ACCESSIBILITY INDICES AND LINKED TRIPS:
A CASE STUDY OF THE ELDERLY

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Submitted in partial fulfillment of
the degree of Doctor of Philosophy

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SUMMARY

The confusion over the concept of accessibility in transport planning and the deficiencies of existing accessibility indices are examined by developing a conceptual framework of accessibility with a fundamental distinction being drawn between the, often conflicting, theoretical and practical dimensions.

The theoretical validity of alternative indices is assessed with reference to the problems and assumptions implicit in defining, measuring, valuing and aggregating the variables and components comprising accessibility. The major deficiencies of existing indices are identified as the inability of indices to take account of the potential to link trips between more than one activity location and the level of assumptions implicit in valuing and aggregating accessibility information. In this context, it is argued that accessibility information is more appropriately expressed on a comparative basis in the form of a profile rather than as a composite single-unit index and that the present confines of accessibility measurement must be extended in line with current developments in disaggregate travel and activity modelling.

The sensitivity of accessibility levels to the use of alternative value judgements, alternative forms and levels of aggregation and the inclusion of information on the potential to link trips is examined by undertaking a case study. Accessibility profiles are developed for 23 zones in the London Borough of Hammersmith and Fulham showing the accessibility of the elderly to post offices and grocers. In a practical context, the profiles assist in identifying areas and individuals with relatively poor accessibility. The incidence and nature of linked trip-making and its significance and implications for accessibility measurement are explored further by analysing the results of a survey of the elderly's travel patterns. It is concluded that future accessibility analysis should be undertaken at a disaggregate level, taking account of the potential opportunity available from non-home as well as home origins.

Accessibility Multi-Purpose Elderly Inner-City Pedestrian

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CHAPTER ONE

RESEARCH CONTEXT AND STRUCTURE

1.1. INTRODUCTION

This research has been undertaken through a Science Research Council CASE(Co-operative Award in Science and Engineering) award in collaboration with the London Borough of Hammersmith and Fulham. The concept of accessibility has been investigated in the context of local transport and land-use planning in the Borough of Hammersmith and Fulham - a second tier local authority in the Greater London area. The research focuses on the role of accessibility as a transport planning tool set within a framework of policy decision-making.

The broad aims of the research are to formulate accessibility indices appropriate to local transport planning policy decisions and in so doing identify the deficiencies of existing accessibility measures and to analyse the extent to which these deficiencies distort and misrepresent accessibility information. In this light consideration is given to the range of local transport and planning issues in which the notion of accessibility has an input and to the problems and assumptions inherent in defining and quantifying accessibility. The research is, therefore, taken to comprise two dimensions. Firstly, accessibility is seen to have a practical content relating to the operational requirements of the index and, secondly, is seen to have a theoretical content relating to the principles of measurement. The research problem is fundamentally one of reconciling the conflicting practical and theoretical requirements of accessibility measurement.

1.2. PRACTICAL CONTEXT

The research is undertaken in the context of accessibility levels in inner urban areas and, more specifically, the London Borough of Hammersmith and Fulham. The practical aim of the research is to provide accessibility information on which the Local Authority can identify areas (and persons) with poor accessibility relative to the other areas of the Borough and which assists in formulating policies that alleviate these accessibility problems. Whilst the notion of accessibility is potentially of considerable use to local authorities in land-use and transport policy formulation and decision-making its precise intended application requires some clarification.

Accessibility measurement, within the context of local authority policy decision-making, has been afforded considerable attention over recent years but has been clouded in confusion and ambiguity due largely to the diverse range of issues and uses to which it has been applied. These alternative applications of accessibility indicators can be attributed to the changing emphasis of transport planning. Polus and Kumove (1979), for instance, identify five broad applications of accessibility as traffic engineering, environmental planning, transport and land-use planning, urban economics and urban development where, in each case, the term takes on different meanings. Similarly, Morris et. al. (1979) note that accessibility can be utilised in evaluating a transport/land-use system, modelling travel choice situations, modelling urban development and in describing spatial structure. Pirie (1979) has also noted the extensive use of the concept and identifies physical planning, home location, transport modelling (trip generation and mode choice) and urban economics (real income transfer) as subjects having an accessibility input.

The early use of accessibility was largely in response to increasing vehicle ownership which in turn led to a greater ability to travel (increased mobility). At this time transport planning was undertaken largely in the context of traffic and highway engineering in that the volume of vehicles, network capacities and road speeds were the basic parameters in the assessment of alternative transport schemes. The realisation that car ownership would ultimately reach a saturation point at which a significant proportion of the population would still be dependent on public transport together with a growing environmental awareness (for instance, the recognition of the social costs of congestion and pollution) diverted the attentions of transport planning to modal choice. The bulk of research focused on developing transport models through the now familiar stages of trip generation, trip distribution, trip assignment and modal split. The emphasis, however, was still placed on vehicle and personal movement between points on appropriate transport networks. Within this context Jones (1975) argues that this was "a mistaken emphasis on mobility and travel need as the basic issues in transport planning" and that accessibility has been confused with vehicle and personal movement.

The emergence of transport planning from the disciplines of highway engineering was accompanied by a recognition of the increasing influence of transportation on land-use planning. Bruton (1975) clarifies this point by stating that "transport and land-use planners have to realise the potential of transport to shape the urban environment by influencing the accessibility of locations within the urban area". More recently Morris et. al. (1979) note that "much greater emphasis is being given to the distributional questions and evaluation of alternative land-use/ transportation plans is no longer based entirely on efficiency criteria". Morris et. al. (1979) qualify this further by the statements that "the focus of transport planning is moving from vehicular mobility to personal mobility (Dalvi, 1978) and from traffic congestion to accessibility provision (from Wilson, 1972)". In general the construct of accessibility is associated with the shift away from traffic functional planning to viewing transport as the integration of the individuals' activity system (Benwell, 1977) and, thus, accessibility becomes a reflection of the demands of different social groups to reach destinations of specific interest and the ability of the transport system to satisfy these demands (Polus and Kumove, 1979).

Transport planning, has, therefore, diverted its attention to evaluating policies and programmes with regard to accessibility rather than simply vehicle movements. In an urban context this is seen to stem principally from three factors. Firstly, the notion of accessibility has, according to Breheny (1978), increased in significance over recent years due to both the energy crisis and the concern over the relative accessibility of different community groups to urban resources and the degree to which this affects the 'real income' of such groups. It is recognised that certain groups of the population are liable to be accessibility disadvantaged in that they do not and cannot gain access to a private car because of age, income and/or health constraints. This is supported by the 1975/76 National Travel Survey data which indicates that 46% of households do not own a car (Town, 1980), and, thus, an even greater proportion of individuals have no access to a car.

Secondly, whilst urban areas have higher public transport route densities and service levels than rural areas the maximisation of travel is not in itself an appropriate criterion on which to judge service performance and may lead to an inefficient use of resources and add to the social costs of congestion. For this reason there has been a shift from increasing the ability to travel in urban areas to improving accessibility. For instance, Gillespie (1980), in discussing the role of urban transport policy, argues that "the objective of mobility is accessibility" and, similarly, the Independent Commission on Transport (1974) states that "access, not movement, is the true aim of transport".

Thirdly, whilst mobility has been increasing in urban areas the provision of opportunities has been declining. The outward migration of industry and people has led to the inner city areas containing a disproportionate share of low income groups (Gillespie, 1980) for whom opportunities are increasingly inaccessible.

The long established urban communities have suffered a general decline in the provision of local facilities and services because of decentralisation or closure.

Within this context accessibility is seen as a major factor in determining the individuals "quality of life" (Hagerstrand, 1974) and constitutes a basic component of an individual's or area's social profile. In this sense it is considered important that land-use as well as transport policy is determined with regard to improving personal accessibility and, in order that this may be achieved, it is necessary to establish techniques that provide a true and comprehensive representation of accessibility levels on which policy decisions may be taken.

1.3. THEORETICAL CONTEXT

The confusion and ambiguity arising from the different meanings and applications of accessibility have led to the lack of any consistent definition of the concept and the absence of any comprehensive framework in which indices can be assessed.

The majority of authors, in studying the concept of accessibility, have placed great emphasis on the problems and complexities of the subject. For instance, Ingram (1971) states that "accessibility is rarely defined let alone measured in quantifiable terms" and Vickerman (1974) adds that "accessibility is not easy to define in unambiguous and quantifiable terms". This ambiguity associated with defining accessibility is also recognised by Ireland (1972) in that "it is an imprecise notion, and a number of possible definitions have been proposed". Jones (1975) adds further support to this view by noting that "there has been some confusion over terminology and a general lack of clarity over the concepts involved". It is not surprising, therefore, that Pirie (1979), in reviewing accessibility, expresses doubt about our full grasp of the concept.

This confusion and ambiguity is further displayed by the frequency with which authors of accessibility literature are forced to revert to Gould's much documented statement that "accessibility ... is a slippery notion ... one of those common terms that everyone uses until faced with the problem of defining and measuring it" (Gould, 1969). Harris (1967) offers some explanation for this by noting that accessibility is a constructed rather than an observed variable and thus "the rules governing its measurement are by no means simple or self evident" (see Ireland, 1972).

Koenig (1980) has concluded that whilst indices "are often appreciated as providing some interesting information ... their apparently subjective and empirical origin and formulation usually confines their practical use to a minor role". The operational dimension to accessibility has tended to dominate the form of the index with the most appropriate definition being dependent on the intended application (Morris et. al. 1979). In turn the diversity and complexity of accessibility definitions have encouraged the quantification of accessibility indices to rely heavily on assumptions implicit within value judgements and aggregation procedures rather than conforming to the principles of measurement. Any consistency or progress in accessibility measurement requires greater attention being given to the theoretical base on which indices are developed.

1.4. RESEARCH STRUCTURE

Within the context outlined above the research compiled in this thesis is structured as indicated in Figure 1-1. A conceptual framework (Chapter Two) comprising a theoretical and practical dimension enables accessibility and its component parts to be comprehensively analysed. A theoretical framework assists in identifying the theoretical validity of indices by providing a basis on which to examine the problems and assumptions implicit in formulating indices as a function of more than one component at the definition, measurement, valuation and aggregation stages. A practical framework determines the most appropriate and feasible form of index with regard to the practical requirements, however, less attention is given to this aspect of accessibility at this stage as it is recognised that the precise form of index is dependent on its intended application. Despite this a number of broad criteria are defined that assist in selecting the most appropriate form of index.

Chapter Three critically reviews the present state of the art of accessibility measurement. A classification of accessibility indices is derived by drawing a fundamental distinction between measures that are based solely on interaction comprising connectivity, distance and time measures and those that take account of the provision of opportunity comprising composite and comparative measures. Within each category of index existing measures of accessibility are examined against the theoretical framework and, with reference to the practical framework, the range of applications for which certain types of index are appropriate is determined. On the basis of this review the relative advantages of indices and areas in which

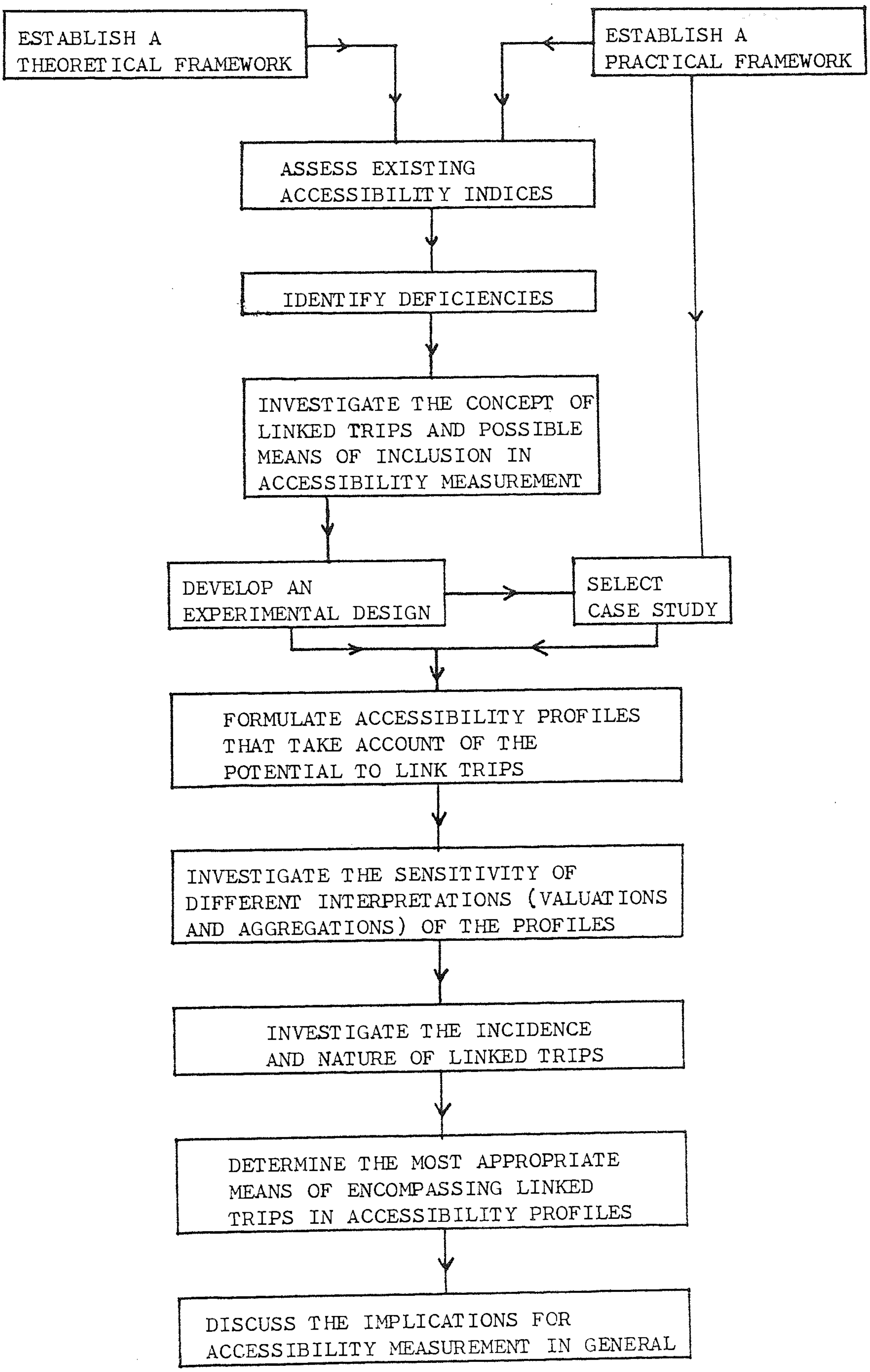


FIGURE 1 - 1 Research Structure

accessibility measurement is currently deficient are identified. A number of theoretical deficiencies of accessibility measurement are highlighted of which the most significant, in the view of the author, is the inability of indices to take into account the potential to combine trips between more than one destination. Also, consideration is given to the assumptions implicit in formulating indices particularly at the valuation and aggregation stages. With reference to these deficiencies, Chapter Three concludes by outlining the relative advantages of expressing accessibility information on a comparative basis in the form of profiles as against a composite single-unit index.

