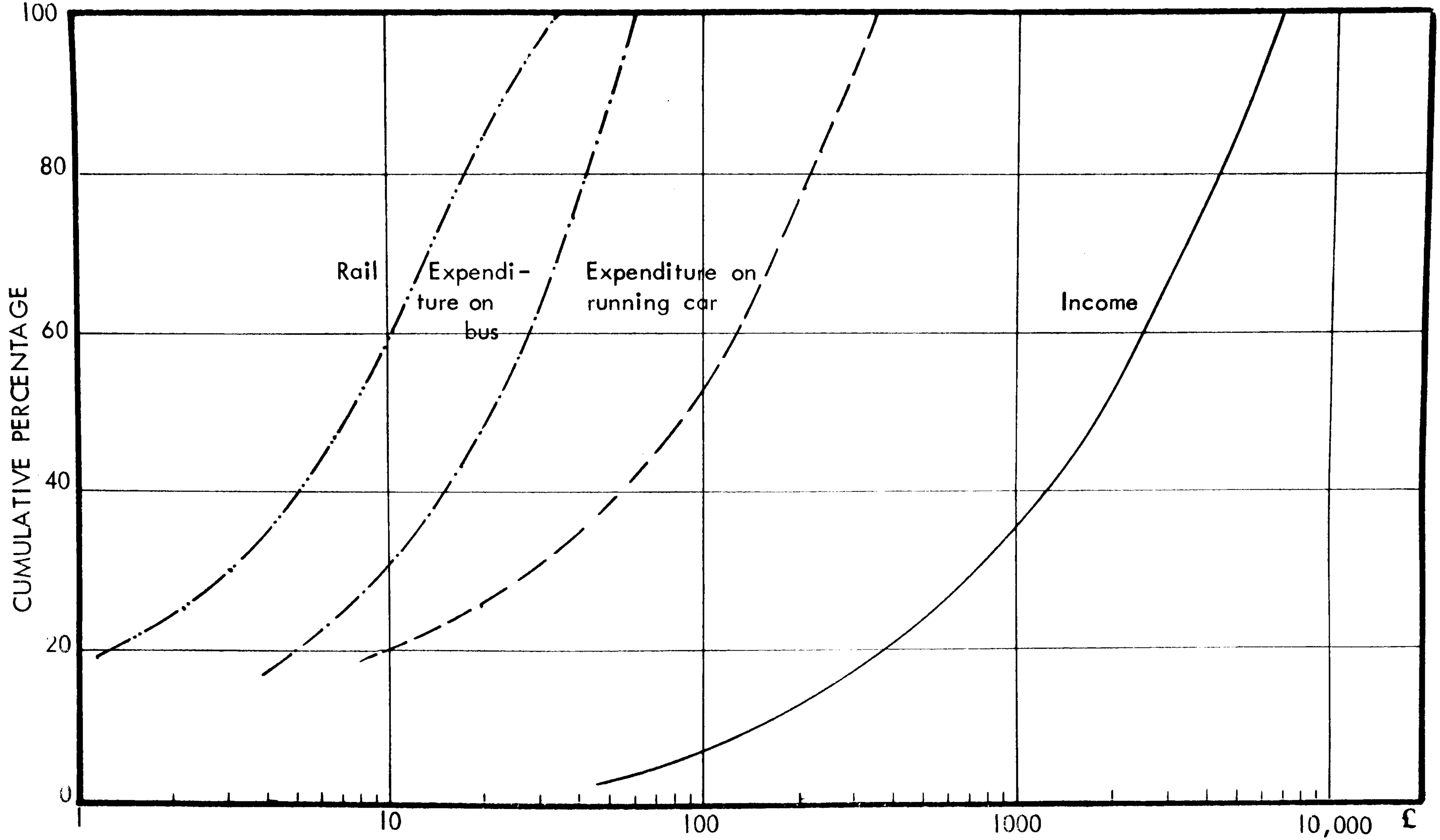


FIG. 9.4

CUMULATIVE HOUSEHOLD EXPENDITURE ON TRAVEL AND INCOME

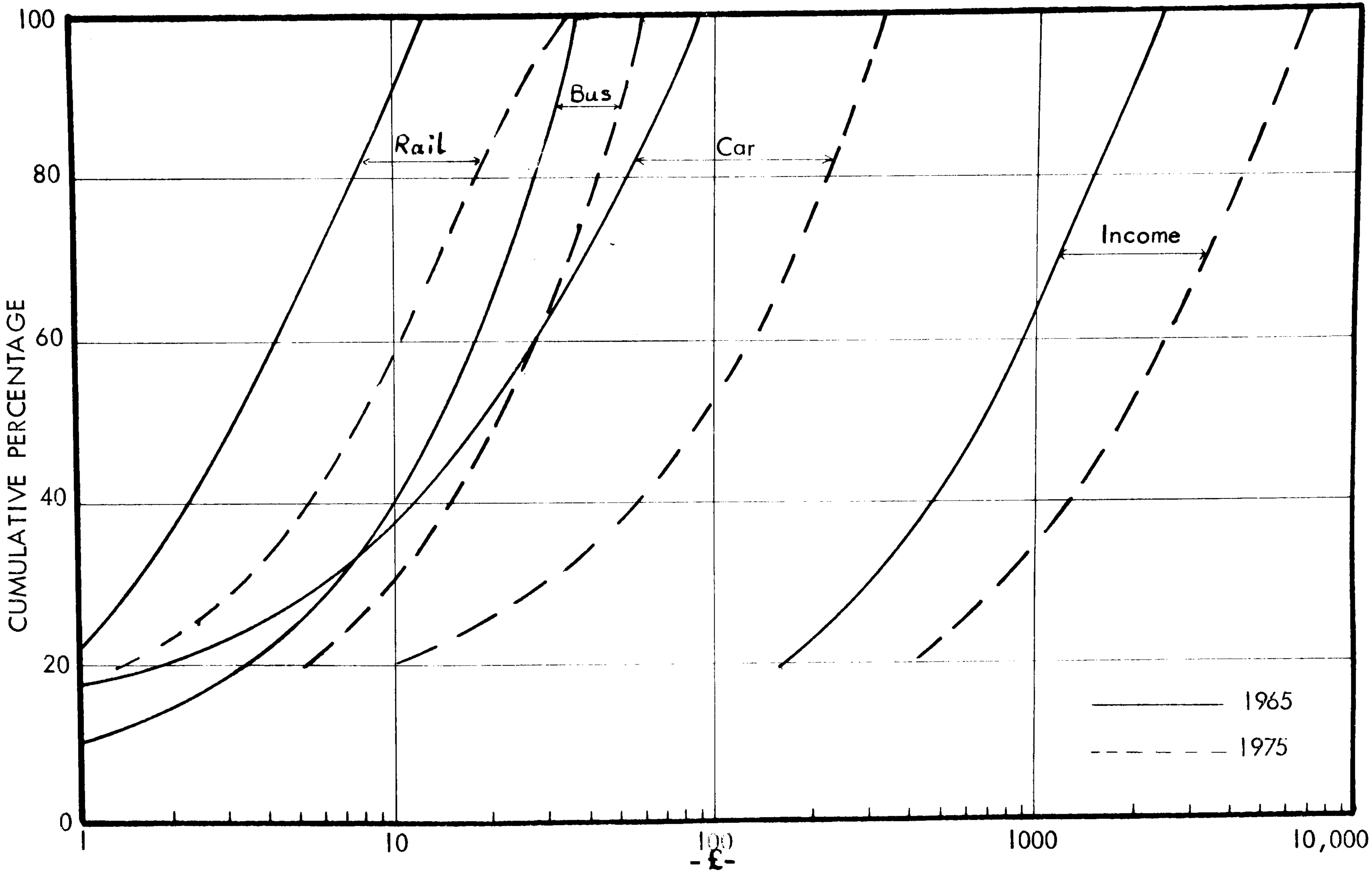
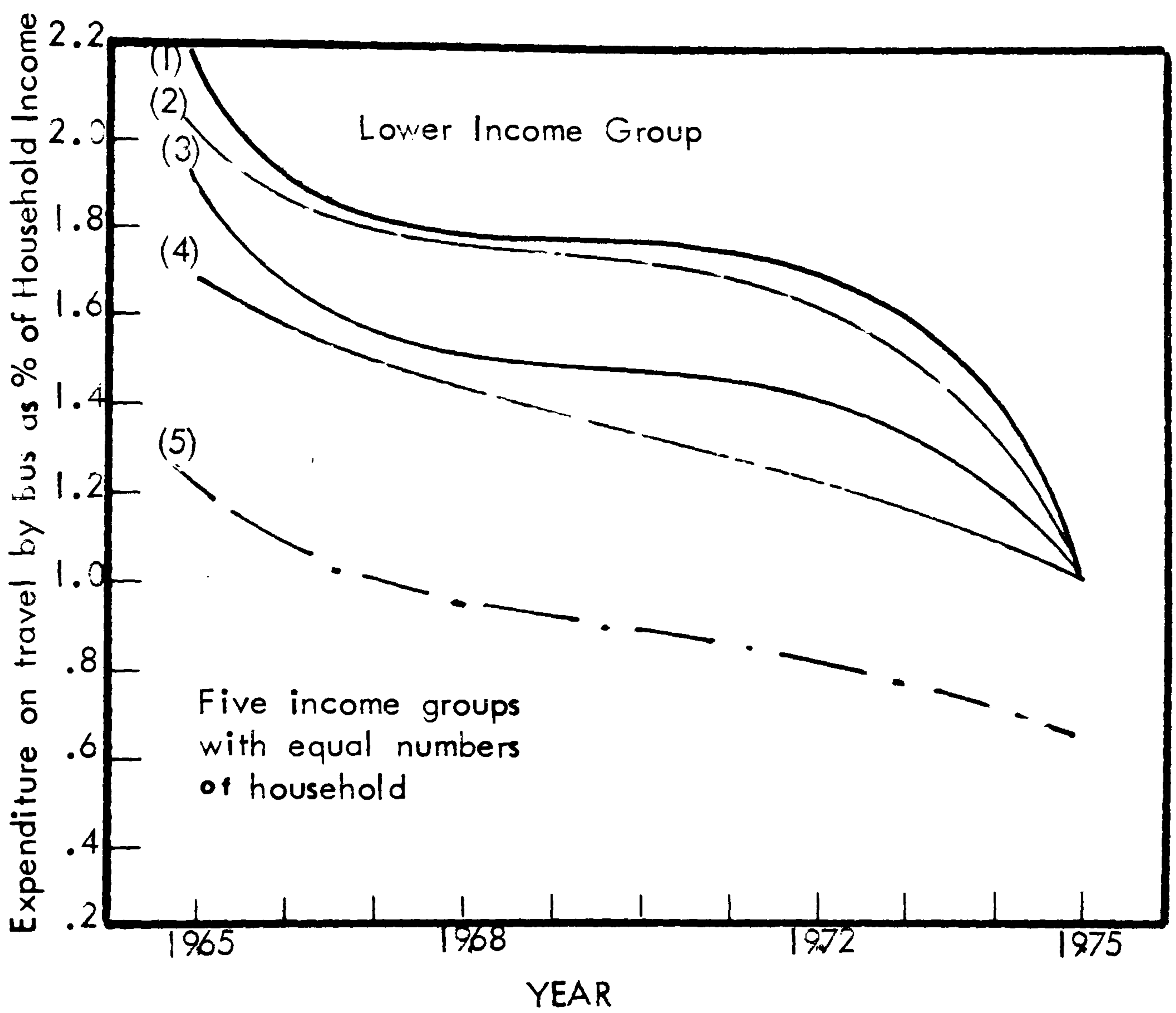
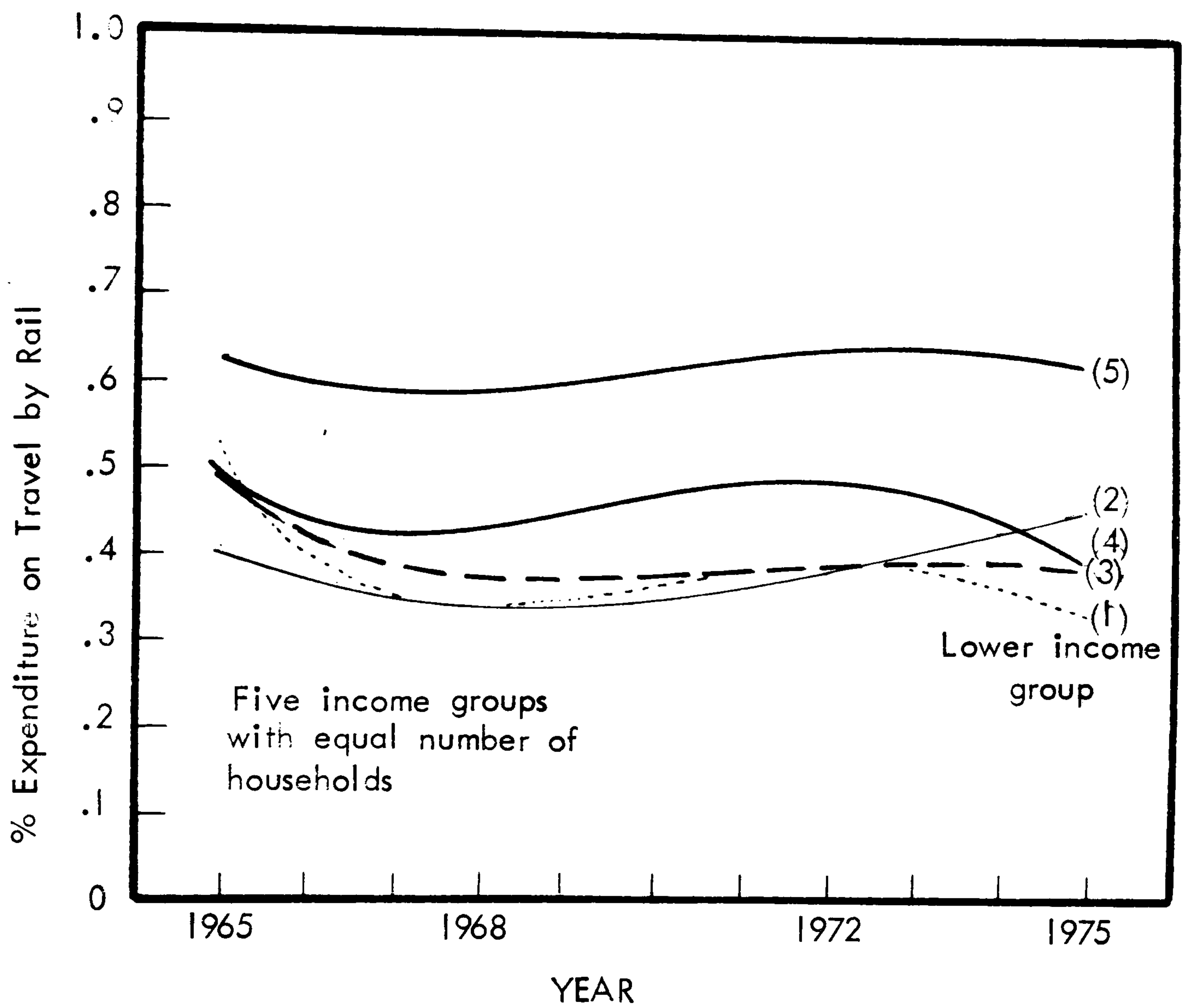