The inability of indices to take into account the potential to link trips is attributed to the present confines of accessibility measurement. The theoretical perspective to accessibility measurement is extended in Chapter Four by examining the concept of linked trips within an activity based framework and with reference to space-time analysis. By taking account of the temporal as well as spatial constraints on journey structures and, more specifically, the sequencing of activity patterns, it is suggested that measures of potential trip linkages might be incorporated into comparative accessibility profiles.

Having established the theoretical deficiencies of accessibility measurement the thesis turns its attention to the practical dimension. Accessibility indices depend not only on the theoretical validity of indices but ultimately on their operational performance. The experimental design outlined in Chapter Five is, therefore, structured in order to firstly establish accessibility profiles that overcome as far as possible the theoretical deficiencies of accessibility measurement and at the same time provide a basis for transport policy decision-making by revealing differences in accessibility provision between individuals and areas in the Local Authority area. Secondly, reverting back to a more theoretical stance, the empirical research is designed to assess the importance of overcoming these deficiencies by determining their influence on relative accessibility levels as interpreted from the profiles and also by investigating the potential misrepresentation of accessibility attributable to the failure to take account of linked trip-making. A case study approach is addopted focussing on the issue of the accessibility of the elderly to local facilities (post offices and grocers).

Chapter Six displays zonal accessibility profiles and provides a statistical analysis of the differences in accessibility levels attributable to the use of alternative value judgements, alternative forms and levels of aggregation and the inclusion of information on the potential to link trips. By developing a range of measures, the accessibility of the elderly in different areas of the Local Authority is revealed. The role of linked trips in accessibility measurement is explored further in Chapter Seven by statistically testing hypotheses on the nature, incidence and rationale of linked trip making with data collected from a survey of the elderly's travel behaviour undertaken in the Local Authority area. On the basis of these results the most appropriate means of accounting for complex journey structures in accessibility profiles of the elderly to post offices and grocers is explored and the implications for accessibility measurement in general are assessed.

CHAPTER TWO

A CONCEPTUAL FRAMEWORK OF ACCESSIBILITY

2.1. INTRODUCTION

The research structure, as outlined in Chapter One, indicates that in order to construct the most appropriate indicator of accessibility it is necessary to consider both the theoretical validity and the practical utility of alternative indices. In order to achieve this it is necessary to establish a set of criteria, or at least reference points, against which indices and their component parts may be assessed and compared.

Foster (1976) states that "while measures of accessibility can ... be defended as a necessity in practical transport planning, ... their theoretical underpinnings are insecure". It is apparent that few attempts have been made to assess the theoretical validity of alternative accessibility indices. It is usual for indices to be selected solely in response to their practical constraints and their intended application. Where attempts have been made to incorporate a theoretical element into the formulative stages of an index confusion arises due to the failure to distinguish between practical and theoretical criteria.

Any comparative assessment tends to be based on the relative merits of different categories of specific indices. An important distinction can, therefore, be drawn between the classification of accessibility indices and the criteria by which indices are selected. Accessibility classifications tend to be based purely on the end product (that is, the index) and, hence, assumptions implicit within the formulation of that index are often overlooked. Significantly less research has focussed on establishing criteria by which the various elements of the indices may be judged.

The majority of indices tend to be justified merely by their ability to meet operational requirements given various practical constraints. Some consideration, however, has been given to establishing guidelines for selecting indices. Breheny (1978) identifies three criteria:-

i) Measures should be concerned with the need for accessibility and not with the market demand for travel.

ii) Measures should identify the incidence of accessibility benefits upon different social groups rather than aggregate user benefit.

iii) Measures should consider accessibility to the range of potential opportunities available and not be concerned with observed or simulated travel behaviour.

More recently, Morris et. al. (1979) have offered four general guidelines for choosing appropriate accessibility indicators for evaluation and, unlike Breheny, have developed these with regard to a classification system. The guidelines are:-

i) The indicators incorporate an element of spatial separation which is responsive to changes in the performance of the transport system.

ii) The measure should have sound behavioural foundations.

iii) The indicator should be technically feasible and operationally simple.

iv) The measure should be easy to interpret and preferably be intelligible to the layman.

Breheny's criteria are essentially practical and tend to be derived from value judgements. In the light of this they cannot be accepted as general practical guidelines as the utility of an index depends on their intended application. Irrespective of the strength or otherwise of the above criteria laid down by Morris et. al. it is apparent that there is a tendency to confuse the practical requirements of indices with their theoretical validity. The first and fourth criteria are practical in that they stem from the operational requirements of the index which in turn depends on its intended application. The third criterion is also partially practical in stating that indices should be "operationally feasible". It follows then that the theoretical content of Morris's criteria revolves around the terms "sound behavioural foundations" and "technically feasible". In both cases any assessment against these criteria depends on value judgements as to their precise meaning.

In order that the theoretical validity of indices can be assessed without imposing any value judgements more specific and rigorous guidelines are needed. Also, the criteria listed above suggests that further consideration should be given to the more general application of practical criteria so as to provide a basis on which more specific criteria can be determined once the intended application and practical requirements of the index are known. As regards the theoretical criteria, accessibility indices are measures of accessibility and, hence, should conform to the principles of measurement pertinent to the formulative process of accessibility indices. This formulative process is a series of operations comprising conceptual and operational definitions, method of measurement, valuation and aggregation of the object being measured (in this case accessibility) for which rules and guidelines can and have been laid down. It is felt then that the theoretical criteria should stem from the theory of measurement rather than the validity or otherwise of alternative broad approaches to accessibility measurement.

The development of a set of criteria or simply procedural guidelines for both the theoretical and practical dimensions of accessibility and the analysis of the concept of accessibility against this criteria provides the context of a conceptual framework of accessibility. A practical framework of accessibility is briefly outlined in the latter part of this chapter but is referred to in greater detail in the light of the empirical accessibility analysis as explained in Chapter Five. Hence, the major part of this chapter is devoted to the development of a theoretical framework.

2.2. THE DEVELOPMENT OF A THEORETICAL FRAMEWORK

2.2.1. Theoretical Criteria

In viewing the formulation of accessibility indices as a set of inter-related operations performed on a set of variables taken to comprise accessibility and each possessing certain properties of measurement the validity, or at least the degree of spurious inference, can be assessed in terms of the level of assumptions implicit within each stage. The fundamental criterion against which to assess indices is the minimisation of assumptions in the measurement process. However, the validity of specific parameters must be judged against more detailed theoretical criteria. In recognising that assumptions are implicit within indices at more than one level, alternative parameters that comprise the index must be assessed with regard to the separate formulative stages. With this in mind and with reference to the extensive literature on the subject (for instance, Hall, 1962, Ackoff, 1962, Harvey, 1969, and JURUE, 1976) the formulation of accessibility indices can be divided into four inter-related stages - definition, measurement, valuation and aggregation.

Whilst recognising that there are basically four stages in the development of accessibility indices the formulative process is complicated for two reasons. Firstly, valuation rather than being seen simply as one of four stages is complicated in that values as well as accessibility variables are subject to definition, measurement and aggregation. In the light of this it is suggested that valuation must be addressed separately following the definition, measurement and aggregation of accessibility variables because of the specific and peculiar problems inherent in defining, measuring and aggregating value. Secondly, the four stages are inter-related and, thus, the validity of an assumption at one stage will influence the validity at later stages. For instance, as explained in greater detail in the following text, measurement is dependent on definition, valuation is implicit within measurement and aggregation may be implicit within definition and measurement and is also closely related to valuation.

a) Definition

Ackoff (1962) draws a fundamental distinction between "conceptual" and "operational" definitions. The former "relates the concept being defined to one or more other concepts" whilst, the latter "relates the concept to what would be observed if certain operations are performed under specified conditions". With regard to accessibility, a conceptual definition specifies the various components utilised in constructing the variable accessibility whilst an operational definition specifies the form of the components and their association with one another. For example, proximity is a conceptual definition whilst network distance between two points is an operational definition. The operational definition determines the precise form of the index and can be derived only in the context of the objectives and intended application of the measure under specific conditions. This definition should also specify exactly what is to be measured.

The distinction between conceptual and operational definitions is useful in describing the formulation of accessibility indices. The definition of accessibility may be undertaken in two stages:

i) A conceptual definition forming part of a conceptual framework in which all accessibility components and, hence, indices can be placed; and

ii) an operational definition in which particular elements of the conceptual definition are selected in accordance with the intended application of the index and their precise form is specified.

b) Measurement

It is generally recognised that measurement and definition are closely inter-related due to their "functional similarities" (see Caws, 1965). Definition is often expressed in a form that pre-supposes measurement.

Harvey (1969) defines measurement as "assigning numbers to objects by mapping these objects into an abstract space of some specified and determinate structure". Ackoff (1962) adopts a wider definition in recognition of the fact that "numbers" imply an ordering process which is not always possible to derive. Measurement is, therefore, defined as "a way of obtaining symbols to represent the properties of objects, events or states which symbols have the same relevant relationship to each other as do the things which are represented". The mathematical properties of this relationship between symbols depends on the scale of measurement. Four different scales can be distinguished (as noted by, amongst others, Hall, 1962 and JURUE, 1976) as:-

Nominal - classifying objects or events;

Ordinal - the ordering of objects or events;

Interval - the ordering of objects or events with reference to a constant unit of measurement but for which no origin can be identified;

Ratio - determination of absolute magnitudes of objects or events for which a natural origin can be identified.

The range of mathematical and statistical operations available for analysing the symbols obtained from measurement depends on the level of scale. For instance, additivity is valid only at the interval and ratio levels.

c) Aggregation

The aggregative process is basically one of establishing either average or summed measures. It is noted that aggregation may be implicit within the operational definition and measurement stages in that aggregate measures may be utilised to represent the properties of variables, for example, zone centroids may represent trip origins and destinations and households (as opposed to individuals) may be taken as the unit of population.

The validity of aggregation can be assessed by the extent to which information and its distributional characteristics are distorted or hidden. Furthermore, the aggregation stage of accessibility measurement assumes greater significance in the context of valuation (as will be shown in the following text).

d) Valuation

Valuation is closely inter-related with aggregation in that before aggregating or simply comparing two or more objects their relative valuation must be expressed and, hence, valued in common or at least comparable terms. As noted earlier in this chapter valuation is in itself subject to definition, measurement and aggregation.

i) Definition of Values

The concept of value is generally a vague term (Cane, 1977), proving difficult to define so as to include all its forms. With reference to Hall (1962) "value resides in an appreciation of an object, event or state of affairs" and, more specifically, in the context of accessibility resides in the relative appreciation of the variables and components defined as comprising accessibility. This appreciation may take the form of economic, moral, truth (logical and factual), political, ethical, aesthetic or religious value.

In association with these different forms of values the operational definition of value outlines precisely what is to be measured and, hence, the source of values and the way in which value is deemed to be expressed must be determined. In this context value may be derived from the attitudes, behaviour, preferences or satisfaction (see Cane, 1977) of:-

- the persons responsible for the measurement;
- experts;

- elected or nominated decision-makers;
- the target group;
- groups identified as possessing similar (accessibility) characteristics to the target group; or
- the population.

ii) Measurement of Values

The measurement of value requires the quantification of the appreciation of an object and, in this sense, the valuation of different variables and components may be expressed by modifying (weighting and factoring) the symbols of measurement as initially utilised in representing the properties of objects (that is, variables). However, it is important to note that the measurement of the appreciation of an object may not be correctly represented on the same scale on which the object is measured. For example, two miles in distance may not be valued as being twice the travel disutility of one mile. For this reason the valuation of an object cannot necessarily be assumed to possess the same mathematical properties as the initial symbols utilised in measuring the object. Indeed, the measurement scales of most values is valid only at an ordinal level in that the magnitude and degree of difference between different levels of appreciation cannot easily be determined. Various methods of quantifying value as opposed to purely subject response have been devised in an attempt to provide a scale on which the intensity of appreciation can be registered. For example, both the Von Newman and Morgensten Utilities and Churchman's and

Ackoff's Scale (as described in Hall, 1962) have been used in an attempt to measure value on an interval scale. The former, however, assumes that individuals can give a preference order for all events of interest and express preferences for objects with stated probabilities. Alternatively, the Churchman and Ackoff Order Scale attempts to determine the distances between objects on the measurement scale by, firstly, ordering objects according to expressed preferences and, secondly, comparing expressed preferences for various combinations of items. Although such a method places constraints on the distances between objects it is not sufficient to guarantee an interval scale.

iii) Aggregation of Values

The aggregation of values is a fundamental stage in the formulation of accessibility indices. Within the context of valuation, three levels of aggregation are identified:

- The combination of different intensities of appreciation of the same object but which are expressed in different units, for example, the representation of travel disutility through a generalised cost function. This stage is appropriate where components of accessibility are defined as comprising more than one variable and, hence, the measurement scales of valued variables must be commensurate.

- The averaging or summing of different intensities of appreciation of the same object (variable or component). This is only valid where the measurement scale of value is expressed on an interval or ratio scale.
- The combination of appreciations of different objects (components) identified as comprising accessibility. This stage gives rise to the formulation of an accessibility index as a combination of a series of components and is dependent on the measurement and appreciation scales of the different components being commensurate.

The formulative stages of accessibility indices (as described in the preceeding text) are summarised in Table 2-1. The process is complicated not only by the separate stages within definition, measurement, valuation and aggregation but also by the interrelationship between the stages. Measurement is dependent on the operational definition and aggregation may be implicit within both measurement and definition. Moreover, the definition and measurement of values is related to the definition and measurement of variables in that values are implicit within both the method and units of measurement and, hence, the two stages are in some cases inseparable. The aggregation stage gives rise to the accessibility index by combining variables and components as defined, measured and valued in the preceeding stages.

Definition	conceptual	identifying the components of accessibility;
	operational	identifying the variables comprising each component.
Measurement		assigning symbols to represent the properties of variables.
Aggregation		summing or averaging symbols for each variable.
Valuation	definition of values	identifying the appreciation of variables;
	measurement of values	determining the intensity of appreciation of variables;
	aggregation of values	combining different intensities of different types of appreciation of the same variable;
		averaging or summing appreciations of the same variable (representing each component);
		combining appreciations of different components.

TABLE 2 - 1 The Formulative Process of Accessibility Indices

The following text examines the assumptions implicit in alternative approaches to each stage of the formulative process. Given the above inter-relationships between the various stages it is appropriate to examine the assumptions implicit in defining, measuring and valuing variables comprising the components of accessibility within the same section of text (section 2.2.3). Similarly, it is considered appropriate to initially examine the conceptual definition stage of accessibility (that is, identify the components) (section 2.2.2.) and, latterly, examine the aggregation of variables and components (section 2.2.4.) within separate sections of text.

2.2.2. The Conceptual Definition of Accessibility - Identifying the Components

Having established the stages in the formulation of accessibility indices (as summarised in Table 2 - 1) the assumptions inherent in alternative approaches to each stage can be determined. Due to the inter-relationship between the operational definition, measurement and valuation stages (as noted in the preceeding text) the alternative approaches at each of these stages will be discussed within the same section of text. However, before investigating operational definitions and subsequent stages to accessibility measurement it is necessary to determine the assumptions within various conceptual definitions.

Authors of previous accessibility studies have largely concluded that interaction (transportation) and activity (land-use) are the main contributors to the concept of accessibility (see Benwell, 1977). Further insight into this concept is provided by, amongst others, Zakaria (1974) who defines accessibility as "the travel performance and the quality of interaction between land-use activities". Similarly, Mitchell and Town (1977) state that accessibility is "a function of both the spatial location of people relative to activities and the mobility available to them to reach these activities". In the widest sense then, accessibility can be interpreted as the ease of activity participation. It can be defined, therefore, as comprising components representing 'ease' and 'activity participation'.

It is apparent that the concept of ease is derived from both the geographical location of people and activities and the ability to overcome the spatial separation which, in turn, is partly dependent on the availability of transport facilities. The concept of activity participation is a function of the needs of the individual and the opportunities offered by that activity. Thus, a more specific contextual definition of accessibility is suggested as being a combination of population characteristics, interaction and activity (as identified by Jones, 1975). The concept of accessibility may, therefore, be expressed in three component boxes each with sub-components that require their own conceptual definitions. Population characteristics encompass geographical location, the ability to overcome separation (mobility) and activity needs. Interaction encompasses the provision of transport facilities and separation (proximity) whilst activity characteristics comprise geographic location and the provision of opportunity.

a) Population Characteristics

i) Location

The location of the population may be defined for each individual or group of individuals as the point at which the trip to the activity(s) in question originates.

ii) Mobility

In the field of transport planning confusion has frequently arisen over the distinction between mobility and accessibility. Broadly, mobility concerns the ability to reach opportunities (desirable destinations). Burkhardt and Eby (1973) define the concept of mobility by stating that it "represents the supply function of transportation services facing an individual (or group)". Jones (1975) recognises a wider definition to the concept of mobility comprising two components:-

- the ease with which a person can move about related to their physical fitness, availability of different modes, and some indication of the resources they can expend on travel; and
- the degree to which a person is free of restrictions.

In assuming mobility to be function of the characteristics of the individual, then the availability of transport is more appropriately defined as a sub-component of interaction.

iii) Needs

The relationship between mobility and need can be expressed with reference to Hillman et. al. (1976), "mobility is a means to an end, a potential for satisfying certain needs". The concept of need in transport planning has raised much discussion in recent literature and has prompted Burkhardt and Eby (1973) to conclude that "previous attempts to define need for transportation are incomplete, ambiguous and arbitrary". Difficulties arise in distinguishing between the concepts of need and demand, the former may be taken to include demand plus any extant latent demand. Moreover, the concept of needs may be defined either in terms of the need for transport or in terms of the need for activity participation. Hillman et. al. (1976), for instance, recognises needs other than those of reaching destinations including meeting people and physical exercise.

b) Interaction

i) Transport Facility Provision

The concept of transport facilities can be defined as comprising two elements:-

- the provision of route infrastructure; and
- the availability of different modes of transport.

The latter element may be included within the definition of mobility in that the availability of private transport modes is a characteristic of the individual.

ii) Separation

The concept of separation may be defined as the deterrence of travelling between two or more points and, more specifically, as spatial, temporal or economic travel disutility. Separation is a fundamental component of accessibility whereever the activity location differs from the population location and, hence, necessitates travel.

c) Activity Characteristics

i) Location

The location of an activity may be defined as the point at which the activity is undertaken or, to be consistent with the definition of the population, the destination of the trip to the activity in question.

ii) Opportunity

The concept of opportunity arises from the premise that trips are undertaken in order to achieve a benefit from participating in certain out-of-home activities. The concept of a benefit clearly depends on the needs of the individual.

The concept of accessibility is seen to comprise three fundamental components each with a set of sub-components. The sub-components are inter-related not only within each component but also between components (for instance, need and opportunity). The assumptions implicit within the conceptual definition stage relate essentially to the extent to which all the above components and sub-components are taken as being pertinent to the concept of accessibility. For instance, accessibility may be taken as being a function of interaction rather than interaction and opportunity or, alternatively, interaction may be defined as comprising solely separation rather than transport facility provision and separation. More contentious and less explicit assumptions arise in operationally defining, measuring, valuing and aggregating the above set of components.

2.2.3. The Operational Definition of Accessibility Components and the Measurement and Valuation of the Variables

In determining accessibility as a set of components each represented by one or more variables, the operational definition of the components and the subsequent measurement and valuation of the variables are seen as being dependent on one another. The following text, therefore, examines the level of assumptions implicit within these stages collectively.

a) Population Characteristics

i) Location

Having defined the location of the individual as the trip origin it is necessary to consider the assumptions implicit in operationally defining the trip origin. At the most disaggregate level trip origins may be defined as the individual's place of residence whilst at a more aggregate level, average trip origins, in the form of nodes or zone centroids, may be adopted reflecting the average location of a group of individuals. (See section 2.2.4. on aggregation). It is important to note that trips may originate at non-residential locations. Pirie (1979), in recognising this fact, refers to the "origin assumption" that all trips are home-based.

In defining the origin locations of trips a distinction can be drawn between on-network and off-network nodes. The former is a simplified version of the latter as it omits the off-network measure of separation by assuming transport network nodes to be trip origins. Public transport boarding points and interchanges are normally well defined, whilst problems arise with the simplification of the road network in that:-

- several levels of the road network can be defined; and
- nodes can be defined as intersections, links or abstract aggregate nodes.

Finally, whilst there is no explicit measure of location, it is recognised that the measure of separation is dependent on the definition of location. Any attempt to simplify the locational component of accessibility introduces assumptions about the relative importance of different parts of the network which is then reflected in the measure of separation.

ii) Mobility

With reference to Jones' (1975) definition of the concept of mobility, various operational definitions have been applied. Factors such as physical fitness, the availability of different modes of transport, the availability of resources for expenditure on travel and the freedom from restrictions are assumed to be functions of, for instance, age, car ownership, income and more recently, life-cycle respectively. It is further assumed in differentiating between various levels of the above characteristics that there will be a difference in mobility between the categories and a similarity within them. Mobility may also be defined behaviourally as the actual movement performed. Clark et al. (1974) defines a measure of average mobility as "the number of annual kilometres of personal travel per head of population".

Alternatively, the amount of travel performed may be expressed in terms of the number of trips undertaken over a specified time period. It is apparent that measures of perceived mobility may also be expressed in similar units.

Mobility is similar to accessibility in that it is a constructed variable with no generally accepted definition or measurement. In all cases it is assumed that one or more variables reflect the conceptualisation of mobility and, hence, it is measured and valued in terms of these variables.

iii) Needs

Depending on whether needs are defined in terms of transport and/or activity participation the measurement and valuation of need is implicit within the interaction and/or opportunity components respectively. By taking account of the needs of individuals, one is effectively setting different standards of accessibility depending on the individuals requirements. In measuring these activity requirements assumptions have to be made as to which discretionary activities, in addition to any obligatory activities, constitute need. Clearly, difficulties are encountered in setting uniform needs for individuals identified as having similar characteristics. Alternatively, behavioural measures ignore any extant latent demand whilst perceptual measures are likely to fluctuate widely between individuals depending on intangible factors such as expected life-style. Moreover, unless need is measured in terms of the total benefit from undertaking a set of activities, the units of measurement will be approximates. For example, the number of trips over a specified time period implies that the benefits of any trip are constant.

b) Interaction

i) Transport Facility Provision

Both the route infrastructure and the mode of transport are factors in determining the magnitude of separation and may be quantified in separation units (see following text). The availability of private transport modes may be operationally defined in terms of personal or household vehicle ownership or availability and in this sense can be treated as an element of population characteristics (mobility). The availability of public transport may be operationally defined as the frequency of service in terms of headways or waiting time. Headways may be defined in terms of theoretical headways (from timetables), theoretical headways modified by a reliability factor (Holroyd and Scraggs, 1966) or observed and perceived headways. By summing headways over a period of time the distribution of service availability is concealed. Alternatively, by assuming that the population have no prior knowledge of service schedules and, hence, arrive at the boarding points at random, a measure of average waiting time may take account of variable frequencies.

The provision of the transport infrastructure influences the measure of separation in two ways. Firstly, the spatial element of separation is dependent on the network configuration and may be measured according to the degree to which the route diverges from the straight line (the route factor) and is also implicit within units of network separation. Secondly, the capacity of the infrastructure constrains movement and, hence, increases the spatial and temporal elements of separation.

ii) Separation

The measurement of separation is dependent on the definition of the population and activity locations in that these define the points between which separation is measured. The extent to which mobility and transport facility provision are encompassed within separation measurement depends on the choice of operational definition and method of measurement.

A distinction can be drawn between discrete topological measures (connectivity measures) and continuous variables of separation (distance, time and cost). Connectivity measures as derived from graph theory comprise the number of links and nodes separating two or more points and, thus, assume that separation is wholly attributable to the disbenefit of interchanging at nodes and that each interchange is of equal value. It is generally recognised, however, that separation is more adequately measured on a continuous rather than a discrete scale. Spatial impedance may be measured either as network distance or as straight-line distance. The latter overlooks the constraints imposed by physical barriers and the network structure (that is, the infrastructure provision). Alternatively, air-line distance may be valued by multiplying it by a route factor derived from the degree of divergence of the network from the straight line.

Both connectivity and distance measures take account of infrastructure provision but overlook mobility and transport mode. For this reason temporal impedance is generally regarded as a more sensitive measure of separation as it enables the measurement of both mobility and transport facility characteristics by distinguishing between modes.

Further differentiation is applicable to units of time in the valuation stage. The relative valuation of time spent in different travel activities (that is, walking, waiting and in-transit) can and have been undertaken through a variety of measurement techniques but, as indicated by Table 2-2, has not produced universally accepted values.

STUDIES	In-vehicle time	Public Transport waiting time	Walking time
SELNEC	1.0	1.0	1.0
Tyne - Wear Study	1.0	2.3	1.7
London Transport Executive	1.0	(4 mins.interchange)	1.5
Rogers et. al.	1.0	1.7	2.4
Rogers	1.0	3.2	2.5
Steele and Rogers	1.0	2.1	2.8
Quarmby	1.0	2.3) 2.6) excess time	
WYTConsult	1.0	2.3	1.7

Source: Goodwin (1976), apart from WYTConsult (1977)

TABLE 2-2 A Comparison of Coefficients of Time Spent in Different Activities

The monetary cost of separation, like time, is also sensitive to the transport mode. A distinction can be drawn between actual cost reflecting the values of the market and the subjective cost reflecting the values of the trip-maker. A difference exists between the two in that elements comprising monetary cost other than petrol (including oil, general wear and tear) may be subconsciously excluded from a subjective assessment whilst other costs may be included.

The above operational definitions are partial in that separation is measured in terms of only one element rather than as a combination of all the above elements. Generalised time and generalised cost measures can, therefore, be developed to represent a combination of these elements in common units. Problems arise in that the relative values of each element vary with individual preference and that there is a tendency towards double-counting. It is normally assumed that each element of a generalised cost function measures a different aspect of separation. Moreover, in deriving a comprehensive generalised operational definition of separation that includes abstract components such as comfort, convenience and effort (see Goodwin, 1976) problems of measurement and valuation are encountered.

The valuation of separation irrespective of the operational definition or units of measurement may be derived from a number of sources (as outlined in the preceeding text). It may be assumed on the evidence of aggregated travel behaviour that time, distance and generalised cost measures do not hold a linear relationship with the impedance of separation and, hence, a factor may be applied. The form of the function is normally derived from actual behaviour and tends to assume that the effect of spatial deterrence decays (attenuates) in some fashion. Due largely to the reliance on travel behaviour as the source of values there is little consistency over the precise form of the function. Clearly, travel behaviour, depending on where it is observed, will reflect factors other than separation.

c) Activity Characteristics

i) Location

The activity location can be operationally defined in the same way as the population location (see preceeding text). Similarly, the measure of activity location is implicit in the measure of separation. By defining the activity location as the trip destination in terms of the place of activity participation or an aggregate representation of this, the activity location becomes the trip origin for any subsequent trips including the return trip to the initial trip origin. Similarly, trip origins may also be defined as trip destinations. By defining the individual's location and the activity location always as the trip origin and destination respectively it is assumed that all trips are made to just one out-of-home activity location (that is, home-based trips) and that the level of impedance incurred is equal for the outward and return trips.

ii) Opportunity

The operational definition of the opportunity available at the activity location may take a variety of forms and, hence, the quantification of the benefit from participating in an activity can be assumed to be represented by numerous variables. Measures of behaviour record the actual amount of activity participation undertaken at facilities assuming that existing demand represents the available opportunity and implying that there is no latent demand arising from the constraints imposed by other factors. Behavioural units of measurement comprise, for example, the number of trips made to the facility over a certain period of time and, alternatively, the amount of money spent at that facility. The first assumes that all individuals participating in an activity at a facility gain the same level of satisfaction. The second assumes that satisfaction and, hence, opportunity are reflected in the individual's willingness to pay the market values for goods or services.

Measures of perceived opportunity enable the multitude of factors comprising opportunity to be aggregated through the subjective valuation of the population. However, for this reason the measurement scale on which different levels of opportunity are recorded will be restricted to an ordinal ranking (unless certain assumptions about the additivity of values are accepted). Moreover, as with behavioural measures, it is implicitly assumed that the individual's knowledge of potential opportunity is complete.

Alternatively, a variety of operational definitions based on activity characteristics that are assumed to be approximate representations of benefit may be utilised. Facility size by, for example, floor space, the number of employees and total turnover are all based on the valuation assumption that the measures are proportional to the opportunity offered at that facility. In addition the total number of commodities (the supply) or the number of available commodities (the supply that exceeds the demand) may be measured. Neither measure accounts for the quality of the commodity. This may be represented by the economic benefit derived from the commodity relative to other like commodities. Thus, for example, jobs may be differentiated by wage rates and retail goods by price. Attempts have also been made to represent the economic benefit by consumer surplus (Neuburger and Wilcox, 1976).