FIG. 9.5



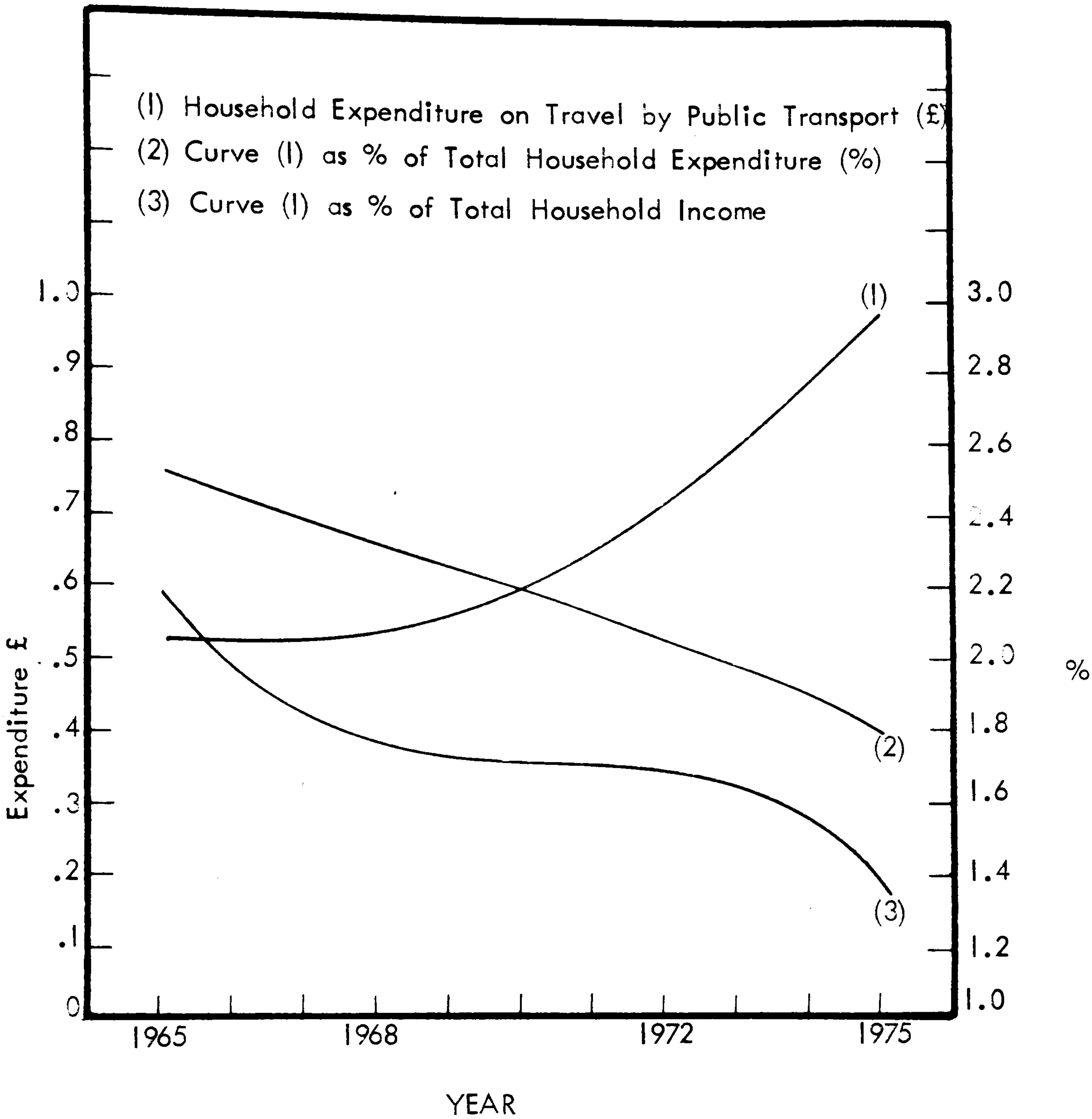
Expenditure on Travel by Bus as % of Average Household Income.

FIG. 9.6



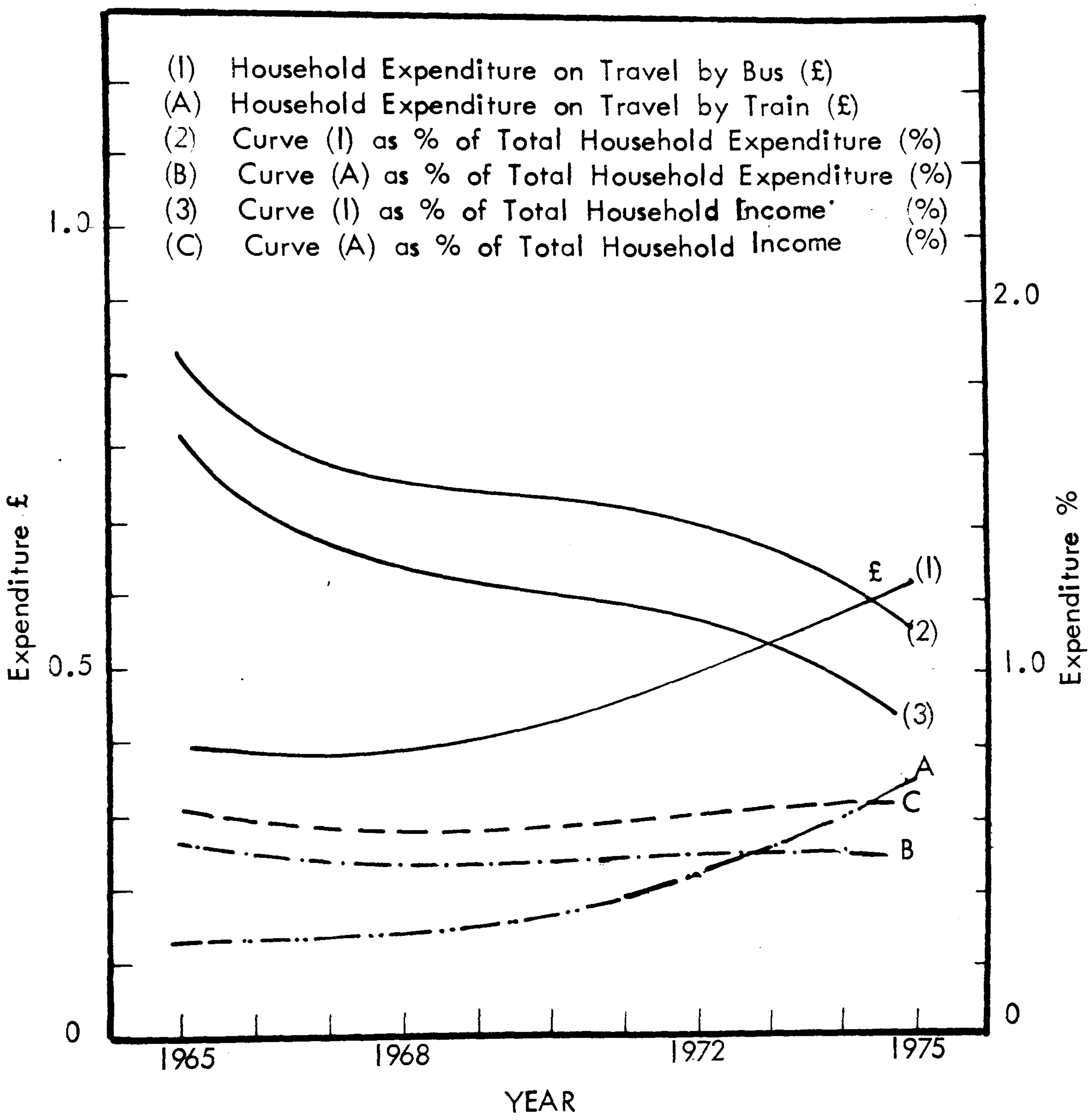
Expenditure on Travel by Train as % of Average Household Income for Five Income Groups.

FIG. 9.7



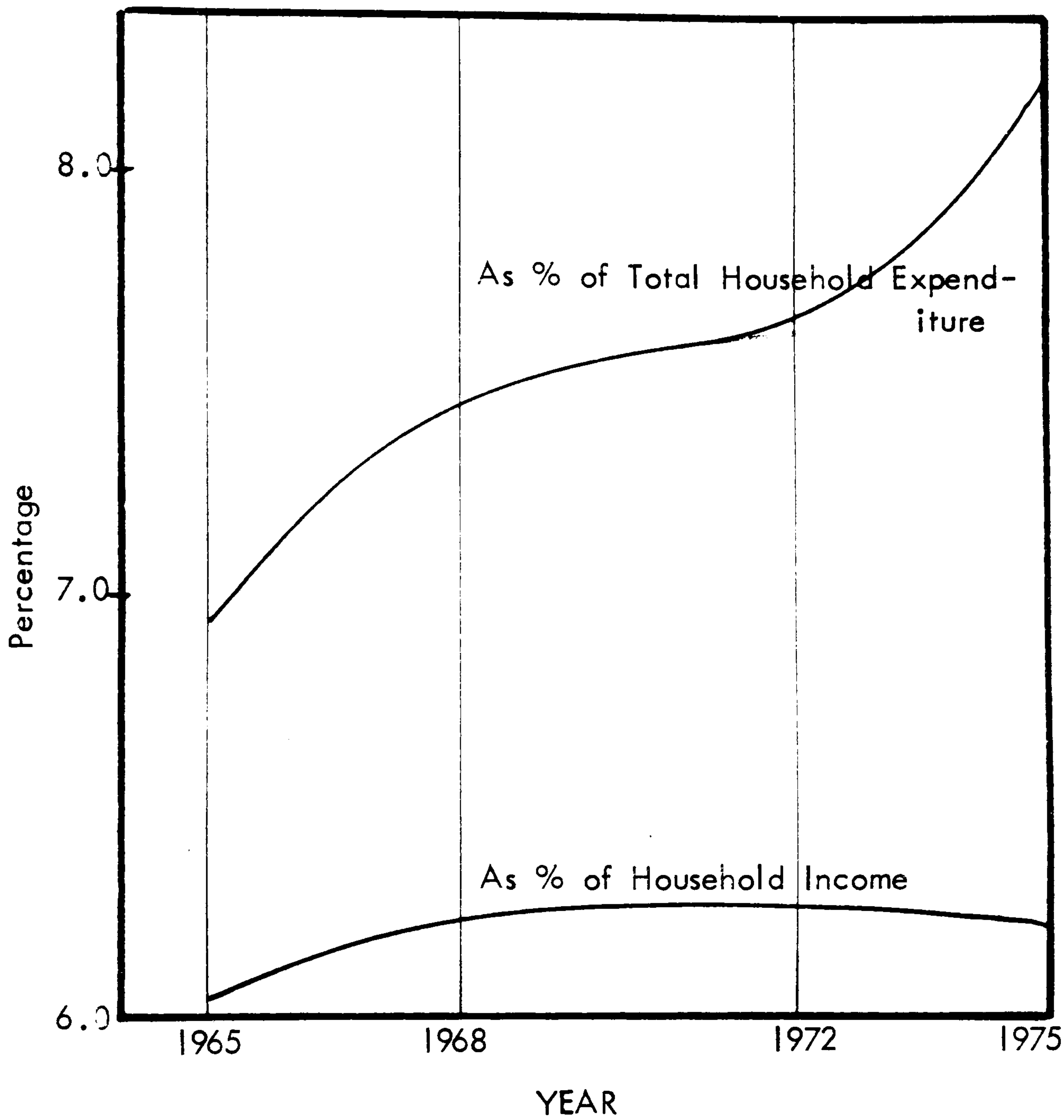
Expenditure on Travel by Public Transport per Household/Week (Bus and Train)

FIG. 9.8



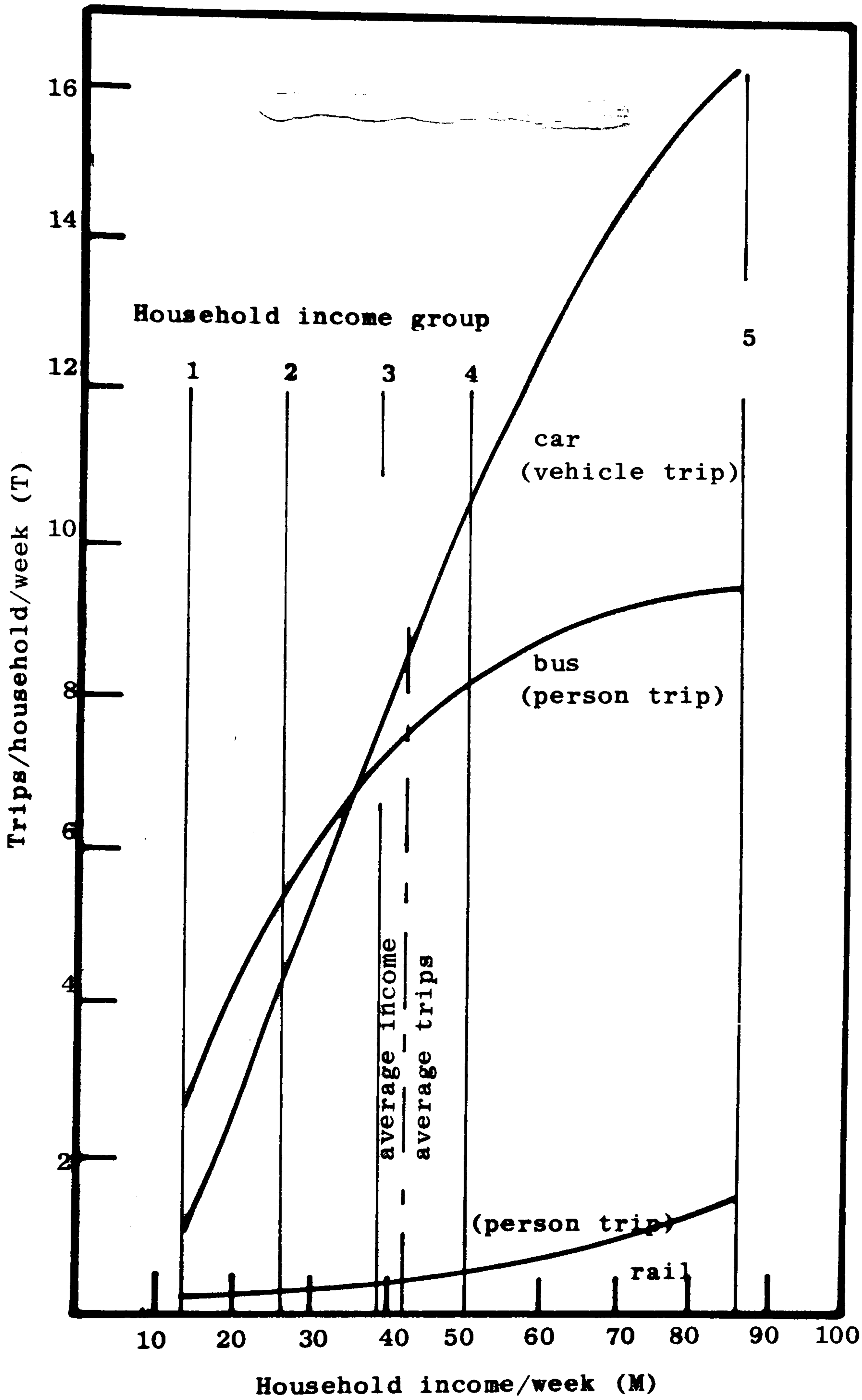
Expenditure on Travel by Bus and Rail Per Household Per Week

FIG. 9.9



Total Expenditure on Travel - Car, Bus and Rail.