2.2.4. The Aggregation of Variables and Components

It has already been determined that aggregation is in some cases implicit within the definition and measurement of variables and that aggregation in the context of valuation consists of the combination of valued variables, the averaging or summing of variables to represent a component and the combination of accessibility components. The following text, therefore, firstly, examines the assumptions implicit in aggregating variables within each component and, secondly, examines the combination of different components.

a) The Aggregation of Variables within Components

i) Population Characteristics

The aggregation stage is the step taken in measuring accessibility of one person to measuring accessibility of a group of persons. Individuals may be aggregated by location (for example, place of residence or zones) and/or by mobility and need homogeneity (for example, social group or life-cycle classification). In each case it is assumed that there are similarities in characteristics within the groups and differences between them. It is also apparent that aggregation is inherent in the use of certain measures, for instance, income and car ownership may be measured at a household rather than a personal level and activity requirements may be averaged out over a period of time.

Aggregation by location is possible either by summing the level of separation for all persons and obtaining an average or by deriving an average location (a centroid). Locations, when aggregated to a zonal level, can be defined as:

- the centre of gravity of a zone;
- the centre of the zone weighted according to the population location.
- the major trip-generation and/or trip-attraction point;
- the whole zone, so that trips are assumed to start and end at the nearest edge of the zone.

All four methods fail to take account of the differences and, hence, distributional implications of intra-zonal trips and distort the measure of separation for inter-zonal trips.

ii) Interaction

As with all aggregation procedures the distributional characteristics of transport facility provision and separation are concealed when average or summed measures are constructed. For instance, the spatial distribution of the infra-structure is concealed through aggregated measures such as route density whilst the summing or averaging of separation measures for more than one mode of transport conceals the relative attributes and, hence, importance of each mode.

The aggregation of the different elements of separation is implicit within generalised cost functions. Whilst time, distance and cost are all valid on a ratio scale, their aggregation to a generalised cost form necessitates relative valuation and, hence, assumes certain additive properties.

iii) Activity Characteristics

Activities may be aggregated by location and/or opportunity. Aggregation by location is again possible by either summing the level of separation for all activities and dividing by the number of activities or by deriving an average destination location (zone centroid). It is noted that this is identical to the aggregation of population location.

The aggregation of opportunity involves grouping the activities according to one or more of the type of opportunity measures outlined in the preceeding text. Activities may be defined by facility type and with reference to trip-purpose. The categorisation of trip-purpose relates back to the measurement of need, hence, groupings are based on the type of activity and, in some cases, the personal and household characteristics of the users. For instance, employment may be categorised by job definition and income categories.

The aggregation of facilities defined as providing for the same need requires a quantitative measure of the opportunity. For example, different employment locations may be measured by the wage rates and/or the number of jobs available. However, the aggregation of accessibility to different activity types requires a common measure of opportunity and a valuation of the relative benefit of each activity type. The assumptions necessary to achieve this are considerable and, hence, it may be desirable to develop a series of accessibility measures each for a specific trip-purpose.

b) The Combination of Components

The final stage of the aggregation process develops the accessibility index through the combination of the accessibility components as described above. It is recognised that, whilst accessibility comprises three components each with their own sub-components, the measurement and valuation of accessibility is expressed in separation and/or opportunity units. The form of the index is derived from the definition and the level of aggregation of all the components. Mobility and location characteristics and transport facility provision are inherent in the measurement of separation whilst need is implicit within opportunity measures.

The aggregation process as shown in Figure 2-1 identifies four distinct types of fully aggregated index. It is apparent, however, that numerous variations can be introduced by:-

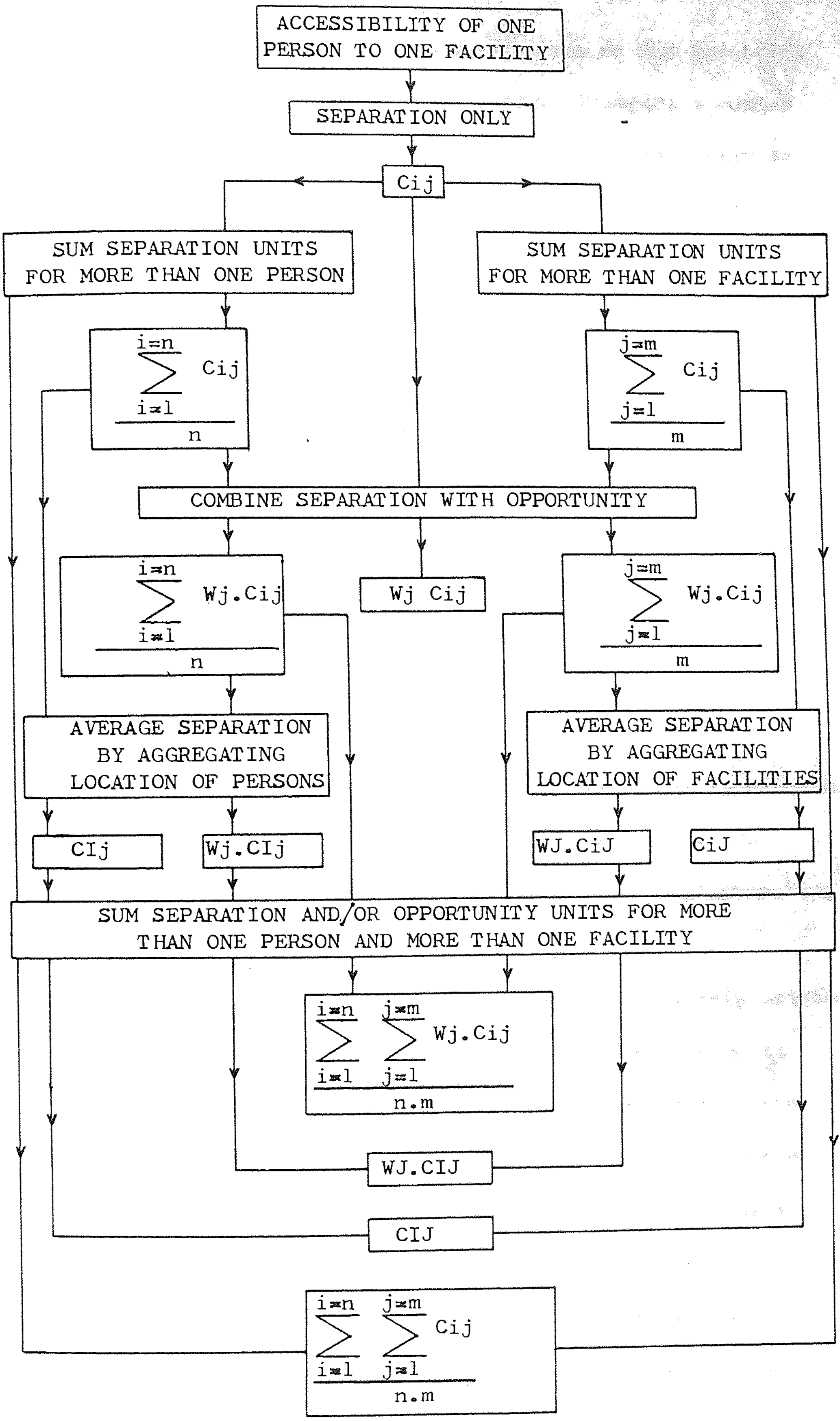
- varying the measures of separation; and
- varying the measures of opportunity.

Moreover, the indices may be displayed in different forms and not taken to the highest level of aggregation possible.

The ultimate problem of developing an accessibility index is the aggregation of separation and opportunity measures in order to produce a single composite index. It is noted that, in order to achieve this, assumptions must be made as to the relative valuation of separation and opportunity. Similarly, in order for the index to retain its additive qualities measurement units common to both separation and opportunity must be derived.

2.2.5. Conclusions

It is concluded that the theoretical framework is useful in assessing the different component measures of accessibility at a theoretical level and assists in highlighting those areas where there could be a strong dependency on assumptions. Any generalisations at this stage are, however, preliminary in that the theoretical framework forms only one part of the overall conceptual framework. In fact the importance of the practical framework is made apparent in that the relative advantages of many indices and the significance of the assumptions implicit within them cannot be determined



i = location of persons
I = average location of persons
n = number of persons
Cij = separation between i and j

j = location of facilities
J = av. location of facilities
m = number of facilities
Wj = opportunity at j

FIGURE 2-1 The Aggregation of Accessibility Components without reference to the intended application or the practical constraints and requirements of the index. However, a number of areas where the assumptions are questionable and likely to lead to distortions within the index can be identified at this stage.

- Behavioural measures of accessibility components or sub-components based on actual performance rather than need or potential opportunity for activity participation fail to recognise that accessibility is a function of a number of inter-related factors. For example, the amount of travel undertaken may reflect the location of activities as well as the mobility of the individual. Similarly, the number of persons visiting a particular facility may reflect transport facility provision and separation levels as well as opportunity. Likewise, the use of behavioural data to value unlike variables in common units, for instance, generalised cost is subject to similar short-comings.
- In defining the individual's location as the trip origin and the activity location as the trip destination it is implied that all trips are home-based and that the return trip incurs the same level of travel impedance as the outward trip. The definition of trip origins and destinations may be expanded to encompass all locations (whether individuals or activities) as potential origins and destinations and, thus, recognise non-home based trips and multi-purpose trips.
- "Associated with any type of aggregation is the loss of information" (Dalvi and Martin, 1976). The extent

to which aggregation is acceptable depends on the intended application of the index and, in a theoretical context, the importance attached to the distributional characteristics lost through such a process.

- "As specification error is decreased by successively more comprehensive measures, so measurement error increases" (Pirie, 1979). The complexity of the conceptual definition of accessibility necessitates the combination (valuation and aggregation) of unlike units of measurement. In attempting to take account of all those variables pertinent to accessibility the assumptions and, hence, potential error, is liable to increase.

A more conclusive and critical attitude to accessibility measurement can be taken after developing a practical framework and reviewing existing indices.

2.3. THE DEVELOPMENT OF A PRACTICAL FRAMEWORK

It is evident from past attempts to develop criteria for accessibility measurement (as referred to at the start of this chapter) that there is a tendency to interpret practical guidelines that have been developed under specific conditions as general rules of accessibility measurement. Practical criteria together with theoretical criteria assist in determining the form of the accessibility index. However, the practical utility of accessibility components and, hence, indices can be assessed only in the light of their intended application and are, therefore, dependent on the objectives of the accessibility study. A practical framework of accessibility is taken to comprise two stages:

- The specification of the objectives of the accessibility measurement; and
- the specification of the practical criteria.

A brief outline of these two stages is described in relation to the context and aims of this research. It is recognised, however, that the details can be discussed only in relation to the specific objectives of accessibility measurement (as opposed to the aims of the research as a whole) and is, therefore, referred to in greater detail in determining an experimental design (Chapter Five).

2.3.1. Objectives

In the practical context of this research the application of a measure or measures of accessibility, as outlined in Chapter One, focuses on the use of accessibility information in addressing issues (problems) by identifying areas of poor accessibility in the London Borough of Hammersmith and Fulham and in determining appropriate policies for alleviating these problems. However, with regard to the theoretical context, the application of accessibility measures is at this stage unknown as it is dependent on identifying the theoretical deficiencies of existing accessibility indices (as undertaken in the preceeding theoretical framework and in Chapter Three), extending the accessibility framework in order to overcome these deficiencies (Chapter Four) and developing an analytical framework in which they may be investigated (Chapter Five).

It is evident that the detailed form of an accessibility index is dependent on both the practical and theoretical applications of the index and must be judged against both practical and theoretical criteria. However, in the light of the overall objectives of the research the general form of the index can be determined with reference to the following stages of the formulative process (as described in the theoretical framework).

a) The Definition of the Population Set

The objective of addressing particular accessibility issues within the London Borough of Hammersmith and Fulham implies that the accessibility of one sector of the population within the Borough should be investigated.

b) The Definition of the Activity Set

Similarly, the objective of addressing particular accessibility issues implies that accessibility should be investigated for specific types of activity. Clearly, the definition of the activity set is dependent on the needs and, hence, definition of the population.

c) The Measurement Units of Separation and Opportunity

Both the population and activities for which accessibility information is required assist in determining the most appropriate units of measurement and separation.

d) The Level of Aggregation

The practical objectives of the research require that accessibility levels are for transport and land-use policy decision-making comparable between geographic areas of the Borough. It is also recognised, however, that accessibility problems are incident at the individual level as well as by location and, hence, disaggregate accessibility information is also required that identifies individuals with relatively poor accessibility. The more detailed form of an accessibility index may be determined in relation to practical criteria.

2.3.2. Practical Criteria

The development of any specific practical criteria on which to determine the form of the accessibility index is dependent on determining the precise applications of the index in examining the theoretical deficiencies of existing accessibility indices. However, purely within the practical context of the research three broad areas of practical criteria can be identified:

a) Policy Responsiveness

From the decision-makers view point and in order to reflect differences in accessibility indices and, hence, the defined set of components and variables must be responsive to policy changes.

b) Intelligible

The technical complexibity of accessibility measurement must be retained at a level which is intelligible to the user and decision-maker.

c) Data Availability and Requirements

The availability of existing data and the time and resources involved in collecting data act as constraints on the type of accessibility index to be formulated. It is apparent that the operational definitions and the levels of aggregation of accessibility measures is determined to some extent by the availability of data.

2.3.3. Conclusions

Accessibility indices must ultimately be judged with reference to practical criteria once the theoretical validity has been determined. Initially it is necessary to identify the objectives of the accessibility study before specifying any criteria. However, given the broad context of the application of an accessibility index a framework (as above) can be developed within which more detailed criteria and their influence on the final form of the index can be determined in accordance with the precise objectives. Further and more detailed consideration is given to the practical framework in selecting a case study in which to examine the deficiencies of existing accessibility indices (Chapter Five) and in determining the precise method and units in which accessibility is most appropriately measured (Chapter Six).

2.4. CONCLUSIONS TO BE DRAWN FROM THE CONCEPTUAL FRAMEWORK

i) A conceptual framework provides a basis on which to assess indices. A comparable platform for accessibility analysis has not been developed to date, although there is evidence that the more recent literature on accessibility (see Pirie, 1979 and Morris et. al. 1979), has recognised the need for a 'starting block'. Against this backcloth, therefore, a conceptual framework of accessibility has been developed in this research.

ii) It is recognised that the assessment of accessibility indices should be undertaken as a two-stage sieving process. The first stage determining whether indices are theoretically valid and the second stage determining the most appropriate index in terms of its practical utility. A proportion of indices may be rejected at the first stage due to the inclusion of particular component measures or combinations of component measures. The remaining measures can then be assessed against the practical criteria.

iii) The establishment of theoretical criteria is seen to be fraught with problems and, partly for this reason, has, until now, been overlooked in accessibility analysis. The level of assumptions implicit in indices tends to be the dominant criterion when discussing theoretical validity. However, it is felt that these assumptions are made at different stages in the formulation of an index and, hence, indices are investigated with reference to their definition, measurement, valuation and aggregation.

iv) Practical criteria are more easily defined and, hence, more frequently referred to in accessibility literature. The final choice of index ultimately depends on its intended application and practical requirements as the theoretical framework identifies the invalid, rather than the most valid, indices.

v) It is recognised that the two sets of criteria tend to be conflicting in that the most comprehensive and single measure indices rely on a high level of assumption. In order to select indices according to both sets of criteria it is necessary to achieve a balance between theoretical validity and practical utility.

vi) Whilst the conceptual framework provides a basis on which to assess indices and their component measures, it is not evident where the major deficiencies are in the present set of accessibility indices. The following chapter, therefore, critically reviews existing indices with direct reference to the theoretical and practical frameworks.

CHAPTER THREE

A CRITICAL REVIEW OF ACCESSIBILITY INDICES

3.1. INTRODUCTION

The conceptual framework developed in Chapter Two provides a basis on which to assess existing accessibility indices. The components of accessibility and the steps necessary in constructing an index have been identified. It is felt that by reviewing the multitude and diverse range of existing accessibility indices it will be possible to, firstly, show the way in which accessibility components and variables have been defined, measured, valued and aggregated, secondly describe the ways in which different forms of index have been applied in various practical contexts and, thirdly, determine the areas in which existing measures are theoretically deficient. The main criterion by which indices are judged is the level and number of assumptions inherent within indices. Four types of assumption corresponding to the basic four stages in the formulation of accessibility indices are identified, that is, definition, measurement, valuation and aggregation assumptions.

In view of both the number of indices and the widely differing approaches to accessibility measurement it is necessary to develop a structured framework in which indices may be reviewed. The first part of this chapter, therefore, considers accessibility typologies adopted in existing studies in order to determine the most appropriate classification. A simple classification is established based principally on the distinction between interaction and activity based indices. Subsequently, the main text reviews existing indices within the terms of this classification. Clearly, it is not possible to describe and discuss in detail every stage of the formulative process for all existing accessibility indices. This chapter, therefore, reviews the main characteristics of each type of index and places particular emphasis on identifying and discussing the stages in the formulative process of each index at which the dependency on assumptions is greatest.

3.2. A CLASSIFICATION OF INDICES

In order to conduct a systematic review and evaluation of existing accessibility indices it is necessary to establish some form of classification. Numerous indices have been constructed from the various elements identified in the framework developed in Chapter Two. With reference to this framework differences between indices can be attributed to:

- The inclusion (or exclusion) of different components of accessibility;
- the use of the same components but with different variables or combinations of variables; and/or
- the use of the same components and variables but aggregated to different levels.

On the basis of these differences several classifications have been proposed. For instance, Morris et. al. (1979) identify a two-dimensional basis of classification by drawing a distinction between "process" and "outcome" indicators and "relative" and "integral" accessibility as defined by Ingram (1971). Firstly, process indicators are defined as "measures of the supply characteristics of the system and/or individuals" (that is, the availability of opportunity) and outcome indicators as measures of "actual use and levels of satisfaction". Referring back to the theoretical framework it is recognised that this distinction is essentially between potential opportunity and behavioural measures of accessibility. Secondly, relative accessibility is a measure between two points and, hence, reflecting the accessibility to a specified destination; whilst integral accessibility is a measure between one point and all others within a given system and reflects total travel opportunities.

Whilst there is no doubting the validity of the distinction between relative and integral accessibility it is considered to reflect simply the differences in the level of aggregation in that the integral is the sum of the relatives. More appropriate bases on which to classify indices can be identified by distinguishing between the forms of integral process indicators as it is in this area in which most attention has been focussed. With regard to the components of accessibility as defined in Chapter Two the most useful distinction between accessibility indices is, perhaps, that between interaction measures and activity based measures. Apart from the work of Morris et. al. (1979) a number of studies have classified along similar lines. For instance, Breheny (1978) makes the two-way distinction between travel based and activity based indices whilst L.G.O.R.U. (1975) identifies three basic types of measure, the mean trip length as a behavioural (outcome) indicator, interaction measures and activity measures (both process indicators). Similarly and more recently, Jones (1981) identifies three main categories of accessibility measure as, firstly, the spatial separation or linkages between points on a network, secondly, measures that are "concerned with the amount of travel that takes place" and, thirdly, measures that are "concerned with the consequences of the combined distributions of transport and land-uses".

A more detailed classification is proposed by Pirie (1979) who differentiates between different types of interaction and activity measures producing two categories for each. Interaction is grouped into distance and topologic measures and activity into gravity and cumulative opportunity measures. Jones (1976) takes the distinction between interaction and activity further by differentiating between indices by the measure of separation (interaction) and the measure of place (activity). A fundamental distinction is drawn between separation measures that are mode specific and those that are not mode specific and, also, between weighted measures of accessibility and explicit measures of opportunity. The difference in the second distinction being that the latter form of index is expressed in units of opportunity whilst the former is expressed in units of separation weighted by the level of opportunity. It is apparent, therefore, that separation is common to both forms of index.

Clearly, further complexities can be introduced in establishing a classification system that distinguishes between the multitude of accessibility measures by stratifying according to relatively minor differences in indices. It is felt, however, that these differences are best examined by comparing measures within the same broad grouping. Hence, in the light of previous attempts to classify indices the following text, firstly, reviews measures based solely on interaction and, secondly, under the heading of activity measures, reviews developments on this basic form of index. Interaction indices are sub-divided into network connectivity, distance and time measures. Although it is recognised that other separation units are utilised in accessibility (for instance, generalised cost) it is shown that these are normally included only in conjunction with measures of activity. The principle division of activity indices is based on the distinction between composite and comparative indices. The former encompasses a range of gravity based measures and is an aggregate representation of interaction and activity, whilst comparative indices show how interaction and activity vary in relation to each other.

3.3. INTERACTION BASED INDICES

Early measures of accessibility tended to focus more on the performance of the transport system rather than the availability of activities. It is assumed that a simple representation of the transport network can be derived from its geometric properties and on the basis of this rationale a range of connectivity measures have been formulated. It is generally recognised, however, by the majority of accessibility authors that the measurement scale of separation is continuous rather than discrete as inferred by connectivity measures. Moreover, with reference to the theoretical framework (Chapter Two) the separation variables may be required to reflect population characteristics and transport facility provision (in terms of location and/or mobility). For these reasons, distance, time and costs have all been utilised in various forms in measuring separation. Those indices based solely on separation (interaction), that is, those excluding a measure of activity tend however, to be measured in terms of either distance or time. It is recognised from this review of indices that cost measures are normally associated with activity based indices.

3.3.1. Connectivity Measures

Considerable attention has focussed on measures that describe the topologic structure of circuit networks. Whilst the main emphasis has been on the association between network structure and mathematical graph theory the application of resultant indices has been extended to measuring accessibility. The transport network is assumed to comprise links, nodes and circuits (the sequencing of links, starting and finishing at the same node but visiting every other node only once) and, with regard to these three components, a range of indices have been developed.

Measures describing the network as a whole have been summarised by Haggett and Chorley (1969):

- The cyclomatic number (μ) = the observed number of fundamental circuits in the network.
- The Beta index = the ratio between the number of links (L) and nodes (N) = $\frac{L}{N}$.
- The Alpha index or 'redundancy index' = the ratio between the observed number of fundamental circuits (μ) to the maximum number of circuits that may exist in a network, which is, for planar graphs: 2N-5 and, for non-planar graphs: $N\frac{(N . 1)}{2} - (N . 1)$.

With regard to accessibility greater significance is attached to determining differences between different parts of the network as opposed to the network as a whole. Less aggregated indices measuring the connectivity of a particular point on the network have, therefore, been developed by treating graphs as connectivity matrices.

a) <u>Binary Connectivity Matrices</u>

Binary coding may be used for the first order matrix (C^1) with a 1 denoting a direct link and 0 when there is no direct link.

For example:

$$\underline{C} \qquad \text{nodes}$$

$$\begin{array}{ccccc}
 & A & B & C & D \\
A & - & 1 & 1 & 1 \\
B & 1 & - & 0 & 1 \\
C & 1 & 0 & - & 0 \\
D & 1 & 1 & 0 & -
\end{array}$$

C = the connectivity matrix of a graph

If all links are two-way contacts (symmetries) then the lower left-hand side of the matrix corresponds to the upper right-hand side. With one-way contacts (antisymmetries) the matrix is assymetric. Each column of the matrix shows the nodes which are connected to that place whilst each row shows the way in which connection from a place is distributed (Garrison and Marble, 1962). Subsequent orders C^2, C^3 ..... C^n may be obtained through matrix algebra indicating the number of alternative ways of linking nodes (see Appendix A):

$$C^2 = C^1 \times C^1$$

The power expansion process continues until all elements are scored, that is, where k = the highest number of links required to connect all nodes to each other. (k = the diameter or solution time of the graph).

The interpretation of the powered matrix may be approached with two sets of displayed information:

- The total number of k-step connections for each node; and
- the total number of k-step connections for the various pairs of nodes (Cijs).

In order to measure the connectivity of each node to the network a value is required (for each node) to express the ease of reaching all other nodes on the network. The units of measurement given in the above indices is the number of links. Therefore, by summing the Cijs from the kth powered matrix an accessibility measure (the Shimbel distance matrix) is developed ($\sum C^k$ijs).

Garrison and Marble (1964) have applied this method empirically to the Venezuelan airline using 59 cities as nodes.

Two main problems can be associated with the assumptions implicit within this method:

- If dealing with an assymetric graph then the Cijs will differ from the Cjis (see Shimbel, 1953); and
- the importance of indirect nodes declines.

The latter problem has been tackled by Shimbel and Katz (1953) who have developed a procedure for deriving a modified index based on both direct and indirect connections between nodes. Matrix C is converted into a powered matrix where:

$$T^n = a^1C^1 + a^2C^2 \text{..........} a^nC^n = \sum_{i=1}^{n} a^iC^i$$

Problems arise in determining the scalar a. The objective is to attach a weight to indirect links and, as the powering of the matrix increases, to allow k-link connections, so the value of a becomes progressively less (Haggett and Chorley, 1969). The larger values of a emphasise indirect links at the expense of direct links. Previous work in this area has depended on arbitrary weights. For instance, Hebert (1966) analysed the use and implications of a values equal to 0.3, 0.4, 0.5 and 0.6 but failed to draw any general conclusions. Migayi (1966) suggests that a locally consistent standard should be developed by determining frequency distributions of the elements within the matrices and finding a value for a from an analysis of the internal structure of each graph.

b) Shortest Path Matrices

It is apparent that with connectivity matrices there are a large number of 'redundant paths' recorded and, in this situation, the utility of more than one link between two nodes is questionable. Use may be made of the concept of a shortest route tree - a set of links that connect all nodes in the network and that does not have any loops. Various methods have been proposed for determining the shortest route ranging from the simple to the computational to the matrix (see Pollack and Wiebenson, 1959). The matrix method depends on finding the shortest route between every pair of nodes in a network and measures the number of intervening links to be traversed in travelling from one node to all other nodes within the network.

The shortest-path matrix may be used to compare the connectivity of nodes within the network with each cell (ij's) of the matrix representing the number of steps needed to connect the origin and destination nodes (Oi's and Dj's). For each node (Oi) two measures have been identified:

- The largest cell value, that is, the largest value in the row, (the Koenig associated number); and
- the sum of the cell values, that is, the sum of the row values, (the vertex accessibility number).

The second is more refined and uses more information in the matrix. These values refer to rows and, thus, to only the originating paths. It is likely, however, that in most cases the row values will be similar if not identical to the column values (the terminating paths). Statistical analysis of the row values may be conducted with the simplest and most obvious measure being the arithmetic mean - giving the minimum average number of links required to connect a node with any other nodes on the network.

In theoretical terms shortest-path matrices are considered preferable to binary connectivity matrices due to the problem of redundant paths and weighting different levels of linkages.

Whilst there has been an emphasis on the theory of network analysis there are several examples of connectivity as applied to accessibility in a more practical context. Armstrong (1972) initially uses binary connectivity matrices and then proceeds to develop shortest-path matrices in assessing airport accessibility in South Hampshire. Similarly, O'Sullivan (1968) in recognising that for large scale networks "the existence of a service might be more important than distance between stations on the railway system" constructed a binary matrix describing the presence or absence of a direct rail service between counties.

The use of connectivity matrices in determining accessibility is probably best displayed by Muraco (1972) who, in studying intra-urban accessibility, used finite graph theory as the first of three analytical phases. Three graph measures are used to describe the geometric network structure:

- The Shimbel distance matrix (as referred to in the preceeding text) which gives "a powerful measure of nodal accessibility".
- The degree of the node which reflects "the number of network links that are incident to a particular node".
- The associated number which "indicates the number of links in the shortest path from a particular node to its most remote node".

Muraco, unlike the forementioned researchers, has applied measures of network structure to an urban area. It is felt that such measures are more appropriate at a macro level where the existence of a link irrespective of its length is of significance (such as airlines and rail networks) or, alternatively, where links possess similar characteristics. It is suggested in agreement with Garrison and Marble,(1964) that graph theory has proved to be "a useful, simplified scheme for working with some of the properties of transportation networks but .... that some important aspects of network structure are lost when graph-theoretic models are utilised".

Whilst a number of properties (units of measurement) of networks are recognised as being appropriate to measuring the connectivity of either particular points on a network or a network as a whole, problems arise in defining the network (particularly for a combination of modes) and consequently deciding what to measure. Apart from the problems of defining nodes and links and, hence, the total transport network, measures of the impedance of particular links and the interchange between links are required in order to value links and/or weight indirect links.

Despite these limitations of connectivity as a measure of separation the above measures are, in certain instances, recognised as being useful indicators of accessibility. Principally where:

- Links are defined as having similar characteristics.
- The impedance of interchange is the major component of separation.
- The existence of a link irrespective of its length is the most significant factor.

It is felt, however, that the main function of connectivity measurement in the context of accessibility analysis is in describing the transport network on which more precise and policy sensitive methods of separation measurement can be undertaken. Reference is made to this process in the following text.

3.3.2. Distance Measures

The basic network as described by graph theory provides a basis on which to measure separation in units other than nodes or links. In this context a number of studies have utilised distance measures in association with graph theory. For instance, Shimbel (1953) defines four parameters that characterise the internal structure of networks:

- $1(i,j)$ the distance from i to j;
- $A(i,S)$ the accessibility of i to S, where S is the defined network and $A(i,S) = \sum_{j=1}^{n} 1(i,j)$;
- $A^{-1}(S,i)$ the accessibility of S to i; and
- $D(S)$ the dispersion of S where S is the defined network, where $D(S) = \sum_{i=1}^{n} A(i,S)$.