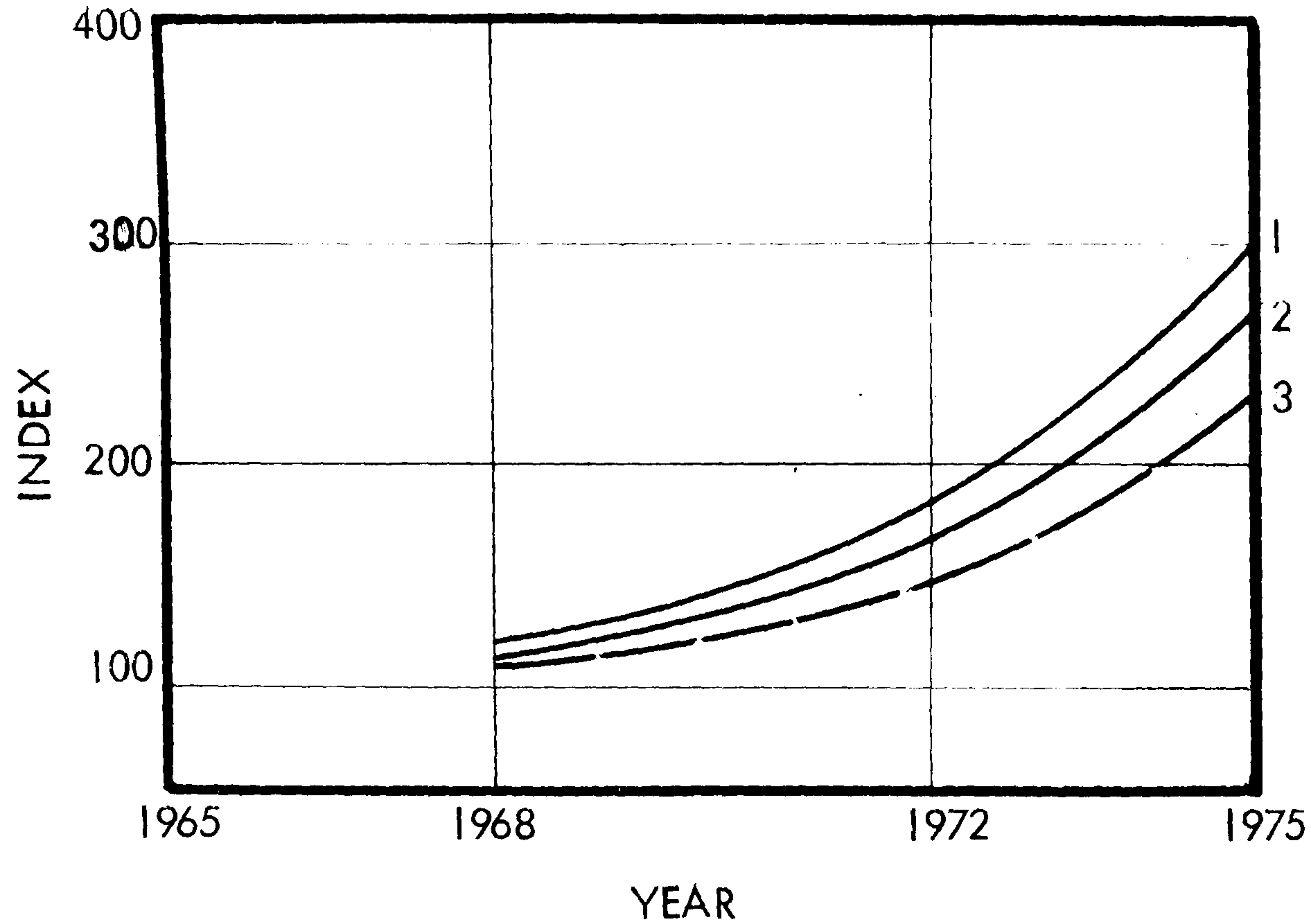
FIG. 9.10



Household trip rate by car, bus and rail
(1972/73)

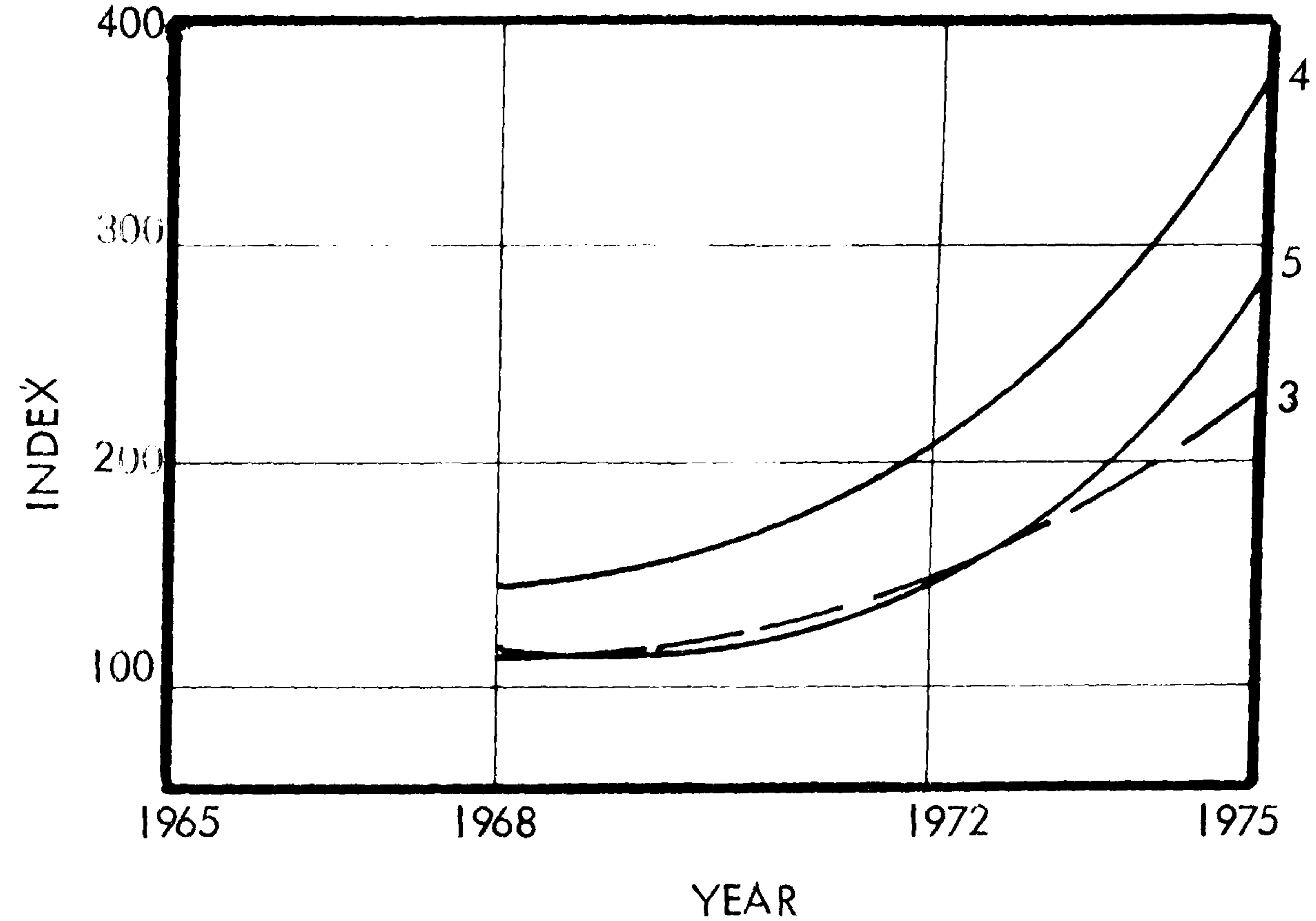
See Tables 8.1, 9.2, 9.g.

FIG. 9.11



- a -

(1) Income Index
(2) Total Expenditure Index
(3) All Goods and Services Index



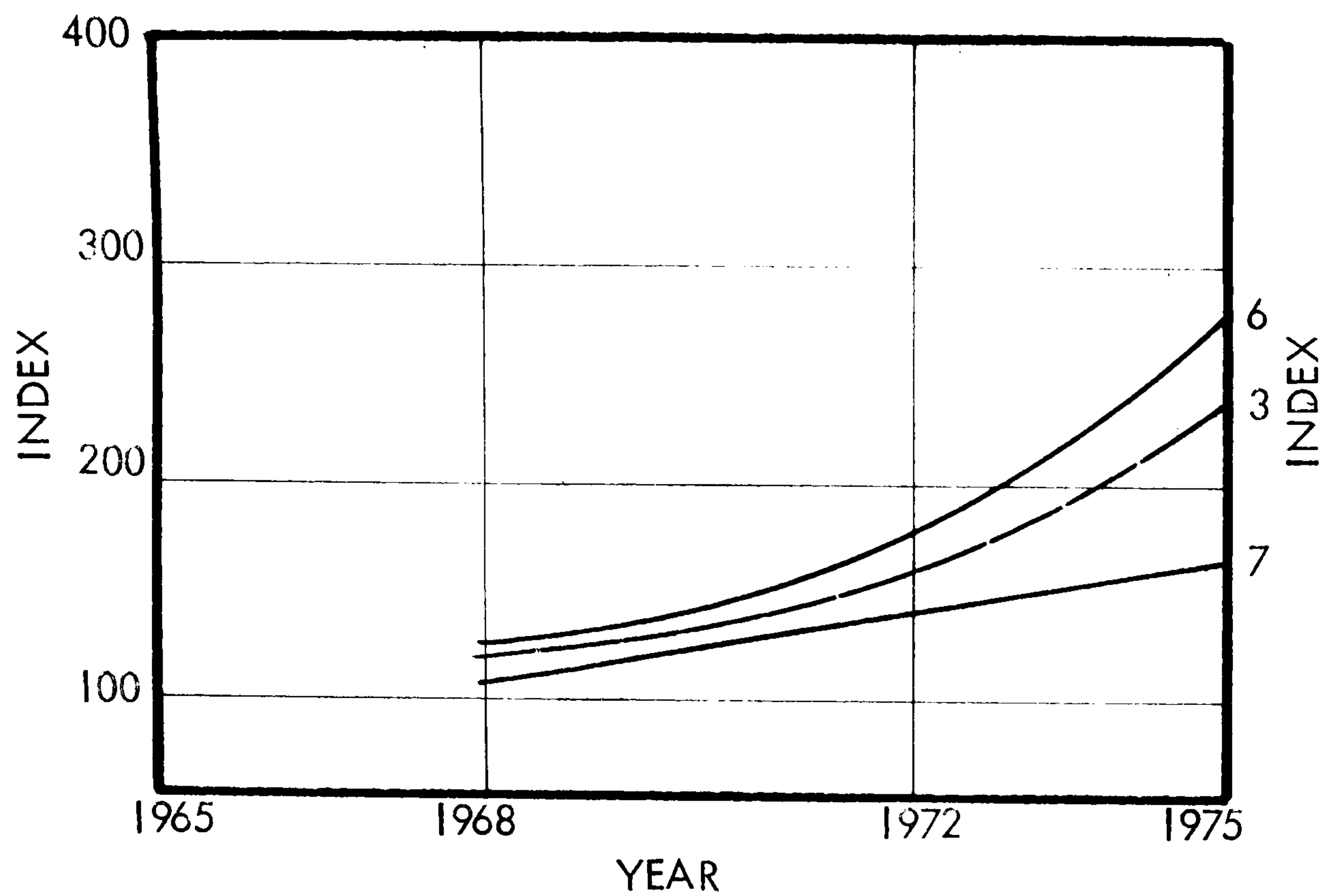
- b -

(4) Money Spent on Running Car Index
(5) Petrol Price Index
(3) All Goods and Services Index

1965 Index = 100 (See Table 6.1)

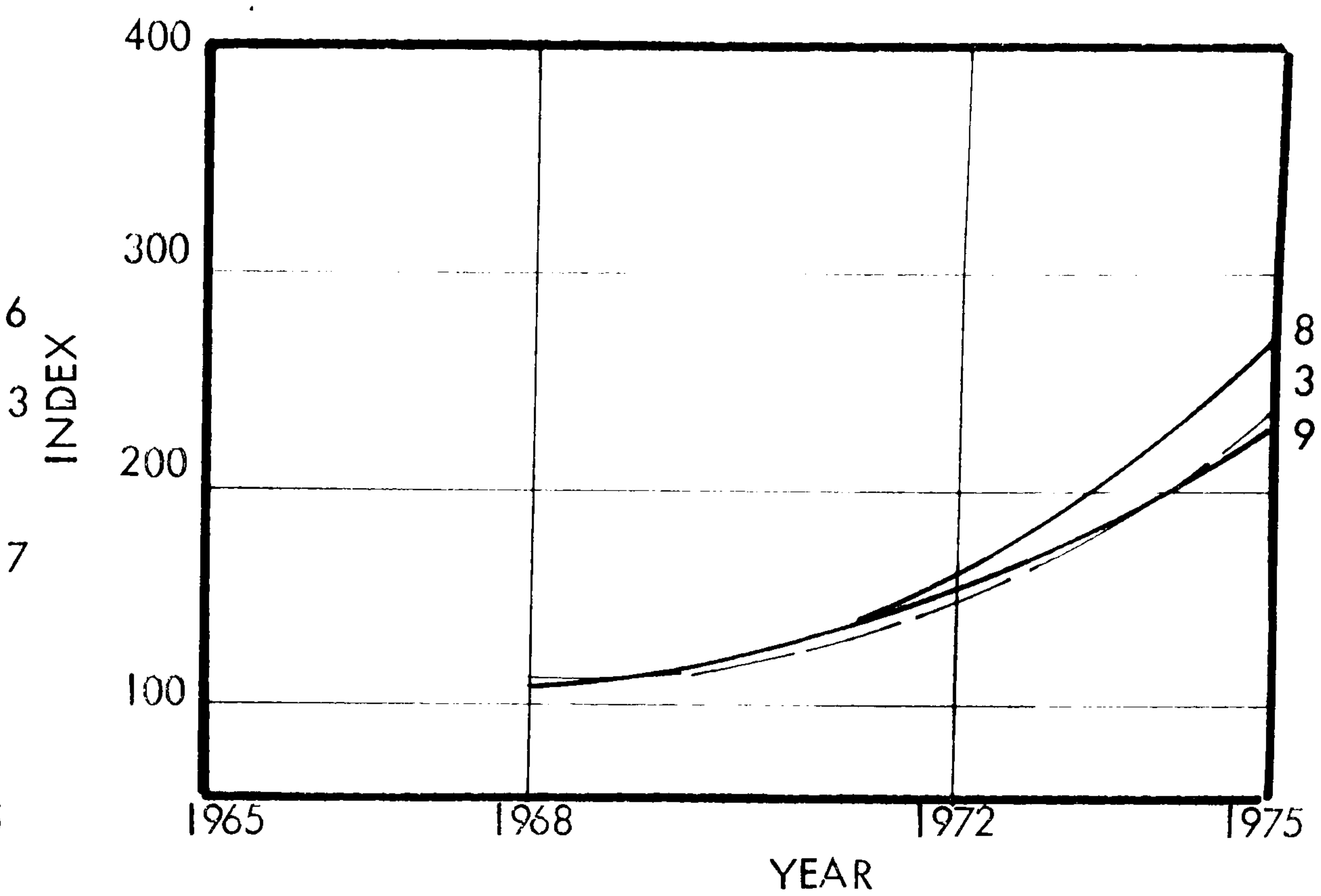
All Goods and Services Index Compared with Other Indices

FIG. 9.12



- a -

(6) Bus Fare Index
(7) Household Expenditure on Bus Index
(3) All Goods and Services Index