Kansky (1963) concludes that the most important measures in graph theory analysis are accessibility (Ai) and circuiting (Ci) and derives both as a function of distances between grid centroids. Accessibility (Ai) is given by:

$$Ai = \sum_{j=1}^{n} idj$$

in which: $\sum_{j=1}^{n} idj$ = distance from vertex i to all other points;

and circuiting (Ci) is given by:

$$Ci = \sum_{j=1}^{n} \frac{(Gj - Dj)^2}{V}$$

in which: Gj = minimum distance by network from vertex j to all other points;

Dj = air distance from vertex j to all other points; and

V = number of vertices (points).

Similarly, Baxter and Lenzi (1975) and summarised in Kirby (1976) defined an accessibility index as the average distance di from a point (or zone) i to all other points (or zones) in an area, and compared various measures of di for an actual town (Reading) with those obtained for certain idealised network patterns. Two patterns were considered:

- A circular area in which a series of radiating roads traverse a family of concentric roads. Holroyd (1966), however, recognises more than one type of routing system and distinguishes between radial-arc routing (all routes by-pass the town centre) and radial-arc/radial routing (depending on which is the shortest route).
- A circular area within which the roads form a square grid. Fairthorne (1965) used the average direct distance multiplied by the route factor to measure the average distance between two random points in a circle, where the route factor is taken as the average ratio of road distance to direct distance (see Timbers, 1967). Fairthorne applied this method to determine the average rectangular distance between all random pairs of points within a

circle (internal journeys) whilst Holroyd extended the same argument to include cross-cordon and through journeys. Kirby (1976) shows, for the general case, that an appropriate measure of "accessibility" is given when the air-line distance is multiplied by the route factor for the particular type of network in question.

The role of distance and network measures in applied accessibility analysis is displayed by Robertson (1976) who uses real road distances and population data on a square grid network to develop an accessibility model which can determine the optimal location for facilities. The Tornqvist (1971) algorithm which allocates population to the nearest facility is applied. Similarly, O'Sullivan (1968) uses network distance to investigate the hypothesis that there is some functional relationship between the spatial structure of transport networks and the geographical structure of the economy. The origins and destinations are represented by the highest populated towns in each county and a final accessibility index is produced by summing the relative scores:

$$A(i,n) = \sum_{j=1}^{n} C(ij)$$

Where $C(ij)$ = the network distance between zones i and j.

Following O'Sullivan's study, Ingram (1971) distinguished between relative (the accessibility between two points) and integral accessibility (the accessibility of one point to all other points) in formulating an operational index:

$$Ai = \sum_{j=1}^{n} aij$$

Where Ai = the integral accessibility at the ith point; and

aij = the relative accessibility of point j at i.

Ingram, in recognising the network as a determinant of accessibility concludes that rectangular distance is a more appropriate measure than straight line distance. Further refinement to the distance parameter is undertaken by examining the appropriate form of decay function. Ingram states that "trip generation literature suggests that a curvilinear function of distance would be more suitable than the linear, inverse relationship". His review of various forms of function concludes that the Gaussian curve is, in comparison with exponential and reciprocal curves, (see Appendix B), the most applicable for quantitative measurement of accessibility. The Gaussian function takes the form: $aij - 100e(-(d^2ij\ V^{-1}))$ where V is a constant determined for a given set of points.

With reference to the theoretical framework the use of decay function is effectively a means of valuing distance on a non-linear scale and as stated in Chapter Two these values may be derived from various sources. However, the need for decay functions arises from the desire to correlate spatial separation with travel behaviour and, hence, most functions are derived from observed behaviour. By incorporating behavioural values into objective measures of distance there is a danger that the basic assumptions implicit in the derivation of these values and the subsequent aggregation of measures are concealed.

The use of distance as a measure of accessibility provides a simple and well-defined representation of spatial separation in that "a significant relationship exists between travel time, travel cost and the distance travelled" (Ingram, 1971). In addition, the validity of the assumptions implicit in taking distance as an approximate measure of separation depends on the transport mode and population characteristics. It is generally recognised that the main problem is the inability of distance to differentiate between modes of transport and, hence, socio-economic groups (Mitchell and Town, 1977) unless different values in the form of decay functions are utilised. It is felt, therefore, that distance is appropriate only in measuring separation on a single mode network where interchanges of nodes are not significant or where it can be measured and valued to provide an adequate representation of spatial impedance on a linear or non-linear scale.

3.3.3. Time Measures

As stated above and in Chapter Two, time is a potentially more sensitive measure of interaction than distance in that it enables a distinction to be drawn between transport modes and,hence, encompasses more than just separation (as defined in Chapter Two). Largely for this reason, time has been used in comparing the level of accessibility provided by public and private transport networks and in determining the availability of public transport. Also, as with distance, time has been utilised in conjunction with network analysis as a means of weighting links (for example, see Armstrong, 1972).

Muraco (1972), in studying intra-urban accessibility, initially uses finite graph theory to define the geometric network structure and then weights the linkages by travel time based on the posted speed limits. Similarly, Savigear (1967) utilises travel time as a measure of spatial separation between zones of a town. The minimum time paths of the network are developed from graph theory and shortest route analysis. Unlike Muraco, Savigear modifies travel time according to network congestion (derived from demand) and the shortage of parking space.

In contrast to Savigear's approach based on the spatial separation of the road network a number of studies have concentrated on public transport accessibility. In this context it is generally recognised that a measure of the actual on-network travel time or distance is incomplete. Forbes (1964) in analysing accessibility to an urban centre for commuters argues that "accessibility is judged less by the time taken to do the journey and more by the frequency of service available". The author, therefore, adds a frequency of service measure to the actual in-transit time based on average headways and displays the results in the form of an isochrone map.

Johnson (1966), who measured accessibility for aggregated origin locations (villages) to aggregated destination locations (towns), also recognises the influence of elements other than travel time in measuring temporal interaction. Interaction by public transport is measured initially by time and service availability, the two measures are then assigned values aggregated to an ordinally ranked index. However, unlike Forbes, Johnson implicitly incorporates a measure of opportunity by attempting to take account of the synchronisation between transport provision and opportunity availability (opening hours). For instance, for accessibility to entertainment a daily bus leaving a town after 9.30 p.m. scores two points. Referring back to the valuation/aggregation stage of the theoretical framework developed in Chapter Two it is clear that the assumptions necessary in attaching points to each parameter are likely to have a significant impact on the final index. Little theoretical justification can be provided for the use of weightings that tend to be almost wholly dependent on arbitrary value judgements.

The influence of both spatial and temporal co-ordinates on separation are incorporated into the London Travel Survey (Freeman Fox et. al., (1964) public transport (bus) accessibility index. The frequency of service in a zone is combined with a measure of the area of the zone to develop an index reflecting transport facility availability (AI):

$$AI = \frac{\sum_{i} Nij}{Aj}$$

where Nij = off peak frequency (buses/hr) of buses on route i travelling through zone j; and

Aj = area of zone in square miles.

Due to the level of aggregation a number of likely distortions are apparent in such an approach. Firstly it is assumed that services are equally distributed within a zone and secondly, the index fails to take account of the route and/or destination of bus services.

As with the London Travel Survey index, a number of authors have measured accessibility to the public transport network.

Whilst this is seen as only a partial measure of accessibility it provides a useful insight into the measurement of walking and waiting time as opposed to actual in-transit travel time. For instance, Rassam and Ellis (1972) argue that in urban transportation access to the public transport may be significant and, hence, go on to develop models for estimating the average access walking time and the average access travel time (walking or driving).

The above accessibility studies indicate that time is a useful unit for aggregating and valuing different components of interaction particularly with regard to public transport. It is noted that time is sensitive to differences in interaction between population groups and trip-purposes and is, therefore, considered to be a more policy responsive measure than distance. However, it is felt that there is a tendency to over-simplify and place too much faith in the combination and aggregation of the different components of interaction. For example, the indices described above tend to overlook the full implications of valuing and aggregating, walking, waiting and in-transit times in order to produce a single unit measure of accessibility.

In summary, time units provide a more sensitive representation of interaction than distance or network (connectivity) measures. However, greater problems may be encompassed in selecting the method of measurement in that time measures effectively require that fixed average speeds between two points are determined and, hence, take into account distance. Similarly, distance measures take into account the geometric properties of the network in that nodes and links must be defined and, thus, time, distance and connectivity may be taken as forming an inter-related hierarchy of interaction measures.

Finally, with reference to the above interaction based accessibility studies, it is noted that in defining nodes and, hence, the points between which separation is measured, a number of assumptions are implicity encompassed in the measurement process. The majority of measures of distance and time are from spatially aggregated origins to spatially aggregated destinations (zones), for instance, Johnson (1966) and Savigear (1967) and are, therefore, indicators of place accessibility rather than personal accessibility. In this sense, accessibility measurement takes no account of the population characteristics in terms of either mobility or needs. Whilst spatially aggregated measures of accessibility are appropriate in many cases accessibility is in some cases (and as illustrated above) assumed to be a characteristic of the place rather than the person. In all cases, it is assumed that origin locations can be defined solely as residential locations and similarly destinations are defined as activity locations. Moreover, no account is taken of the separation between activity locations and the identification of non-residential origins is overlooked. The network based measures described above, whilst assuming origins and destinations to be nodes on the transport network do enable the connectivity between different nodes (through circuits and indirect links) to be included in the representation of accessibility. It is felt, therefore, that connectivity measures of the network serve as useful descriptors of the transport network on which to measure interaction in terms of time or distance.

3.4. ACTIVITY BASED INDICES

As stated in Chapter Two, the majority of authors recognise that accessibility is a function of the availability of activities rather than simply the interaction between two points. The above interaction indices are, therefore, considered to be partial in their representation of accessibility. The inclusion of an activity measure raises a number of issues central to any discussion on the form of accessibility indices and, hence, considerable attention has focussed on the measurement of activity and its inclusion in an accessibility index.

A fundamental distinction can be drawn between those indices that attempt to combine the separation (interaction) and opportunity (activity) measures (composite indices) and those indices that express the distribution of one component in terms of the other (comparative indices).

3.4.1. Composite Indices

A range of composite indices have been developed in order to express the combined influence of travel deterrence and the attention of opportunities in a single measure of accessibility. Different approaches have been derived from the principles of gravity, entropy, economic utility, intervening opportunities and potential opportunities.

a) Gravity Models

The principle of gravity in transport modelling has been applied through the formulation of a variety of spatial interaction models. Carrothers (1956), in reviewing the gravity or potential concepts of human interaction states that "the gravity concept of human interaction postulates that an attracting force of interaction between two areas of human activity is created by the population masses of the two areas and a friction against interaction is caused by the intervening space over which the interaction must take place". This can be expressed by:

$$Tij = aibj\ Oi\ Djf(Cij)$$

Where Tij = the number of trips between zone i and zone j;

Oi = the number of trips leaving zone i;

Dj = the number of trips arriving at zone j;

Cij = generalised cost of travel between zones i and j; and

ai and bj = constants.

In the case where the number of trips leaving zone i and arriving at zone j is known, that is, $\sum_j Tij = Oi$

and $\sum_i Tij = Dj$

then the model is referred to as being doubly-constrained.

The separation term in the above equation is specified as a generalised cost function (Cij) which is normally assumed to take the form:

$$Cij = a_1 t^k ij + a_2 W^k ij + a_3 d^k ij + Pj^k$$

where $t^k ij$ = travel time for journey from zone i to zone j by mode k;

$w^k ij$ = waiting (or excess time) associated with this journey;

$d^k ij$ = distance from zone i to zone j by mode k;

Pj^k = terminal cost at destination end of trip, for example parking charges; and

a_1, a_2, a_3 = constants representing the value of the travelling public associates with each component.

Several accessibility studies have adopted this type of measure principally with a view to expressing the relative importance of all variables considered to affect spatial deterrence. However, recent literature (for instance, Grey, 1978, and Goodwin, 1978) have questioned the use of generalised cost functions and a number of problems have been noted. The combination of different elements has given rise to "index number traps which involve reading into indices extra properties which they were not given when constructed and which are often inconsistent with the basic principles on which they were designed" (Grey, 1978). For example, the measurement of waiting time and terminal costs in like units requires a series of value judgements. Also, it is unclear as to whether there is any double counting in that two or more of the generalised cost elements may be measuring the same deterrence factors, (for example, time and distance). The following text shows that generalised costs tend to be used as measures of separation in conjunction with gravity based models and indices based on micro-economics.

In addition to the doubly-constrained gravity model three further cases are identified as the production-constrained case (where Oi is known), the attraction-constrained case (where Dj is known) and the unconstrained case (where neither Oi or Dj are known). Vickerman (1974), amongst others, argues that in an accessibility context it is necessary to use either the production constrained or unconstrained model whereby exogenous elements Wj, and Wi, Wj reflecting attractiveness replace Dj and Oi, Dj respectively. The equations are now given as:

$Tij = aiOiWjf(Cij)$ for the production constrained case,

and $Tij = kWiWjf(Cij)$ for the unconstrained case.

The value of Wi is determined according to the trip-generating qualities of zone i whilst Wj represents the attractiveness of zone j.

It is important to distinguish between the role of gravity based models in determining accessibility on the one hand, and their role in traffic forecasting and trip generation and distribution modelling on the other. Most attention has focussed on the latter and, whilst attempts have been made to study the relationship between trip generation and accessibility, the reliance on expressed demand as an indication of accessibility for evaluation purposes is questionable. A common criticism has been that the models lack theoretical foundations related to human behaviour and are purely inductive, curve-fitting exercises (Ewing, 1974). With reference to the theoretical framework established in Chapter Two it is evident that the values are derived purely from the users revealed behaviour.

Also, the gravity model is perhaps more appropriate at the zonal rather than the individual level in that trip origins and destinations are taken to be a function of zonal as opposed to personal characteristics. It is generally recognised in transportation planning that the gravity model is less reliable when data is disaggregated and, hence, the interaction and flows between relatively large scale aggregated zones or systems are more appropriate to analysis on the principles of gravity. However, despite the inappropriateness of gravity modelling for accessibility measurement, the principles of gravity have provided a basis on which to derive alternative composite indices.

b) Entropy

A theoretical approach to the gravity concept of interaction has been provided through the notion of entropy taken initially from the physical sciences and adapted from information theory. Wilson (1970) explains entropy with reference to a system comprising a fixed spatial distribution of numbers of workers in residences and a fixed spatial distribution of the number of jobs. A "state" of the system is the assignment of individuals to the origin/destination (o/d) matrix. In order to restrict the number of assignments it is necessary to impose constraints (as with the gravity model). The "distribution" is the set of totals of individuals travelling from i to j. It is apparent that for a given distribution there are numerous states. If it is then assumed that any state of the system occurs with equal probability then the most probable distribution can be determined by finding that distribution that has the greatest number of states associated with it.

On the basis of the above principles, Erlander (1977) uses the entropy of the trip matrix as a broad measure of accessibility within a transportation system. The constraints are set as follows:

$$Oi = \sum_{j} Tij$$

$$Oj = \sum_{i} Tij$$

$$T = \sum_{i} \sum_{j} Tij$$

Where Tij = trips from zone i to zone j; and

T = total number of trips.

In the situation where all the zones on the network are equally attractive maximum accessibility would occur where the $\frac{Tij}{T}$ is the same for all zones. Hence,

$\frac{Tij}{T} = \frac{1}{n}$ where n = number of cells in the o/d matrix.

If this is now applied to the notion of entropy as derived from information theory:

$$H = - \sum_{i} \sum_{j} \frac{Tij}{T} \log \frac{Tij}{T}$$

Where H = entropy

Then, for maximum accessibility:

$$H = - n \frac{1}{n} \log \frac{1}{n} = \log n$$

It is apparent, then, that the higher the entropy the greater the trip distribution implying better accessibility, alternatively, the lower the entropy the greater the severity of restrictions on the trip-end matrix which implies a lower level of accessibility.

To summarise, it is felt that entropy maximising models provide a macro-analytical approach using statistical techniques to determine accessibility. The use in operational accessibility measurement is limited in that it provides a measure of the accessibility of a system as a whole which, in turn, is a function of the dispersion of trips within the system. Clearly, the main attributes lie in its ability to deal with large, complex systems relatively easily on an aggregate level. In this sense entropy is appropriate to determining place as opposed to personal accessibility and, with reference to the valuation stage of the theoretical framework (Chapter Two), contains values derived from behaviour (in terms of trip distribution).

c) Economic Utility Measures

In utilising the principles of the gravity model as a demand function the economic benefits occurring from a change in accessibility of a given accessibility situation have been derived using economic theory. A trip is seen as economic good for which the demand is a function of the net utility arising from buying that good. By assuming that the demand for this good (that is, the number of trips) increases as the cost falls the resultant change in the net utility as a measure of accessibility has been calculated.

A number of studies have focussed on assessing accessibility benefits arising from a transport or land-use plan for those persons who change behaviour (that is, visit new destinations, change mode of transport or generate new trips) as well as those persons whose behaviour is unchanged. Neuburger and Wilcox (1976) and Neuburger (1971) have developed an approach that determines the net utility from a change in accessibility in terms of the change in consumer surplus and shadow prices.

The unconstrained gravity model of the form;

$$Tij = ke^{-\lambda(Cij + Gi + Aj)}$$

where Tij = trips from zone i to zone j;

Cij = generalised cost of a trip from zone i to zone j;
Gi = inherent generative qualities of zone i;
Aj = inherent attractiveness of zone j;
k = trip rate; and
$e^{-\lambda}$ = exponential function,

is assumed to represent a traditional demand function for trips. The net utility in terms of the change in consumer surplus (the integral of the demand function) is represented by the difference in proximity (Cij), the difference in the generative qualities of zone i (Gi) in terms of the desirability of zone i for residence ignoring accessibility and the difference in the attractiveness of zone j (Aj) as a place of work in terms of wage rates, types of employment but excluding nearness to residences. In this form the surplus function is assumed to represent an aggregate accessibility index which will respond to changes in both transport and land-use.

However, in the production and fully constrained gravity models the demand generated at zone i and in the latter case also the demand attracted at zone j are constrained and, hence, in this form the gravity model is not strictly a demand function. In order to measure the change in consumer surplus it is assumed that a shadow price sufficient to achieve the constrained level of demand is actually charged. The surplus function can then be derived by adding the shadow prices to the actual transport prices.

As an alternative to the consumer surplus approach Daly (1975) utilises the principles of gravity modelling in determining a composite measure of accessibility in terms of the net utility.

The index calculates the net benefit of undertaking a particular trip by a specified mode so that:

$$Aikpt = \log \sum_j \sum_m \exp(Bjpt - Cijkmt)$$

where Aikpt = access for zone i, car ownership category k, trip purpose p in time period t;

Bjpt = benefit derived from destination j for purpose p in time period t;

Cijkmt = generalised cost of travelling from i to j for car ownership category k by mode m in time period t.

By viewing the index in a trip-predicting form (that is, a gravity model) Daly points out that it is possible to obtain values for Bjpt and the generalised cost weighted from observed data. The index is seen to be particularly useful in predicting the effects of land-use or transport change on the demand for rural public transport. It should be noted, however, that the use of observed data for determining the values of both the benefit and cost of a trip, as with other gravity based indices, assumes that actual demand reflects preference (and, hence, the net utility of a trip) and overlooks the possibility of there being any latent demand. Moreover, the net benefit (utility) from undertaking a particular trip is dependent on factors other than simply the cost of travel between zones and the benefits provided at zones. Koenig (1980), for instance, in exploring the relationship between trip generation and accessibility, derived a utility function from micro-economic consumer behaviour. The approach is dependent on two assumptions principally covering the measurement and derivation of values:

- People associate a cardinal utility with each of the alternatives they are facing and take the choice associated with the maximum utility to them as individuals.
- As it is not possible for a planner to evaluate all factors affecting the utility associated with each alternative by a given individual, this utility can be represented as the sum of a non-random component (for the predictable factors) and a random component (for the non-predictable factors).

Koenig (1978 and 1980) measures the net utility (Ui^k) of an individual of type k living in zone i from a trip as:

$$Ui^k = \frac{1}{x} \log e \; Ai^k + \text{constant}$$

where $$Ai^k = \frac{\sum Sj^k e^{-xkcij}}{\sum Sj^k}$$

where Sj^k = number of potential destinations for individuals of type k in zone j;

e^{-xk} = the exponential parameter associated with the destination choice decision for individual k; and

$C^k ij$ = the "cost" of travel between i and j for the individual of type k.

The index is based on the assumption that increasing accessibility leads to an increasing trip rate. It is recognised, however, that the net utility derived from making a trip is also dependent on the number of trips already being undertaken and for this reason Neidercorn and Bechdolt (1969) argue that the maximisation of utility is dependent on the constraints on the total amount of time and money that individuals are willing to spend on travel.

It is evident that both consumer surplus and behavioural utility models have, according to Koenig (1980), "the important advantage of being expressed in economic terms, thus, associating an economic value with the range of choice offered to an individual" and that they provide a comparatively strong theoretical base for accessibility measurement. The ability to express opportunity (attractiveness) and separation components in common economic terms is, however, heavily dependent on value judgements as to the precise economic benefit from undertaking a trip and the generalised cost factor. The reliance on revealed preference (demand) for determining these values overlooks any suppressed demand and, hence, such an approach is more appropriate to predicting demand given a change in any of the accessibility related variables rather than to determine the level of accessibility provision.

Whilst the use of economic theory in accessibility measurement provides a degree of mathematical elegance the assumptions implicit within the index are similar to those criticised in other indices as described in the preceeding text. With reference back to the theoretical framework, whilst accessibility variables measured in monetary units are valued on a ratio (and, thus, additive) scale of measurement, their scale of valuation does not necessarily possess the same mathematical properties. The aggregation, therefore, of interaction and opportunity is not valid simply because both are measured (as opposed to valued) in monetary units. Moreover, with regard to the definition of location, the spatial aggregation of utility infers that an individual's maximum utility is a function of the generalised cost and range of choice available within a zone rather than at a specific location. Whilst this may be interpreted as reflecting the potential to undertake multi-purpose trips between destinations within a zone, the precise nature of journey structures is again simplified and distorted by the aggregation process.

d) Intervening Opportunities

Stouffer (1940) adjusts the basic behavioural assumption inherent in the gravity concept by suggesting that there is no necessary relationship between mobility and distance and instead hypothesises that "the number of persons going a given distance is directly proportional to the number of opportunities at that distance and inversely proportional to the number of intervening opportunities". This can be expressed as:

$$\frac{\Delta y}{\Delta s} = \frac{a. \Delta x}{x. \Delta s}$$

where Δy = number of persons moving from the origin to a circular band of width Δs;

x = cumulated number of opportunities between the origin and destination s;

Δx = number of opportunities with the band of width Δs; and

a = a constant.

Schneider (1960) in recognising that the utility of opportunities is dependent on the location of competing opportunities as well as separation developed a measure of intervening opportunities for the Chicago Area Transportation Study. The concept of intervening opportunity is based on the premise that the probability that the trip from zone i to zone j will be beyond zone j is equal to Rij:

$$Rij = e^{-uV_{ij}}$$

where e = base of the natural logarithm;

Vij = the cumulative number of trips (or opportunities) between zone i and zone j; and

u = the parameter of unwillingness to travel.

Subsequent refinements to the measure have attempted to take cognisance of the fact that the willingness to travel varies between individuals (Seidman, 1965). The formulation is, therefore, expressed as:

$$Rij = (A + Vij)^{-B} e^{-CV_{ij}}$$

where A,B, and C (replacing u) are parameters indicating the trip-making propensities of the socio-economic group for which accessibility is being measured and are derived from existing trip distribution patterns. Rij, e and Vij are defined as above.

Once Rij has been established the probability that a trip originates in zone i and ends in zone j is given by:

$$Pij = Ri\,(j - 1) - Rij$$

where Ri (j - 1) = the probability that a trip originating in zone i will travel beyond zone (j - 1).

The inaccessibility of zone i is then given by the measure of separation (distance) between i and j multiplied by the probability of travelling from i to j:

$$Ii = PijCij$$

It is apparent that the application of the intervening opportunities index is subject to difficulty on two accounts. Firstly, there is no general function for the propensity to travel parameters which, in effect, represents the needs element of the population component (as defined in the conceptual definition of accessibility). The reliance on existing trip distributions as determinants of travel propensity assumes that expressed demand reflects preference and, in this sense, is similar to gravity based measures. Also, it is likely that accessibility itself is a determinant of trip distributions.

In comparison with other composite indices, Schneider's model has the advantage of taking account of competing opportunities. It is also argued that "the model is more interested in a given trip-maker whilst a more gravity based measure concentrates on the attractiveness of zones as a function of land-use" (Robinson and Le Fevre, 1977). However, although a measure of intervening opportunities is sensitive to the propensity to travel it still produces a zonal, rather than a personal, measure of accessibility. Moreover, assumptions are again implicit within the definition of origins and destinations. The probability that an individual visits a particular activity location is likely to be dependent on, not only the intervening opportunities from the individual's home, but also the spatial distribution of other non-home activity locations.

e) Potential Opportunity Measures (The Hansen-type Index)

Potential opportunity measures of accessibility focus on the supply characteristics of accessibility rather than attempting to model or predict travel behaviour. This type of index was developed initially by Hansen (1959) and has provided the foundation for more recent studies. In order to show that accessibility and the availability of vacant developable land can be used as the basis of a residential land use model Hansen (1959) defines accessibility as "a measure of the spatial distribution of activities about a point, adjusted for the ability and the desire of people or firms to overcome spatial separation". For instance, accessibility to employment is given as:

$$A1 = \frac{S2}{T^{x}1 - 2} + \frac{S3}{T^{x}1 - 3} + \frac{Sn}{T^{x}1 - n}$$

Where Sn = employment in zone n (no. of jobs)

$T1\text{-}n$ = distance between zone 1 and zone n

x = some function of distance.

In addition to employment, accessibility is also measured for shopping and recreation activity (measured in terms of annual retail sales and population respectively). Despite the wide use of the index little agreement exists over the attenuation of distance, that is, the form of the deterrence function and for this reason Pirie (1979) suggests that functions "should be subjected to empirical testing before use in a new setting". As noted earlier in this chapter, deterrence functions are a means of valuing separation on a non-linear scale and are derived from (and measured in terms of) the trip-makers observed behaviour. Hansen, on the basis of empirical examinations argues that an exponential distance function is the most appropriate with the values varying according to the trip purpose. Also Wachs and Schofer (1972), in analysing accessibility to jobs via the public transport system, use an exponential function in the index:

$$Ai = \sum_{j} \frac{Ej}{tij^{2.2}}$$

where Ai = the index of accessibility of origin i;

Ej = the number of jobs in destination zone j;

tij = the minimum travel time from origin i to destination j via the public transportation system in minutes; and

2.2 = exponent reflecting the theoretical and empirical findings that travel time is not on a linear scale.

Similarly, Vickerman (1974), in testing the hypothesis that accessibility and attraction are important determinants of trip generation and total mobility as well as spatial interaction, uses an inverse square distance function ($1/d^2ij$). The separation measure (developed from network analysis) and the attraction measure (for shopping and leisure trips) are formulated independently and then combined in a single index produced for each zone:

$$Ai = \sum_{j} \frac{Wj}{d^2ij}$$

where $Wj = \sum_{k} e_k Nkj$

ek = expenditure weight on goods of type k; and

Nkj = the number of establishments of type k in zone j.

More recently, Martin and Dalvi (1976), in comparing accessibility by public and private transport have developed a modified Hansen measure of the form:

$$Ai^k = \sum_{j=1}^{n} \frac{Wj \exp(-BC^k ij)}{\sum_{j=1}^{n} Wj}$$

where Ai^k = accessibility afforded by mode k to household residents in zone i;

Wj = measure of attractiveness of zone j;

$C^k ij$ = cost of travel from zone i to zone j by mode k; and

B = constant.

It is clearly apparent that the index has the added advantage of distinguishing between modes of transport. This is derived from the separation measure in that the distance function is replaced by a function of inter-zonal travel times. Four measures of "areal attractiveness" (opportunity) are used (total employment, convenience retail employment, durable retail employment and population) and are found to play a key role in determining the geographic distribution of relative public transport accessibilities.

The fact that both Hansen and Martin and Dalvi develop indices for each trip-purpose is indicative of the problems involved in aggregating attraction measures for unlike opportunities. Tomazinis (1961) modifies the index to represent three types of accessibilities:

$$Ai = \sum_{j=1}^{n} (As + Ac + Ae)$$

where Ai = total accessibility of zone i;

As = social accessibility;

Ac = commercial accessibility; and

Ae = employment accessibility.

As, Ac and Ae are all calculated using the Hansen formulation but with opportunity measures of population over 5 years of age, sales workers and employed workers respectively. This type of index seemingly has the advantage of producing a single value of total accessibility, however, the validity of this level of aggregation is open to serious doubt. Little evidence is provided in the literature to support the valuation of different opportunities on a commensurate scale. Tomazinis implies in the index that, on the basis of the above units of attraction, social accessibility is of equal importance to commercial and employment accessibility.