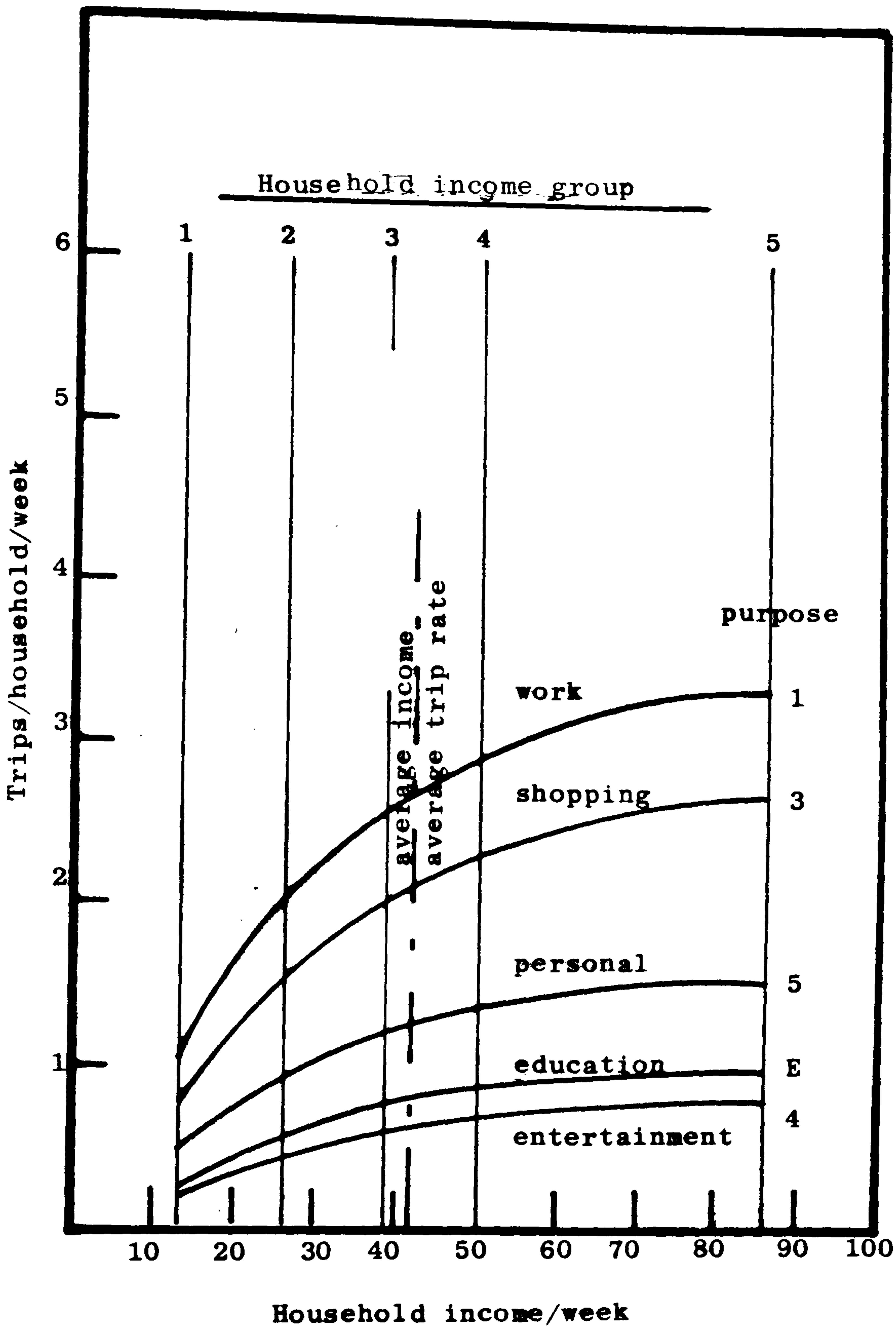


- b -

(8) Household Expenditure on Rail Index
(9) Rail Fare Index
(3) All Goods and Services Index

1965 Index = 100 (See Table 6.1)

FIG. 9.13



Bus trip rate
1972/73

FIG. 9.14

FIG. 10.1   LOCATION OF HAMILTON

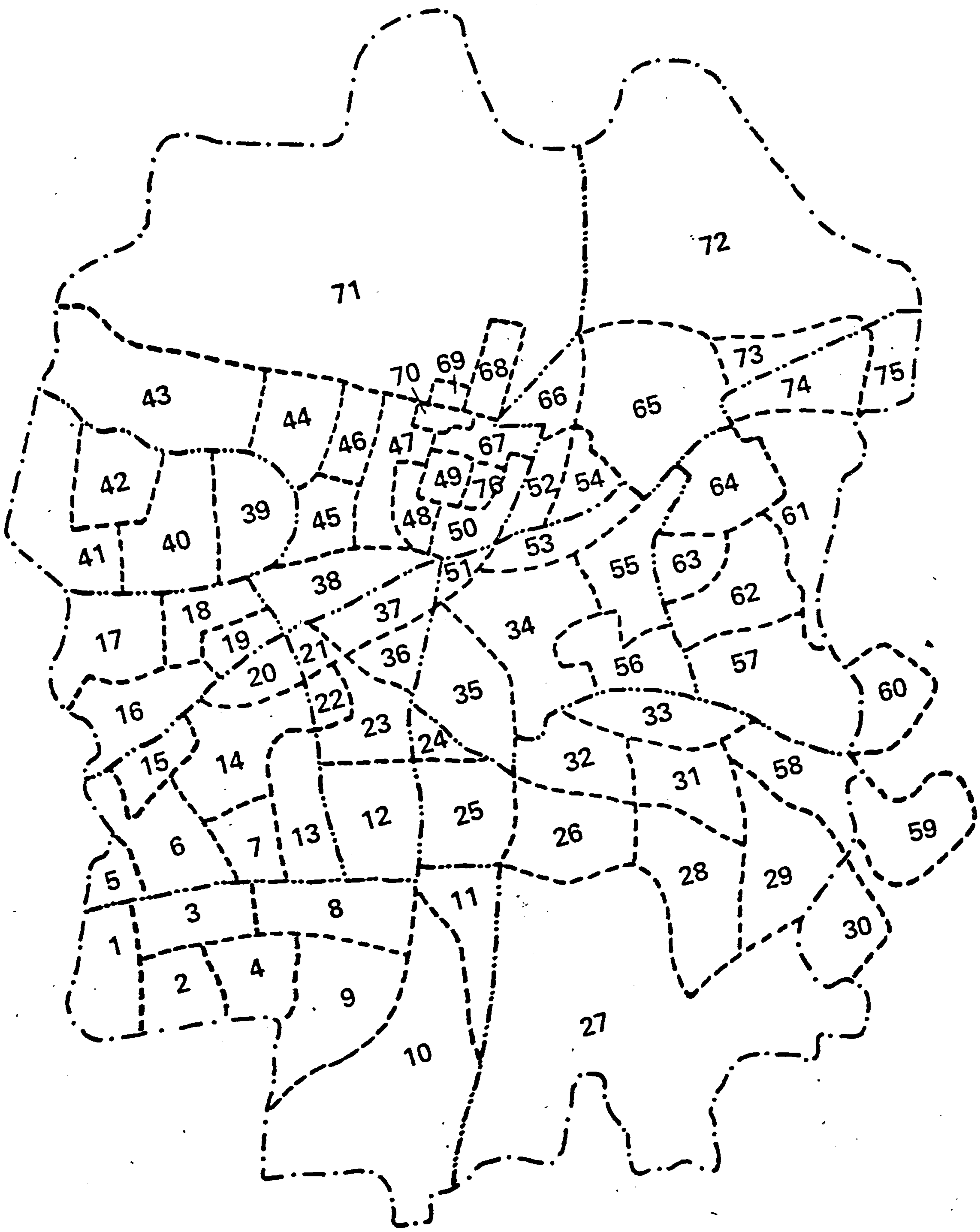


FIG. 10.2 HAMILTON ZONING SYSTEM

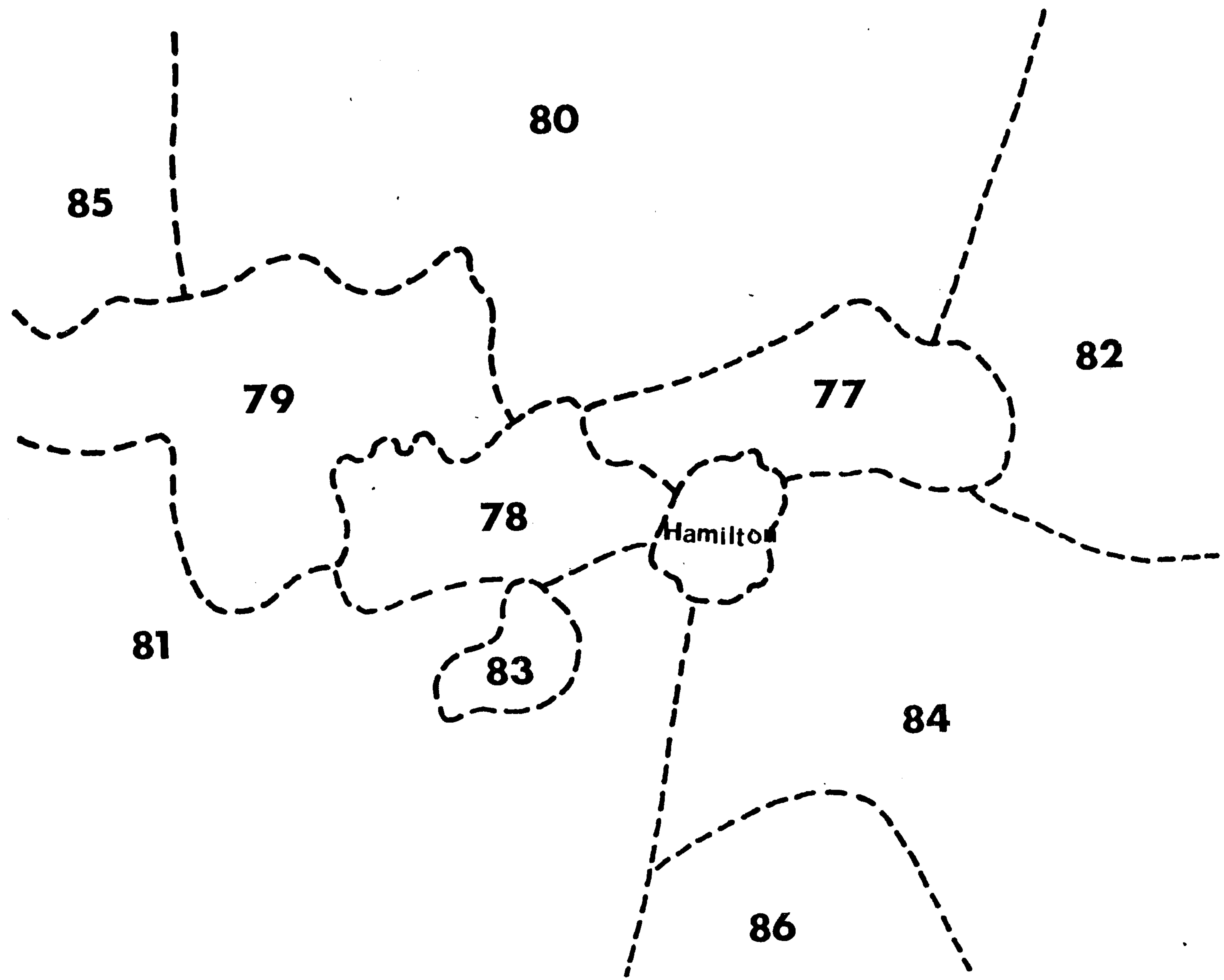


FIG. 10.3 HAMILTON EXTERNAL ZONES.

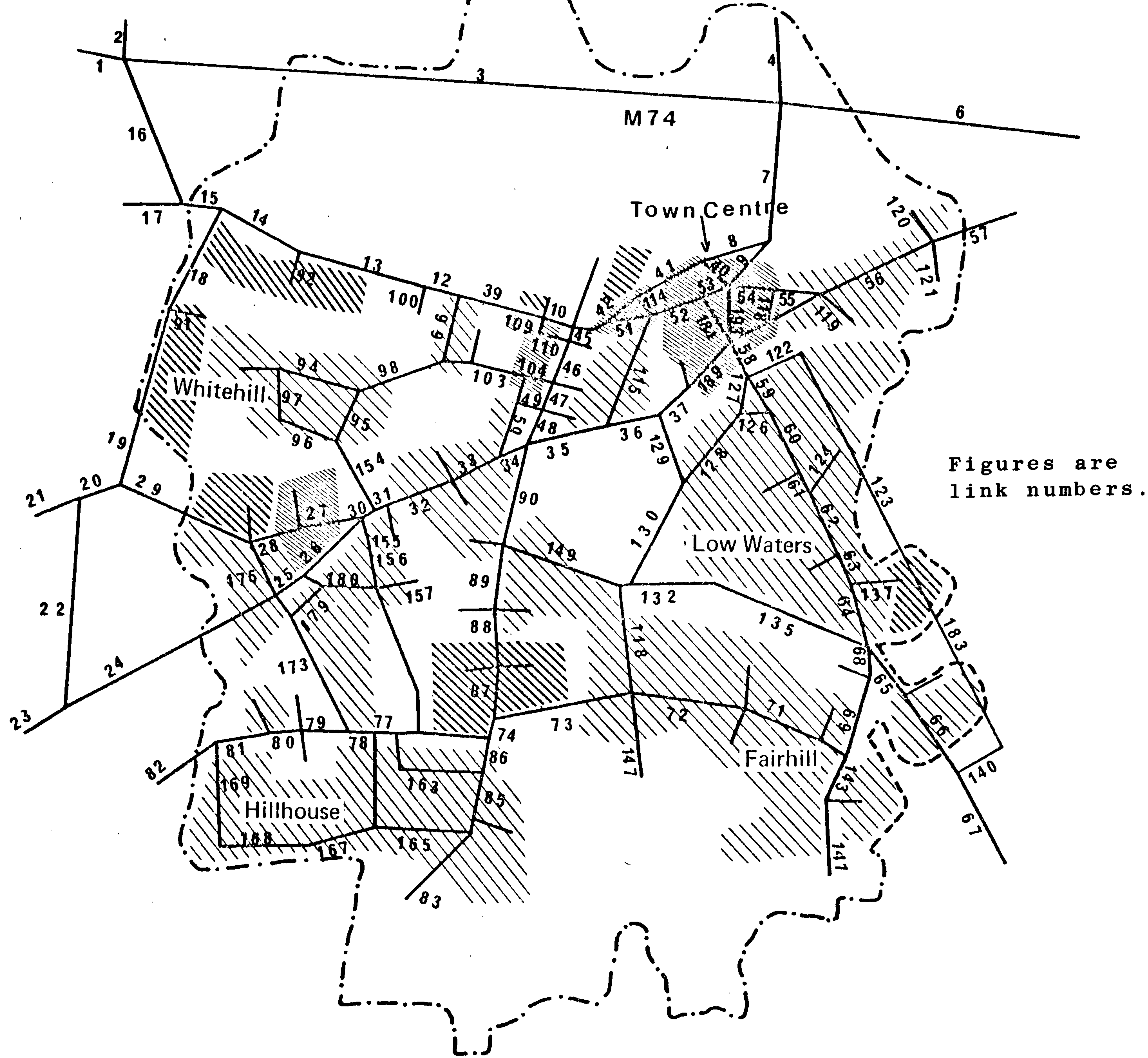
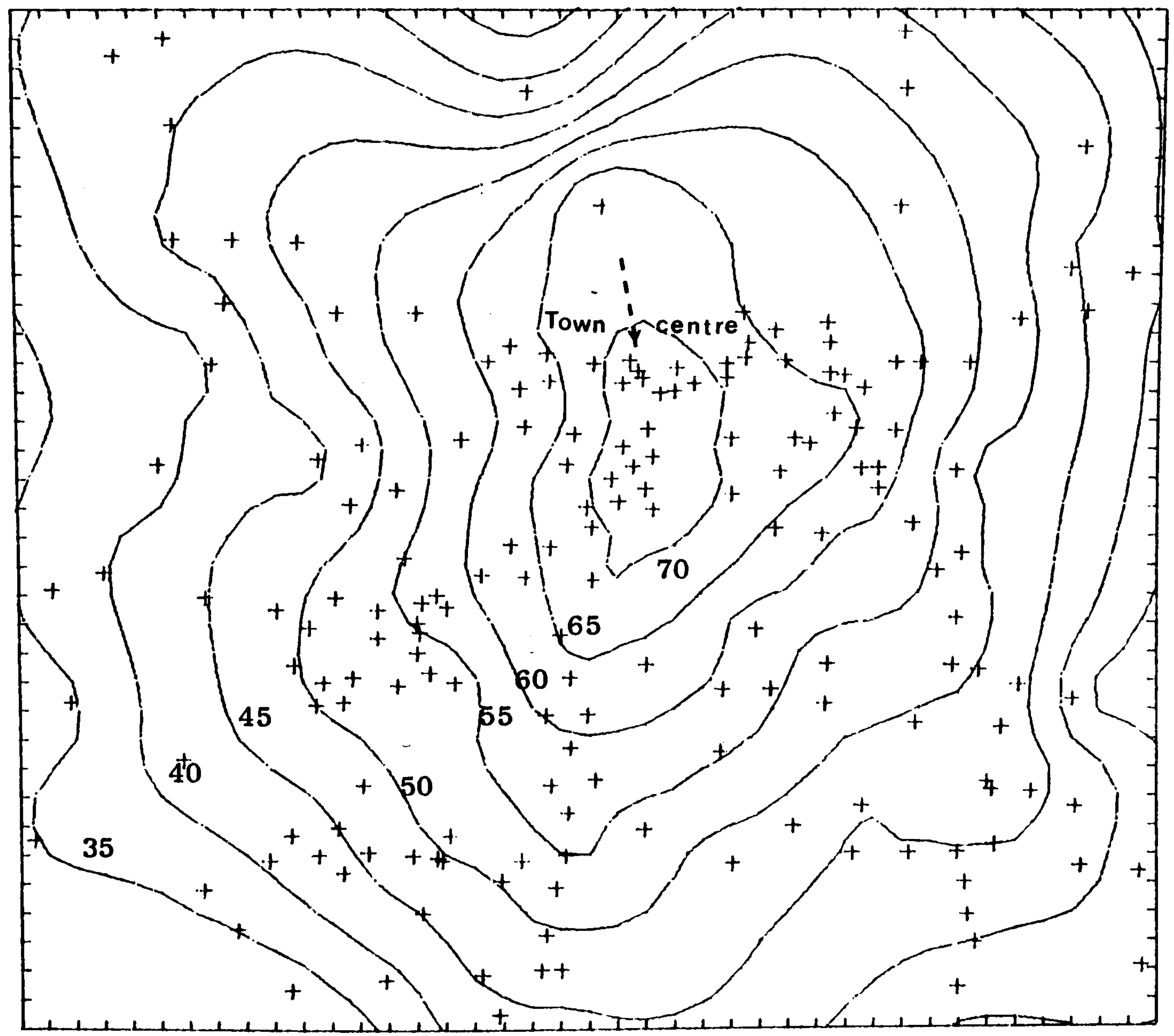


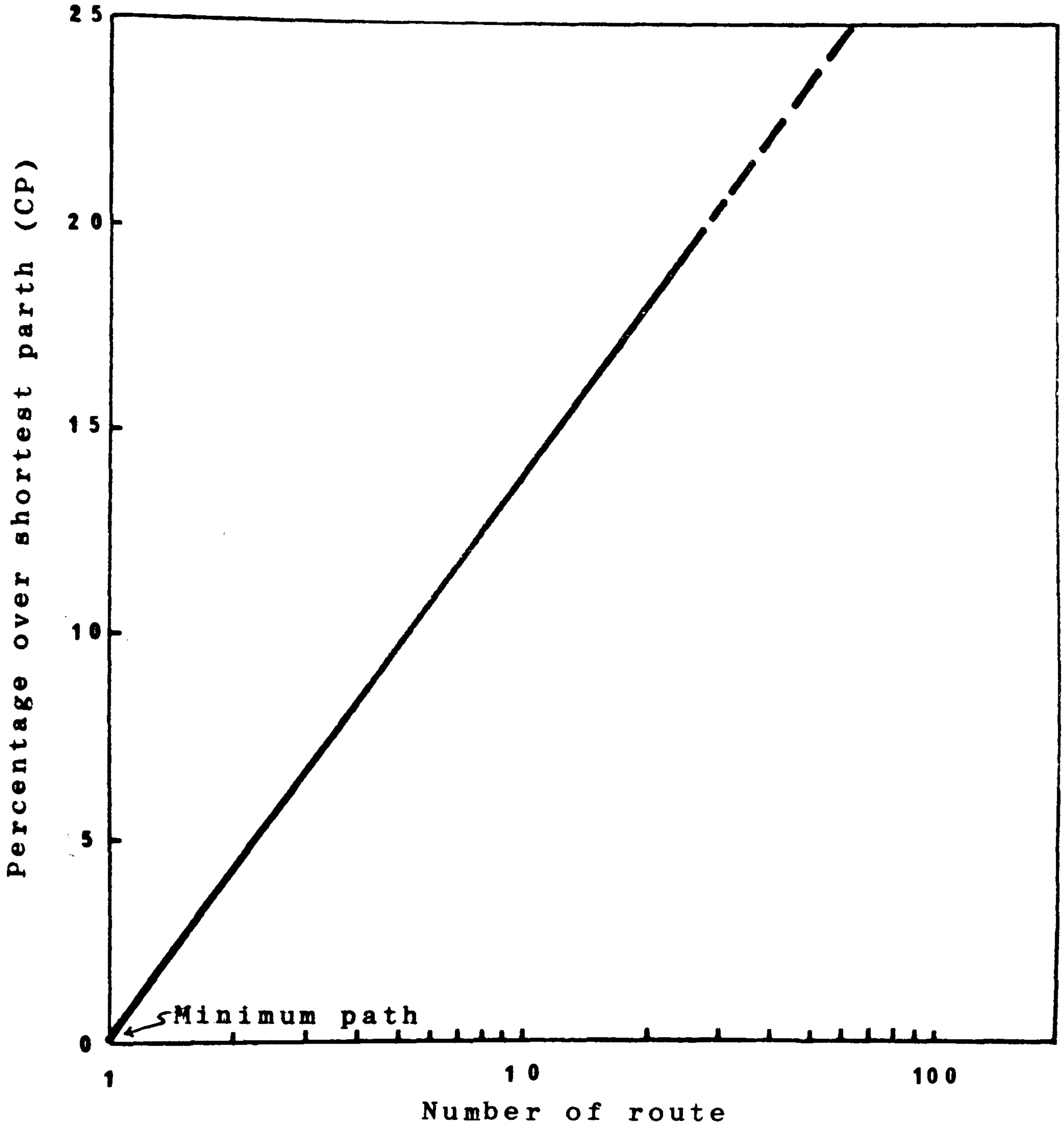
FIG. 10.4 HAMILTON ROAD NETWORK.



The figures represent relative weight of centrality.

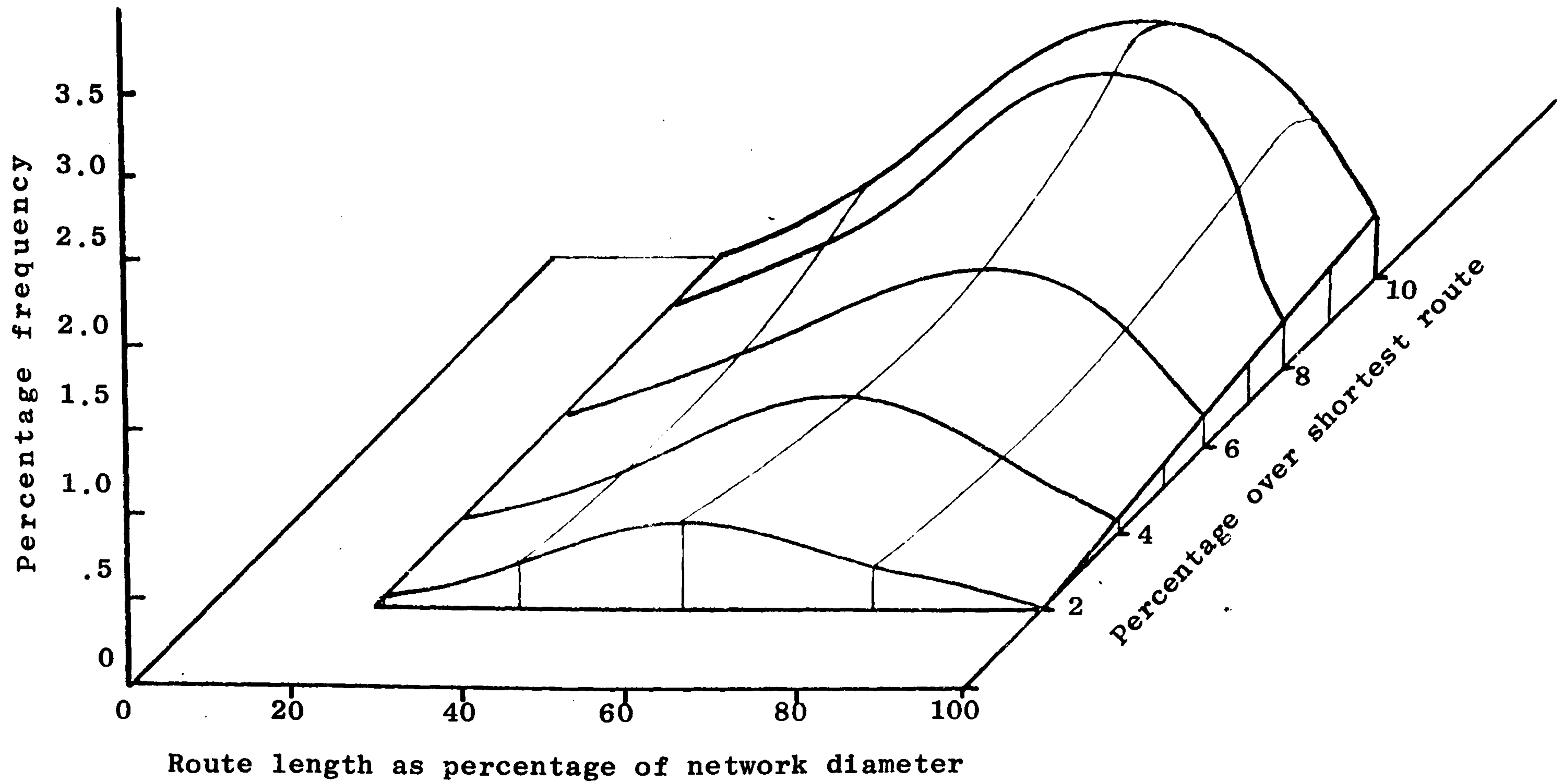
The points represent the links of road network.

FIG. 10.5 ACCESSIBILITY COUNTOUR LINESFOR HAMILTON.



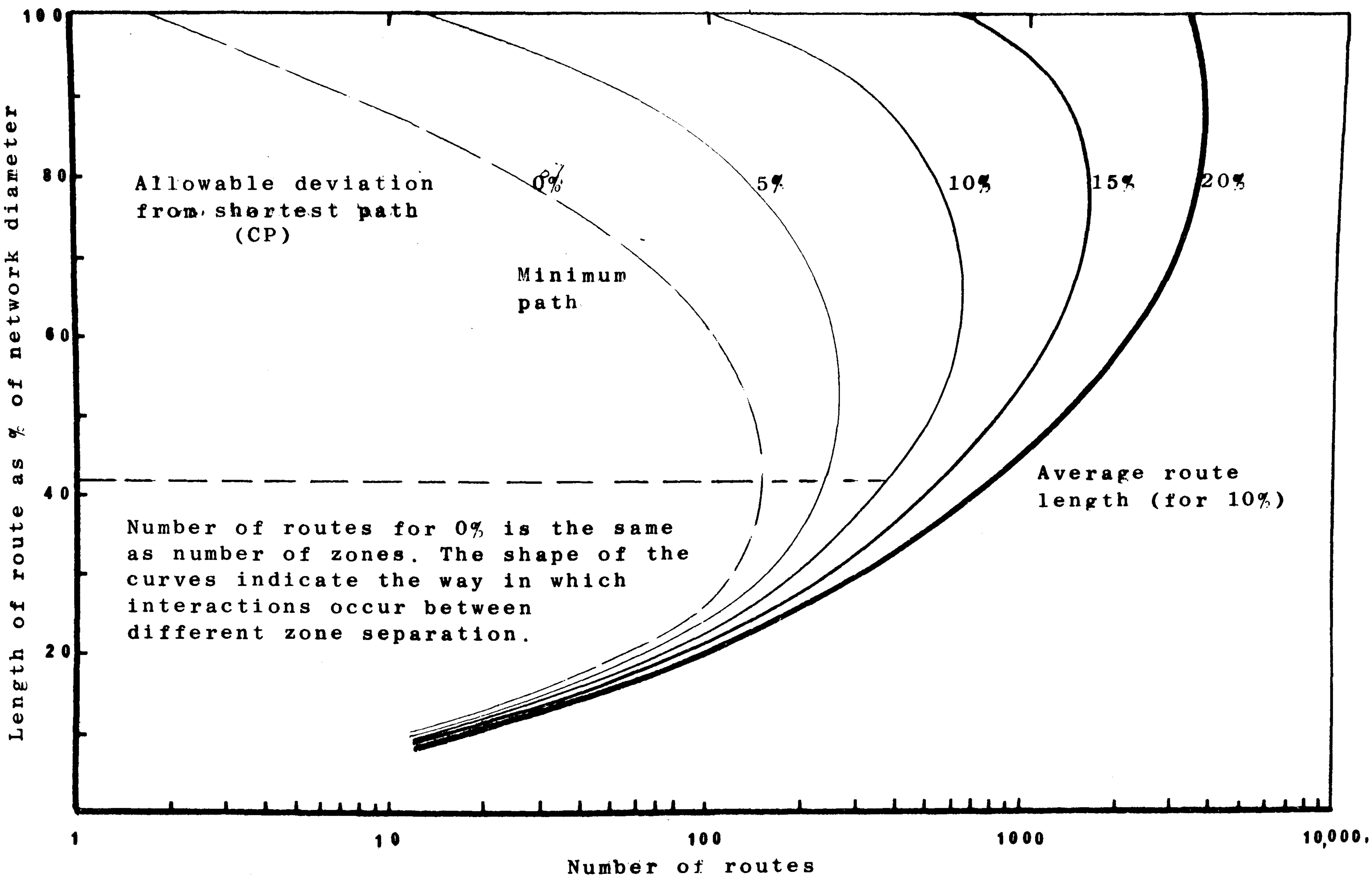
Average number of routes
between a pair of O-D
(Hamilton Network)

FIG. 10.6



Note : the journey unit is in terms of distance
the minimum paths omitted (see Table 10.2)

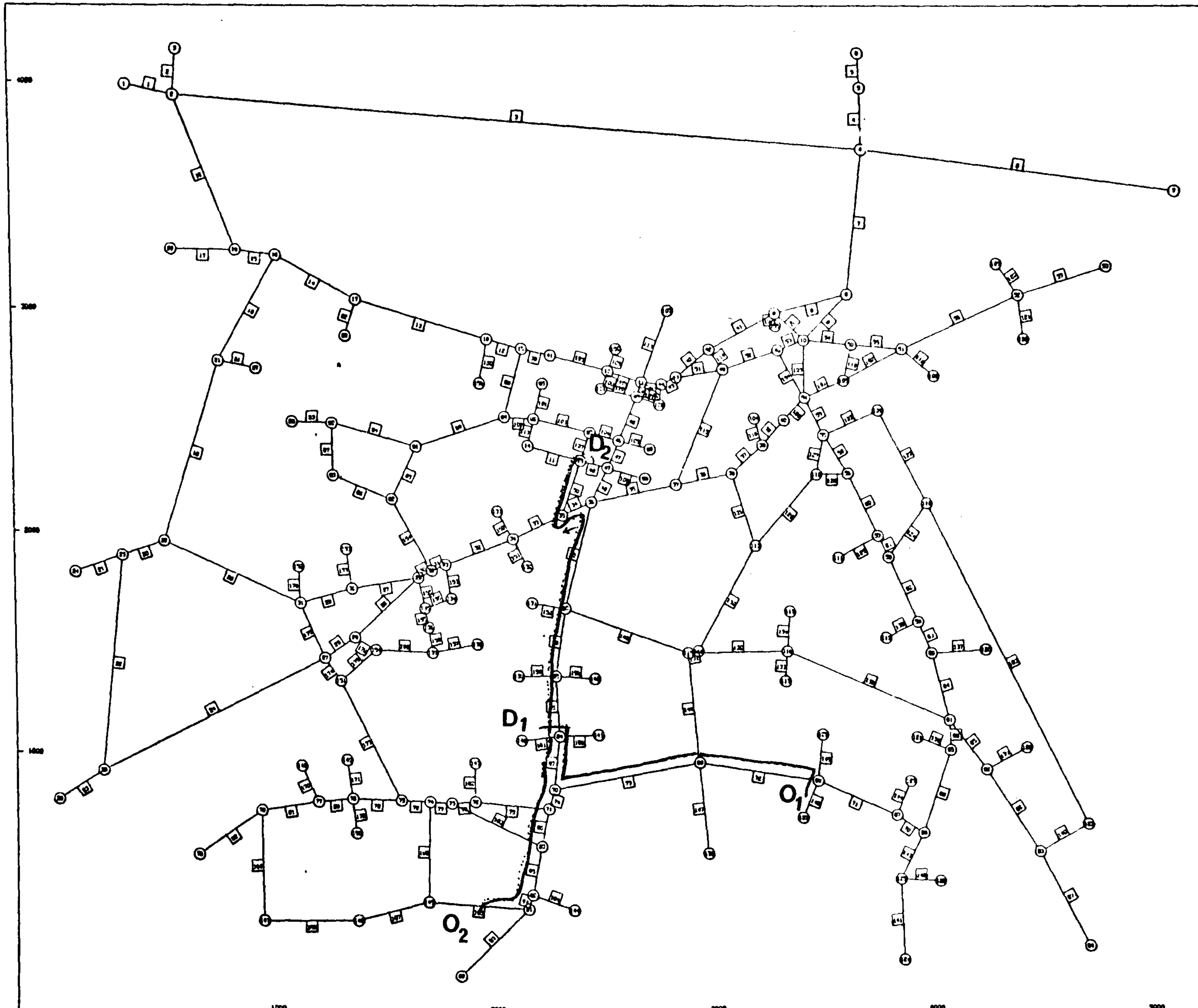
FIG. 10.7 ROUTE FREQUENCY DISTRIBUTION (%)
FOR HAMILTON NETWORK.



Number of possible routes between 677 pair of O-D for different allowable deviation from shortest path.

FIG. 10.8

NETWORKS



Network 10.1

One route example

UNIVERSITY OF STRATHCLYDE
DEPARTMENT OF CIVIL ENGINEERING
TRAFFIC ENGINEERING SECTION

GEDIAS SYSTEM
NETWORK DESCRIPTION DIAGRAM

NETWORK 30017
TITLE 42
FILE 1
SCALE 1.00

EXISTING NETWORK (2ND SERIES)

COMMENTS:

Origin (O)	Destination (D)
Sec.161	Sec.146 —
Sec.165	Sec.104 —

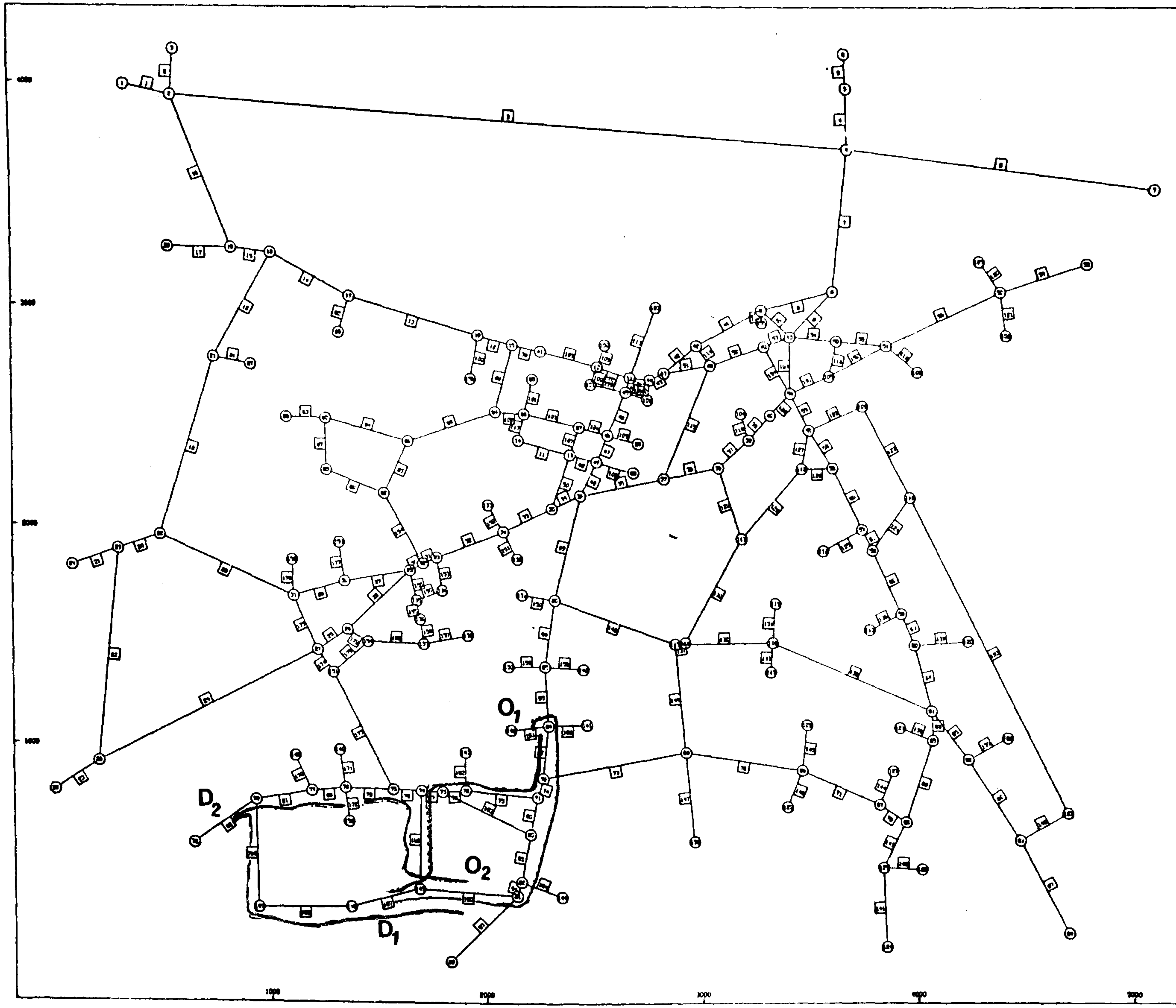
One way ←

DIAGRAM

JHAITKEN

JAN 1976

See Table 10.6



Network 10.2

Two route example

UNIVERSITY OF STRATHCLYDE
DEPARTMENT OF CIVIL ENGINEERING
TRAFFIC ENGINEERING SECTION

GEDIAS SYSTEM
NETWORK DESCRIPTION DIAGRAM

NETWORK	30017
TITLE	42
FILE	1
SCALE	1.00

EXISTING NETWORK (2ND SERIES)

COMMENTS:

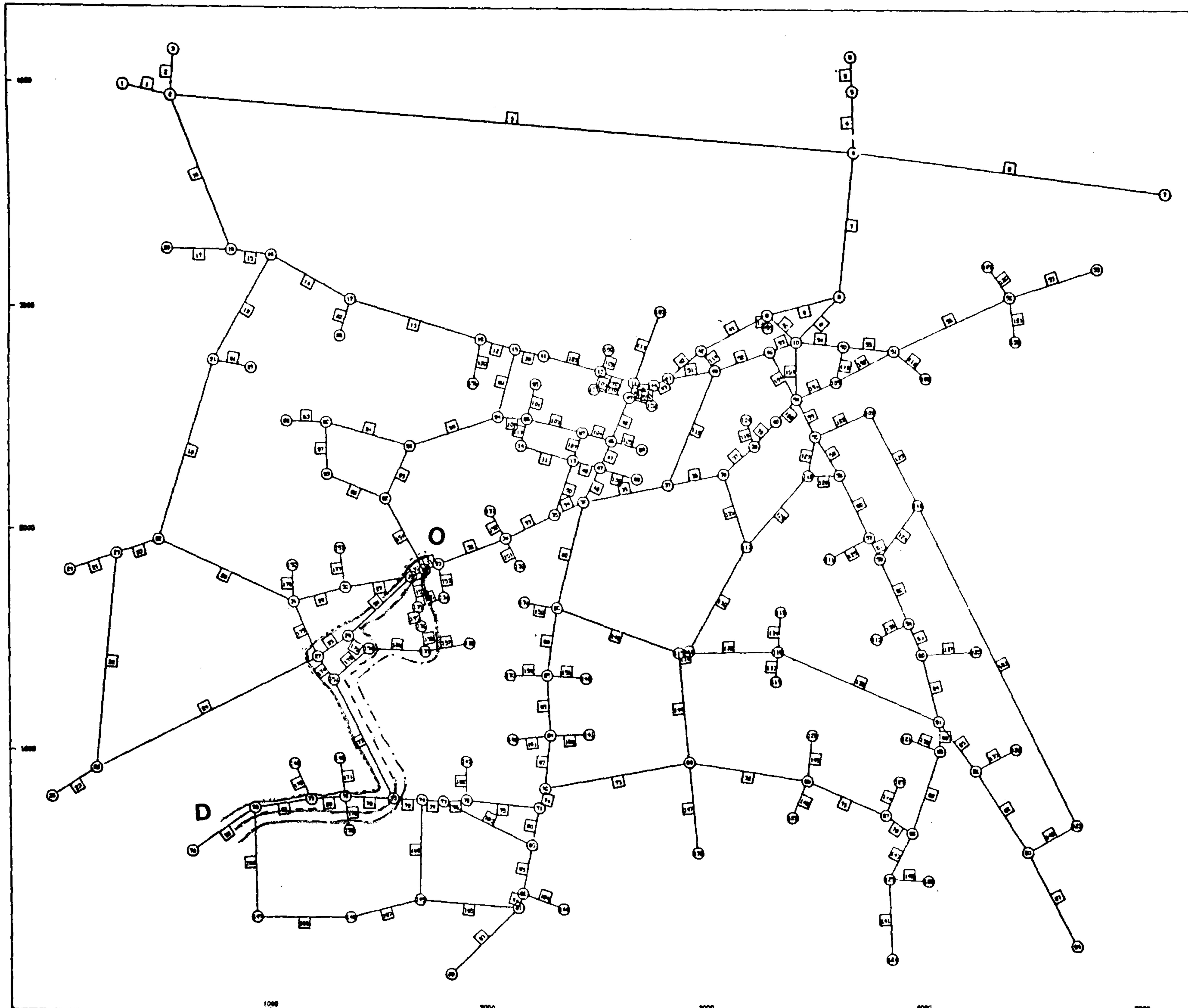
Origin(O)	Destination (D)
Sec.161	167
Shortest route:	——
2nd shortest ;	——
Sec.165	82
Shortest route:	——
2nd shortest :	——

DIAGRAM

JMAITKEN

JAN 1972

See Table 10.6



Network 10.3

Three route example

UNIVERSITY OF STRATHCLYDE
DEPARTMENT OF CIVIL ENGINEERING
TRAFFIC ENGINEERING SECTION

GEOIAS SYSTEM
NETWORK DESCRIPTION DIAGRAM

NETWORK	50017
TITLE	42
FILE	1
SCALE	1.00

EXISTING NETWORK (2ND SERIES)

COMMENTS:

Origin(O)	Destin-ation(D)
Sec.30	Sec.82

Shortest

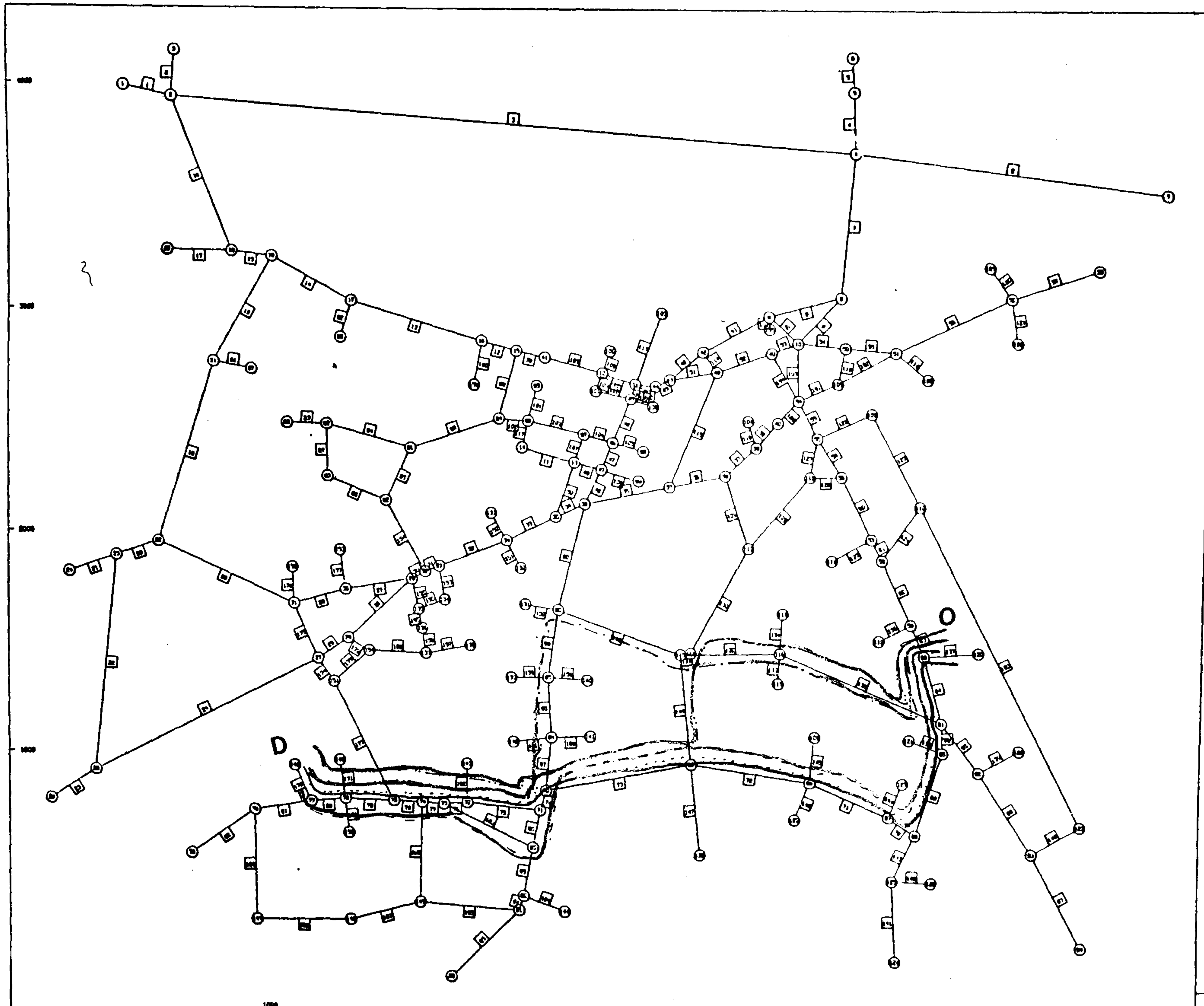
2nd shortest :

3rd shortedt :

DIAGRAM

JMAITKEN

See Table 10.7



Network 10.4

Four route example

UNIVERSITY OF STRATHCLYDE
DEPARTMENT OF CIVIL ENGINEERING
TRAFFIC ENGINEERING SECTION

GEOIAS SYSTEM
NETWORK DESCRIPTION DIAGRAM

NETWORK	50017
TITLE	42
FILE	1
SCALE	1.00

EXISTING NETWORK (2ND SERIES)

COMMENTS:

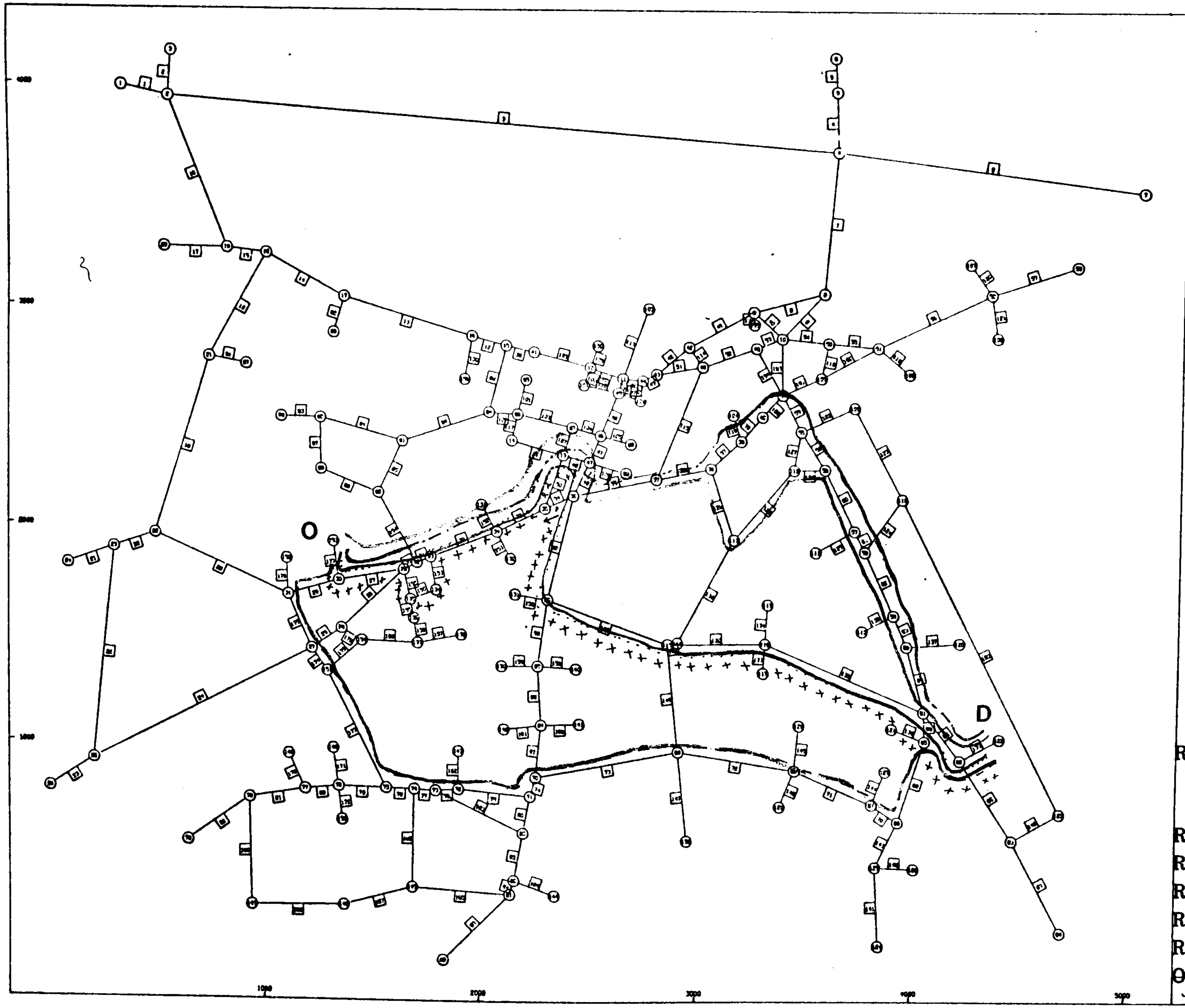
Routes from Sec.137 to 170

	Length
Route 1	3949
Route 2	4225
Route 3	4329
Route 4	4089

DIAGRAM

JMAITKEN

See Table 10.7



Network 10.5

Five route example.

UNIVERSITY OF STRATHCLYDE
DEPARTMENT OF CIVIL ENGINEERING
TRAFFIC ENGINEERING SECTION

GEDIAS SYSTEM
NETWORK DESCRIPTION DIAGRAM

NETWORK	50017
TITLE	42
FILE	1
SCALE	1.00

EXISTING NETWORK (2ND SERIES)

COMMENTS

Routes from Sec.177 to 139.

	Length
Route 1	4391
Route 2	4766
Route 3	4771
Route 4	4812
Route 5	4677
One way	←

DIAGRAM

JMAITKEN

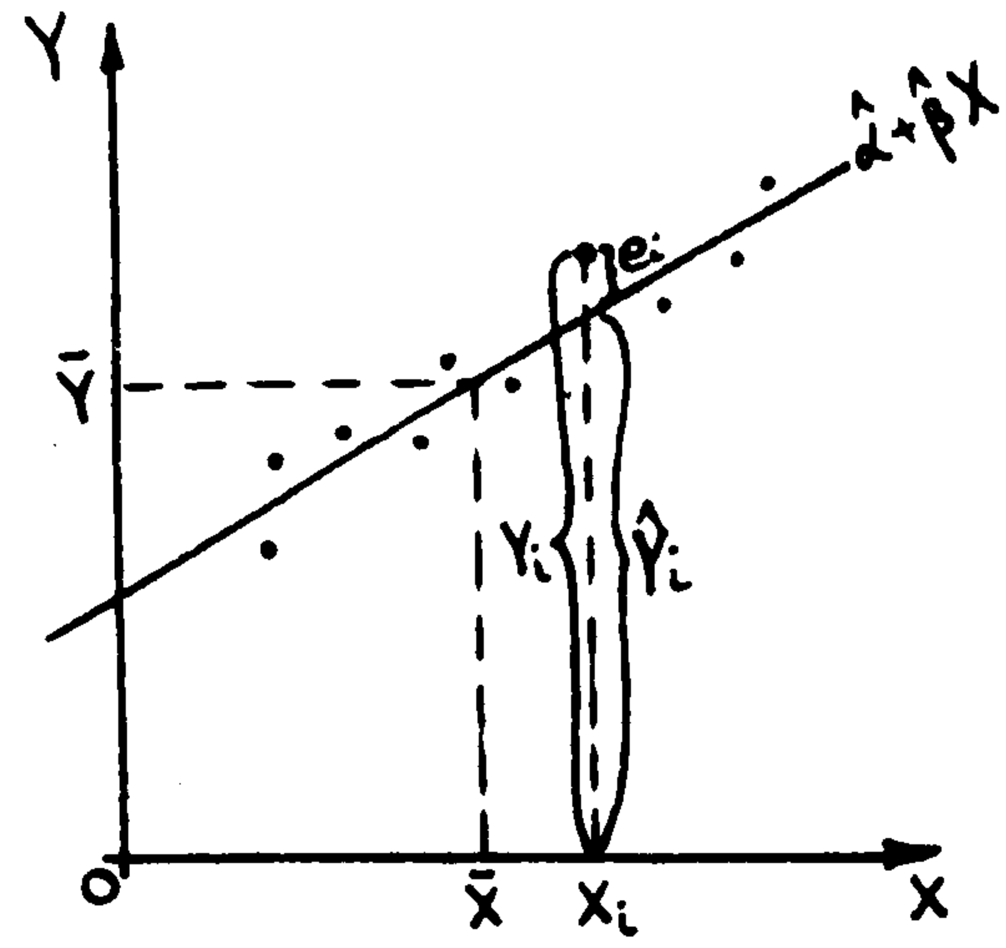
See Table 10.8

APPENDICES

University of Strathclyde
Department of Civil Engineering
Traffic Engineering Section

- APPENDIX -1

Applied Statistics - Summary of procedure for a simple linear normal regression model.



Sample observations are

$X_1, X_2, X_3, \ldots\ldots, X_n$
$Y_1, Y_2, Y_3, \ldots\ldots, Y_n$

Hypotheses are

$Y_i = \alpha + \beta X_i + u_i$ where $i = 1, 2, \ldots, n$

$E(u) = 0$ for all i

$$E(u_i u_j) = \begin{cases} 0 \text{ for } i \neq j;\ i,j = 1,2,\ldots,n \\ \sigma_u^2 \text{ for } i = j;\ i,j = 1,2,\ldots,n \end{cases}$$

Construct table thus

X	Y	X^2	Y^2	XY
X_1	Y_1	X_1^2	Y_1^2	X_1Y_1
X_2	Y_2	X_2^2	Y_2^2	X_2Y_2
⋮				
X_n	Y_n	X_n^2	Y_n^2	X_nY_n
ΣX_i	ΣY_i	ΣX_i^2	ΣY_i^2	ΣX_iY_i

Let
$x_i = X_i - \bar{X}$
$y_i = Y_i - \bar{Y}$
$\hat{y}_i = \hat{Y}_i - \bar{Y}$

Notes: $\hat{y}_i, \hat{\alpha}, \hat{\beta}$ denote "best estimates" of y_i, α, β.

$\bar{\hat{Y}} = \bar{Y}$.

$$\bar{X} = \frac{\Sigma X_i}{n}, \quad \bar{Y} = \frac{\Sigma Y_i}{n}$$

$$\Sigma x_i^2 = \Sigma(X_i - \bar{X})^2 = \Sigma(X_i^2) - \frac{(\Sigma X_i)^2}{n} \qquad S_x^2 = \frac{\Sigma x_i^2}{n-1}$$

$$\Sigma y_i^2 = \Sigma(Y_i - \bar{Y})^2 = \Sigma(Y_i^2) - \frac{(\Sigma Y_i)^2}{n} \qquad S_y^2 = \frac{\Sigma y_i^2}{n-1}$$

$$\Sigma x_i y_i = \Sigma(X_i - \bar{X})(Y_i - \bar{Y}) = \Sigma(X_iY_i) - \frac{\Sigma X_i \Sigma Y_i}{n} \qquad S_{xy} = \frac{\Sigma x_i y_i}{n-1}$$

$$\hat{\beta} = \frac{\Sigma x_i y_i}{\Sigma x_i^2} = \frac{S_{xy}}{S_x^2} = r.\frac{S_y}{S_x} \qquad \hat{\alpha} = \bar{Y} - \hat{\beta}\bar{X}$$

95% confidence intervals are $\hat{\beta} \pm t_{0.25}\dfrac{\hat{\sigma}_u}{\sqrt{\Sigma x_i^2}}$, $\hat{\alpha} \pm \dfrac{\hat{\sigma}_u \sqrt{\Sigma X_i^2}}{\sqrt{n \Sigma x_i^2}}$

where $\hat{\sigma}_u^2 = \Sigma e^2 / n-2$

$$r = \frac{S_{xy}}{S_x . S_y} = \frac{\Sigma x_i y_i}{\sqrt{\Sigma x_i^2} . \sqrt{\Sigma y_i^2}} \qquad t = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}} \text{ with } n-2 \text{ D.F.}$$

$$r^2 = \frac{\text{explained variation}}{\text{total variation}} \qquad 1 - r^2 = \frac{\text{unexplained variation}}{\text{total variation}}$$

$\Sigma y_i^2 = \Sigma \hat{y}_i^2 + \Sigma e_i^2$ ie TSS = RSS + ESS ie $\sigma_y^2 = \sigma_y^2 . r^2 + \sigma_y^2(1-r^2)$

$\Sigma e_i^2 = \Sigma y_i^2 - \Sigma \hat{y}_i^2 = \Sigma y_i^2 - \hat{\beta}^2 \Sigma x_i^2$

Analysis of variance as set out below

	Sum of squares	D.F.	Variance
Explained by Regression line (RSS)	$\Sigma \hat{y}_i^2$	1	$\Sigma \hat{y}_i^2$ (V_R)
Residual (ESS)	Σe_i^2	n-2	$\frac{\Sigma e_i^2}{n-2}$ (V_E)
Total (TSS)	$\Sigma y_i^2 = \Sigma \hat{y}_i^2 + \Sigma e_i^2$	n-1	

$F = V_R / V_E$ compared with values in F-distribution table.

- APPENDIX - 2

Brief summary of Linear Multiple Regression Model.

$$Y = \begin{bmatrix} Y_1 \\ Y_2 \\ \vdots \\ Y_n \end{bmatrix} \quad X = \begin{bmatrix} 1 & X_{21} \cdots X_{k1} \\ 1 & X_{22} \cdots X_{k2} \\ \vdots & \vdots \\ 1 & X_{2n} \cdots X_{kn} \end{bmatrix} \quad \beta = \begin{bmatrix} \beta_1 \\ \beta_2 \\ \vdots \\ \beta_k \end{bmatrix} \quad \hat{\beta} = \begin{bmatrix} \hat{\beta}_1 \\ \hat{\beta}_2 \\ \vdots \\ \hat{\beta}_k \end{bmatrix} \quad u = \begin{bmatrix} u_1 \\ u_2 \\ \vdots \\ u_n \end{bmatrix} \quad e = \begin{bmatrix} e_1 \\ e_2 \\ \vdots \\ e_n \end{bmatrix}$$

$$Y = X\beta + u = X\hat{\beta} + e$$

Least squares estimator of β is $\hat{\beta} = (X'X)^{-1}X'Y$

which is the best linear unbiased estimate with $\mathrm{var}(\hat{\beta}) = \sigma^2$

Unbiased estimator of σ^2 is $\hat{S}^2 = e'e/(n-k)$.

$$R^2_{1.23\ldots k} = \frac{\hat{\beta}'X'Y - \frac{1}{n}(\Sigma y)^2}{Y'Y - \frac{1}{n}(\Sigma y)^2}$$

Test of $\beta_2 = \beta_3 = \ldots\ldots = \beta_k = 0$ is based on

$$F = \frac{R^2/(k-1)}{(1-R^2)/(n-k)} \quad \text{with } (k-1,\, n-k) \text{ DF}$$

Test of $\beta_i = 0$ where $i = 1, 2, \ldots\ldots, k$ is based on

$$t = \frac{\hat{\beta}_i - \beta_i}{s\sqrt{a_{ii}}} \quad \text{with } (n-k) \text{ DF}$$

where a_{ii} is the ith element in the principal diagonal of $(X'X)^{-1}$

APPENDIX-3-

Values of Time Used in Recent British Transport Studies

Year of Study	Study	Price Level	Car drivers working time		Car passengers working time		Adults commuting time		Adults other non-working time	
			Pence per Hour	Annual Growth Factor (per cent)	Pence per Hour	Annual Growth Factor (per cent)	Pence per Hour	Annual Growth Factor (per cent)	Pence per Hour	Annual Growth Factor (per cent)
1968	London	1966	50	2.80	50	2.80	17	2.80	17	2.80
1968	Oxford	1966	60	2.25	60	2.25	20	2.25	20	2.25
1969	W. Yorks	1966	15	2.50	15	2.50	15	2.50	15	2.50
1969	Merseyside	1967	67	3.00	67	3.00	15	3.00	15	3.00
1971	Slough	1968	123	3.25	123	3.25	16	3.00	16	3.00
1972	Edinburgh	1968	110	3.25	94.5	3.25	15	3.00	13.5	3.00
1972	Hull	1968	110	1.90	94.5	2.75	15	1.80	13.5	1.80
1970	Corby	1969	123	3.25	106	3.25	16	3.00	16	3.00
1971	Glasgow	1969	123	3.00	106	3.00	16	3.00	16	3.00
1972	Tyne-Wear	1969	16	3.00	16	3.00	16	3.00	16	3.00
1971	Selnec	1968/9	118	3.25	118	3.25	16	3.00	16	3.00

*Extract from WP 23 = "Urban Transport Evaluation Procedures" by M.Q. Dalvi and K. Martin, Institute for Transport Studies, University of Leeds.

Source: PTRC Spring Course 1976, Transportation Model Theory, 3-7 May (P.Hills)

APPENDIX 4

Examples of Current Valuations of Travel-Time Savings

1. WINFREY, R. (1969 prices)

"Reasonable" values for car users in U.S.A. for normal spread of journey purposes lie in the range .. .. .. $1.00 - $4.00

i.e. @ $2.40 = £1.00 .. .. 42p - £1.67 per hour

2. ROSKILL COMMISSION

The research team adopted the following figures for comparing "access" times to the four sites:

Work trips - car users	£1.07 per hour
truck users	0.47 per hour
Non-work trips - adults	0.16 per hour
children .. .	0.05½ per hour

3. ALDER, W. (1965 prices)

Japanese survey by Brookings Institute:

Sample 80% lie limits for car-users in Japan for normal spread of journey purposes lie in the range .. .. $1.00 - $2.00 per hour

i.e. @ $2.80 = £1.00 .. .. 36 - 72 p/hour

The equivalent range for bus users was reckoned to be .. .. 0.20 - $1.00 per hour

i.e. @ $2.80 = £1.00 .. .. 7 - 36 p/hour

4. R.R.L. TECH. PAPER 75 (1968 prices)

Based upon the T.A.L. (Travel and Accident Loss) Assessment, the following figures were recommended for evaluation of highway improvements:

Work trips - all persons	67½ p/hour
Non-work trips - all persons	15 p/hour

5. HARRISON, A. and QUARMBY, D. (1969 prices)

In M.A.U. Note 154, they report "current British values" related to wage rates* for various categories of people on work-trips:

All workers	97 p/hour
Car drivers	£1.09 per hour
Car passengers	93 p/hour
Goods vehicle drivers ..	50 p/hour
Bus drivers	50 p/hour
Bus conductors	45 p/hour
Bus passengers	57 p/hour
Train passengers	£1.16 per hour

6. SATCHWELL, P. (1971 prices)

Figures adopted by British Rail to justify investment in capital renewal schemes:

Work trips - train passengers	£ 1.31 per hour
Commuting trips - adults	16½ p/hour
Non-work trips - adults	14½ p/hour
- children	5 p/hour

In addition a perceived weighting factor of 2.0 is applied to all walking and waiting time consumed within the system.

Estimates of the growth of average incomes (in real terms) which will affect the overall value of travel time savings vis-a-vis other benefits resulting from transport vary:

National Plan (1964)	4% per annum
Actual (1963-70 incl.)	2.8% per annum
G.L.C. forecast 1966-81	3.0% per annum
Provisional (1971)	2.4% per annum

Relationship between values for 'work'trips and 'non-work' trips

The results of a number of behavioural studies involving the "trade-off" between travel time and travel cost have revealed various proportionate relationships between the value of 'non-work' time savings and average hourly rate of earning:

Commuting trips -	Quarmby & Stopher	20% - 25%
	Barnett & Saalmans	15% - 30%
	Lee & Dalvi	15% - 45%
	Beesley	30% - 50%
	L.G.O.R. Unit	20% - 25%
	G.L.C.	25% - 33%

Other 'non-work' trips-

Roskill	15 %
T.A.L Assessment	22 %
Satchwell (B.R.)	11%

Variations arise from the use of weighted and unweighted elapsed times and modified wage rates as well as basic differences in experimental technique. Much research remains to be done.

Source : PTRC Spring Course 1976, Transportation Model Theory 3-7 May. (P.Hills)

*where these are weighted by the mileage travelled by each income group

APPENDIX - 5 -

Car Operating Costs, 1973

Fixed costs per annum (£) Engine capacity cc's	up to 1,000	1,001– 1,500	1,501– 2,000	2,001– 3,000	3,001– 4,500
Motor and driving licences	25.33	25.33	25.33	25.33	25.33
Insurance	79.16	90.50	103.55	164.42	174.10
Depreciation	95.78	128.08	169.88	257.76	329.21
Interest on capital	38.31	51.23	67.95	103.11	131.67
Garage/parking	52.00	52.00	52.00	52.00	52.00
	290.58	347.14	418.71	602.62	712.31
Running costs (pence per mile)					
*Petrol	1.009	1.308	1.546	1.858	2.317
Oil	0.061	0.076	0.096	0.120	0.166
Tyres	0.111	0.129	0.152	0.219	0.286
Servicing	0.180	0.193	0.202	0.217	0.282
Repairs and replacements	0.650	0.698	0.816	1.039	1.318
Marginal costs	2.011	2.404	2.812	3.453	4.369
*At 40p per gallon.					
For every penny more or less, add	0.025	0.033	0.039	0.046	0.059
Average costs (pence per mile)					
Running:					
5,000 miles per annum	7.823	9.346	11.186	15.505	18.615
10,000 miles per annum	4.917	5.875	6.999	9.479	11.492
15,000 miles per annum	3.955	4.725	5.610	7.477	9.125
20,000 miles per annum	4.376	4.161	4.917	6.478	7.942

Source: AA Schedule of Estimated Running Costs, 1973.

APPENDIX-6-

Breakdown of the operating cost formulae

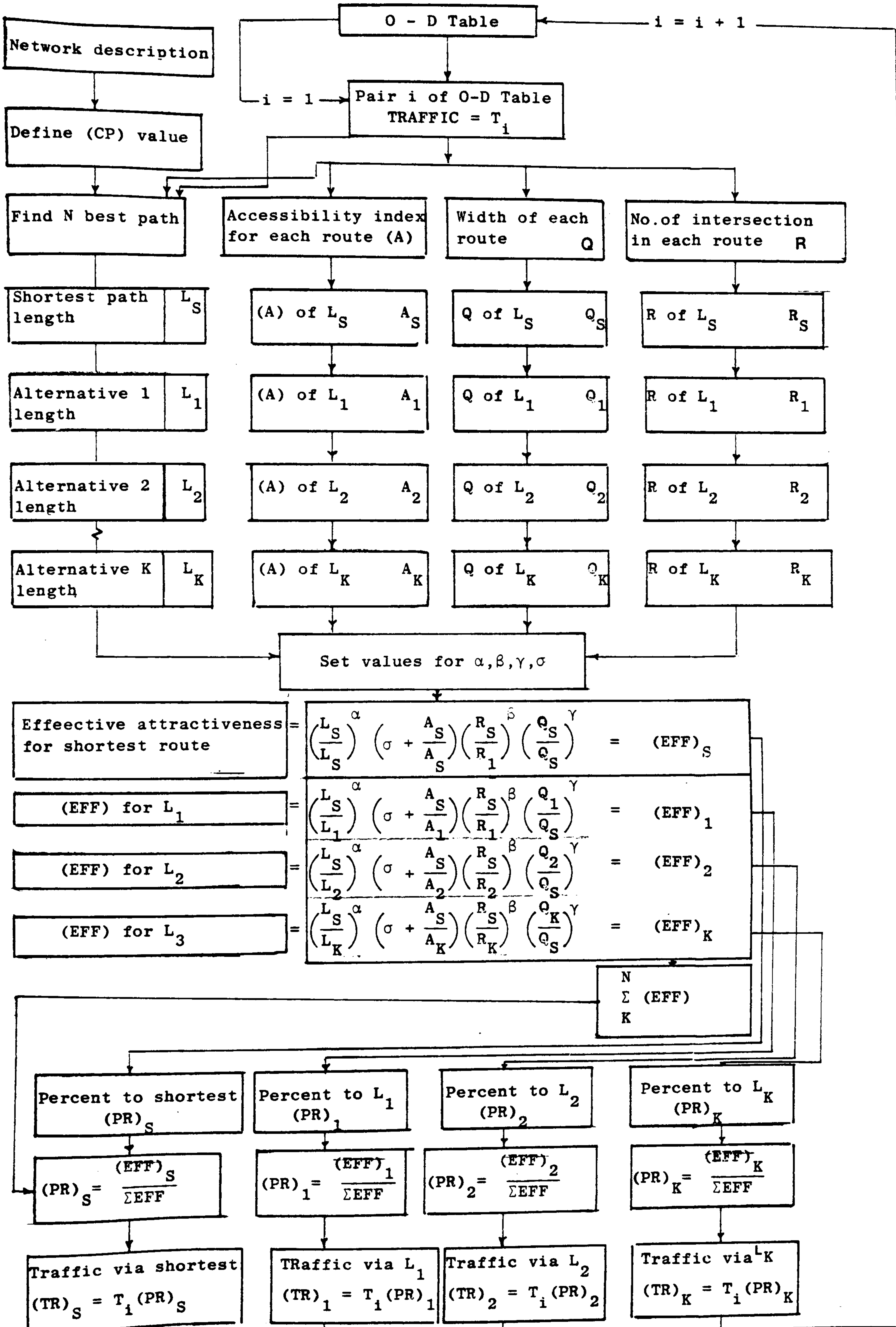
1973

Vehicle	Item	Costs per kilometre a	Costs per kilometre b	Costs per kilometre c	Costs per mile a	Costs per mile b	Costs per mile c
Car	Fuel – net	0.25	13.5	0.000 033	0.41	13.5	0.000 139
	Fuel – gross	0.41	21.4	0.000 053	0.65	21.4	0.000 220
	Oil	0.05	–	–	0.08	–	–
	Tyres	0.08	–	–	0.13	–	–
	Maintenance	0.45	4.1	0.000 010	0.72	4.1	0.000 042
	Depreciation etc	0.30	1.0	–	0.49	1.0	–
	Time	–	81.0	–	–	81.0	–
	Total – net	1.13	99.6	0.000 043	1.83	99.6	0.000 181
	Total – gross	1.29	107.5	0.000 063	2.07	107.5	0.000 262
Van	Fuel – net	0.32	13.9	0.000 036	0.52	13.9	0.000 150
	Fuel – gross	0.52	22.9	0.000 059	0.84	22.9	0.000 247
	Oil	0.08	–	–	0.12	–	–
	Tyres	0.15	–	–	0.24	–	–
	Maintenance	0.87	7.1	0.000 018	1.40	7.1	0.000 077
	Depreciation etc	0.70	2.9	–	1.13	2.9	–
	Time	–	120.0	–	–	120.0	–
	Total – net	2.12	143.9	0.000 054	3.41	143.9	0.000 227
	Total – gross	2.32	152.9	0.000 077	3.73	152.9	0.000 324
Other goods vehicle	Fuel – net	1.11	15.8	0.000 070	1.79	15.8	0.000 290
	Fuel – gross	1.87	26.6	0.000 117	3.01	26.6	0.000 488
	Oil	0.11	–	–	0.18	–	–
	Tyres	0.61	–	–	0.98	–	–
	Maintenance	1.88	6.9	0.000 030	3.02	6.9	0.000 126
	Depreciation etc	1.02	7.5	–	1.64	7.5	–
	Time	–	128.0	–	–	128.0	–
	Total – net	4.73	158.2	0.000 100	7.61	158.2	0.000 416
	Total – gross	5.49	169.0	0.000 147	8.83	169.0	0.000 614
Public service vehicle	Fuel – net	1.37	22.1	0.000 073	2.21	22.1	0.000 304
	Fuel – gross	2.31	37.2	0.000 122	3.72	37.2	0.000 512
	Oil	0.11	–	–	0.17	–	–
	Tyres	0.47	–	–	0.75	–	–
	Maintenance	2.74	11.3	0.000 028	4.41	11.3	0.000 115
	Depreciation etc	1.77	22.7	–	2.85	22.7	–
	Time	–	633.0	–	–	633.0	–
	Total – net	6.46	689.1	0.000 101	10.39	689.1	0.000 419
	Total – gross	7.40	704.2	0.000 150	11.90	704.2	0.000 627

Source : TRRL 661

	References in Tables	Components Separately Identified
	Transport and Vehicles	
77	Net purchase of motor vehicles, spares and accessories	New cars Second-hand cars Car spares and accessories, new and second-hand Motor and motor-assisted cycles and scooters Motor and motor-assisted cycles and scooters
78	Maintenance and running of motor vehicles	Repairs and servicing of road motor vehicles Petrol, oil Driving licences Motor vehicle taxation Motor vehicle insurance Garage rent AA, RAC etc. subscriptions Other road motor vehicle costs, eg cleaning materials, parking fees
79	Purchase and maintenance of other vehicles and boats	Bicycles, perambulators, boats etc. new and second-hand Accessories, repairs and other costs
80	Railway fares	Rail and tube fares, other than season tickets Rail and tube season tickets
81	Bus and coach fares	Bus and coach fares, other than season tickets Bus and coach season tickets
82	Other travel and transport	Taxis and hired cars with drivers Contribution towards cost of travel in friend's car etc. Hire of self-drive cars Water travel, including season tickets Air travel Other travel and transport, eg. household removals and storage, transport of luggage, animals etc.

APPENDIX 8



Relative Attractiveness Traffic Assignment Model.

APPENDIX 9

Relative attractiveness method

Section No.	7	14	29	35	42	51	56	67	73	82	83	149	Notes
Observed	16105	8269	7126	8410	6757	8723	5397	2592	2898	2528	1008	2777	
All-or-no.	15963	7378	6234	10551	7071	5657	5729	=	3128	2596	984	1780	
Multipath	=	=	6280	10400	6848	6120	=	=	3304	=	=	2424	
Cap.Res.	=	11128	3912	7216	6192	8120	=	=	5592	=	=	1456	
γ = 0.1	15963	6954	7092	7755	7085	8418	=	=	2954	=	=	2593	CP=10
γ = 0.5	=	6962	7085	7645	7122	8540	=	=	2938	=	=	2569	$\alpha=1.0$
γ = 1.5	=	6979	7070	7424	7197	8780	=	=	2906	=	=	2523	$\sigma=1.0$
γ = 2.0	=	=	7060	7316	7234	8897	=	=	2893	=	=	2499	$\beta=0.5$
α = 0.1	=	7005	7045	7527	7157	8677	=	=	2920	=	=	2545	CP=10
α = 0.5	=	=	=	5530	=	8671	=	=	=	=	=	=	$\sigma=1.0$
α = 1.0	=	=	=	=	=	=	=	=	=	=	=	=	$\beta=0.5$
α = 1.5	=	=	=	=	=	=	=	=	=	=	=	=	$\gamma=1.0$
β = 0.1	=	=	=	7453	7191	8759	=	=	2904	=	=	2513	CP=10
β = 1.0	=	=	=	7643	7118	8531	=	=	2945	=	=	2587	$\alpha=1.0$
β = 1.5	=	=	=	7762	7075	8393	=	=	2968	=	=	2627	$\sigma=1.0$
β = 2.0	=	=	=	7889	7033	8248	=	=	2991	=	=	2669	$\gamma=1.0$
β = 0.1	=	=	=	7244	7266	8987	=	=	2875	=	=	2464	CP=10
β = 1.0	=	=	=	7417	7194	8776	=	=	2914	=	=	2540	$\alpha=1.0$
β = 1.5	=	=	=	7619	7100	8570	=	=	2943	=	=	2562	$\sigma=1.0$ $\gamma=2.0$

Note : Calibration of relative attractiveness assignment model can be carried out as shown above and a reasonable value of the parameters as given in equation 10.9 can be chosen.

Observed and predicted traffic volume on Hamilton nework..