A less documented criticism of the composite potential opportunity measure is that the level of accessibility is sensitive to the zoning system as well as the separation and opportunity parameters. Dalvi and Martin (1976) reveal that whilst the configuration of the zoning system has a significant effect upon the value of accessibility, aggregation is more significant. It is questionable, therefore, whether an index aggregated to this level provides a true representation of the spatial distribution of opportunities for points within a zone. It is possible that, with any spatial aggregation the differences in accessibility between points within the same zone are greater than the differences between the average accessibility for each zone. It is noted that this problem of aggregation is common to all types of indices and, clearly, the use of any such index in determining transport or land-use policy is severely limited by the potential distortion implicit within it.

In disaggregating opportunity into different activity types, differentiating between modes of transport and recognising the differences between individuals' propensity to travel, composite measurements of opportunity treat accessibility as a characteristic of the individual. However, as with other forms of accessibility index the assumptions at the definition stage infer that all trips are undertaken from residential locations to one particular activity location. This assumption, whilst assisting the spatial aggregation and averaging of origins and destinations ignores more complex multi-purpose journey structures and overlooks the propensity of individuals to travel between opportunity zones.

Finally, with further reference to the theoretical framework as described in Chapter Two, it is apparent that a major problem of the composite, Hansen-type index is the combination of the opportunity and separation units. The interpretation of the units in the overall evaluation can only be undertaken on an ordinal scale (see Whitbread, 1972) as the actual units in which accessibility is recorded are meaningless and simply give an accessibility 'score'. Hence, the index is unable to indicate the actual extent of changes or differences in accessibility. Indices that do not attempt to combine (through valuation and aggregation) the interaction and activity components of accessibility but express the variance of one in relation to the other (comparative indices of accessibility) are discussed in the following text.

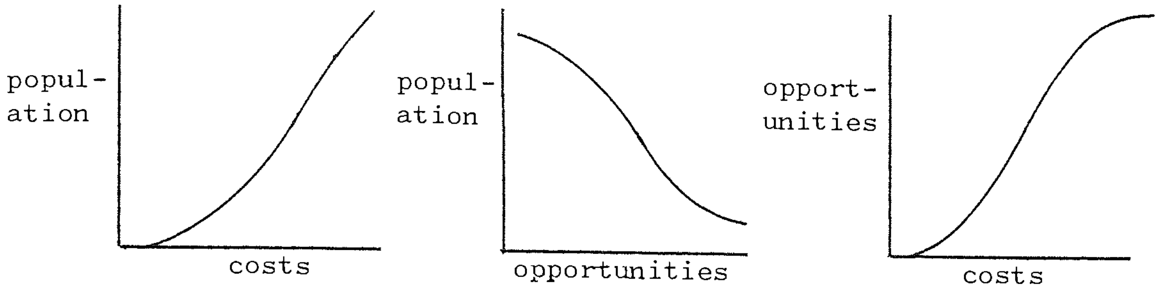
3.4.2. Comparative Indices

Largely in recognition of the problems of combining separation and opportunity measures in the form of a composite index, several accessibility studies have adopted a comparative measure in which the distribution of one component is expressed in relation to the other (Jones, 1976).

The role of spatial opportunity in evaluating land-use plans is displayed by the Centre for Land Use and Built-Form Studies (C.L.U.B.F.S.) who develop a model that defines the "performance characteristics" of the system in terms of the accessibility and proximity (measured in terms of distance) of groups within the community to certain scarce resources (see Breheny, 1974 and Perraton, 1972). More recently Breheny (1978) explores the use of measures of spatial opportunity as a means of summarising the accessibility of certain origin groups to certain opportunities distributed in space. Three dimensions to the issue of accessibility bearing close similarity to the three basic components of accessibility (as defined in Chapter Two) are identified as:

" - The benefits or opportunities to be gained at the end of a trip;
- the cost (distance or time) involved in reaching the benefit; and
- the origin activity or group potentially gaining benefit from access to these opportunities. "

Different accessibility profiles are then formulated by holding one of the dimensions constant and, hence, the distribution of activities can be measured in terms of the variation in the other two dimensions. The results can be expressed by the graphs displayed in Figure 3 - 1.



Opportunities held constant

Costs held constant

Origin activities held constant

FIGURE 3-1 Accessibility Profile Dimensions (after Breheny, 1978)

It is apparent, then, that differences in accessibility can be expressed in terms of different distributions reflected in the shapes of the curve. Breheny advocates the disaggregation of the dimensions in order to show the incidence of accessibility benefits on different social groups and applies the method to determining employment (by S.E.G.) and primary school accessibility in the Gloucester area. However, separation is determined by a private transport generalised cost matrix, based on weighted distances and speeds and, hence, the valuation of different variables on a common scale is undertaken within a component but not between components. In addition it is shown that the measure of opportunity can be refined by incorporating the effects of competition into the index by taking account of the demand as well as the supply of opportunities (for example, the number of vacant jobs rather than the total number of jobs may be taken as the opportunity measure).

Wachs and Kumagai (1973) provide further evidence of the operational use of comparative accessibility measures but do not use a generalised cost function arguing that "a useful approach to the measurement of physical accessibility is the determination of the number or density of travel opportunities of particular types within certain time distances or travel cost ranges from the residential locations of population groups of interest". On this basis an index of accessibility by car to employment in the Los Angeles Region is given as:

$$AI(T)i = \frac{1}{100}\sum_{j=1}^{J}\sum_{k=1}^{K} PijkE(T)ijk$$

where $AI(T)i$ = the accessibility index for zone i using a travel time T;

j = the income category $j = 1, 2, \ldots J$;

k = the occupation category of job class $k = 1, 2, \ldots k$;

$Pijk$ = the proportion of the work force of zone i which is in income category j and occupation category k; and

$E(T)ijk$ = employment opportunities in income category j and occupation category k within T minutes of travel from zone i.

The calculation of travel time is based on the reports of residents and estimates of travel times are obtained from shortest-path algorithms, both are modified according to observed data. The exclusion of public transport travel time is considered to be a weakness of the index which is duly recognised by the researchers in an exploratory analysis of accessibility to health care facilities.

It is evident that the comparative index allows for the disaggregation of opportunities and population by social group and, hence, accessibility can be used as a social indicator providing an input into transport policy. In this context Doubleday (1979) examines the accessibility changes arising from the implementation of the loop-and-link scheme in Merseyside. The results are expressed in the form of a contoured map of accessibility values and graphs showing the distribution of the values of a specified accessibility index within a given population group or aggregation of groups. Opportunity is disaggregated by employment, shopping, education and health and population by socio-economic status and car availability. The separation element is measured in terms of door-to-door time.

Similarly, Sherman et. al. (1974), in evaluating metropolitan accessibility, use the cumulative percentage of the population within various travel time contours of important metropolitan activities as the central expression of accessibility. Values were produced for all combinations of activity type, mode, analysis year (1970 and two sets of data for 1980) and areal split (that is, inner city and suburbs). In addition, measures are developed for the study area population disaggregated by age group, total households, households by income class, households by car ownership, total labour force and labour force by employment type. Given the results in the form of frequency distributions and accumulative graphs a number of accessibility analyses were undertaken. It is shown that the differences in accessibility conditions afforded by alternative land-use and transport systems are small and that greater differences are apparent between private and public transport. Network and zonal aggregations are also shown to influence the shape of cumulative accessibility plots in that by averaging travel times between (interzonal) and within zones (intrazonal) a degree of error is implicit within the index. Further analysis reveals the differences in accessibility conditions between sub-groups of the population and, hence, again demonstrates the use of cumulative, comparative measures as social indicators.

Whilst it is apparent that comparative indices overcome the problems of combining separation and opportunity measures, the problems and assumptions implicit in network and zonal aggregation remain. The effects of network and zonal aggregations, as illustrated by Sherman et. al. (1974) have also warranted attention in other studies. Doubleday (1978), for instance, in using zone centroids in calculating travel time recognises that it is important to ensure that variations in walking times from different parts of a zone to a public transport network are not too great. The larger the zone the greater the diversity of population structure and, hence, the greater the likelihood of there being significant differences in accessibility within a zone. The evaluation of cumulative graphs becomes more difficult when the distribution of accessibility values within a zone is as widely spread as the distribution of accessibility between zones. It is important, therefore, that the spatial (locational) disaggregation is given as much attention as population and opportunity disaggregation.

A second problem associated with the comparative index is the lack of any precise single measure of accessibility. The visual interpretation of cumulative graphs is useful in identifying only large differences in accessibility conditions. Largely for this reason and the need for a policy orientated approach to accessibility measurement, a number of studies have been concerned with the specification of standards. For instance, Zakaria (1974) for the purposes of plan evaluation suggests that accessibility should be determined by the number of opportunities that can be reached within a calculated travel impedance, whilst Mitchell and Town (1977) propose measures that record opportunities within given time bands.

Wickstrom (1977) believes it is possible to develop user standards in terms of opportunity values to satisfy urban needs and suggests that standards for work travel in terms of employment can be calculated by assessment against the average. On this basis Wickstrom defines "balanced transportation" as "that mix of transportation modes which provide facilities offering a desirable level of access to opportunities to residents of an urban area. In addition, it provides these opportunities in accordance with individual needs at the lowest possible cost, considering social, environmental and transportation factors". The index can be expressed as:

$$B = \sum_{b=1}^{b=n} Pb \; ORb$$

where B = a measure of balance with an optimal value of 100;

Pb = the proportion of regional population in sub-areas 1 through n;

ORb = a measure of the ratio of actual to desired opportunities reached within a given travel time standard for each sub-area.

It is considered that OR should take account of the activities desired (trip purposes) and modal use of the residents. Hence:

$$OR = \sum_{p=1}^{p=k} Qp \left(\sum_{m=1}^{m=n} MnOpm \right)$$

where Q = the relative magnitude of the different trip purposes or activities considered for k purposes;

Mn = the relative use of each travel mode considered for n modes;

Opm = the actual to desired opportunities reached in a given travel time standard by each mode (for each trip purpose or activity).

Whilst the use of standards in Wickstrom's index enable the formulation of a single measure of accessibility it is evident that problems arise in deriving their value. Ben-Akiva and Lerman (1978) recognise that both the arbitrary selection of the isochrone (or isodistant) and the lack of differentiation between opportunities according to their proximity are deficiencies of cumulative opportunity measures. In certain cases standards may be implicit in legislative or policy decisions, for instance, Breheny (1978) notes that two miles can be used as a distance standard in determining accessibility to primary schools as beyond this distance a local authority has to subsidise the cost of travel for 5 - 8 year olds.

Further problems are likely to arise in determining the "desired" number of opportunities. Clearly, choice is more important for certain activities but the actual marginal utility of each additional opportunity will depend on a multitude of intangible factors not least being individual preferences. The concept of choice in spatial opportunity measures has been noted by Holst (1979) who, in pursuing a disaggregated approach to accessibility, draws a distinction between facilities where choice is not important and facilities where choice is important. Similarly Black (1977) in studying accessibility and travel in seven Sydney suburbs distinguishes between choice and convenience facilities. For the former accessibility is measured by the number of opportunities within a given distance, whilst for the latter it is measured by the percentage of the population having access to one facility within a given distance. Hillman et. al. (1976) also recognise that choice of opportunity is not important for particular activities and, hence, measure accessibility in terms of the travel time to the nearest facility. A development on this theme has been explored by Cooper et. al. (1979) in analysing personal accessibility. Accessibility to facilities is measured in terms of the generalised cost of reaching the nearest facility, however, in order to account for the importance of choice in employment, the number of opportunities within a given cost is measured. For eleven different person types the number of necessary trips per week to each facility type is estimated and the total weekly travel cost is them assessed against a standard. Although this approach takes account of the fact that "the need for a person to access a particular facility is a function of the socio-economic characteristics of the person" (Cooper et. al. 1979) and, hence, does not simply produce accessibility levels for locations, it can be criticised on it's arbitrary use of standards in terms of both the travel costs and the number of necessary trips to each facility type.

The specification of values is, however, a necessary requisite in deriving single measures of accessibility and forms the subjective context of an index. Unlike composite indices, comparative measures enable the assumptions inherent in deriving values to be made explicit and provide a framework of information on which to assess the implications of alternative assumptions. Similarly, whilst the aggregation and averaging of data may be a necessary stage in the formulation of indices, the potential distortion of information and the underlying assumptions can be made explicit by displaying disaggregated data in the form of comparative profiles.

The comparison between gravity based models and composite measures of accessibility and comparative profiles showing the potential opportunity has been afforded attention in recent accessibility literature. Breheny (1978), in advocating measures of spatial opportunity, argues against the use of models based on observed travel behaviour and those incorporating an attenuation assumption that spatial deterrence decays in some fashion.

It is considered that by determining accessibility by the behaviour of individuals under a constrained set of conditions one "blindly accepts that behaviour reflects demand and that demand reflects preference". The behavioural approach may also fail to identify inefficiencies in the existing system and, in fact, may lead to self-justification of the present state. A number of authors of accessibility literature (including amongst others, Wachs and Kumagai, 1973; Vickerman, 1974 and Lee, 1973) have expressed similar views to those of Breheny.

Moseley (1977) in studying accessibility and transport policy in rural areas, argues that "the central focus of concern must be opportunities not behaviour", whilst Wachs and Kumagai (1973) state that "the use of indicators of accessibility which are opportunity based seem to be more consistent with the objectives of both social reporting and transportation policy-making than with the use of data which are limited to observed trip-making behaviour". As already noted, the choice of index depends ultimately on the operational requirements and, in this context, it is apparent that comparative measures of potential opportunity are more conducive to measuring the accessibility provision afforded to different social groups and geographic areas and can be expressed in policy responsive variables. Measures derived from actual behaviour, however, are, perhaps, more appropriate to determining the aggregate demand given a particular level of accessibility. Doling (1979), for instance, argues that peoples' behaviour is constrained by other peoples' behaviour and, hence, changes in accessibility lead to changes in the number of destinations of trips which, in turn, may lead to changes in accessibility. It is apparent, however, that spatial opportunity measures have the potential ability to take account of this in that, where appropriate, a measure of the demand as well as the supply for opportunities and/or transport can be incorporated into the index.

Those indices that are based on measures of potential opportunity but contain deterrence functions are similarly considered inappropriate for determining the accessibility levels of individuals, social groups and geographic areas as the decay parameters are normally derived from observed behaviour. The fact that problems have been encountered in determining the form of the deterrence function emphasises the inadequacy of the approach (see Breheny, 1978). Doling, however, suggests that spatial opportunity measures are susceptable to the same inadequacies in that they assume a zero attenuation until the isochrone or isodistant bands at which point the benefits decay instantly. In effect this argument reverts back to the problems of defining standards which, as mentioned above, is generally recognised as one of the major deficiencies of this approach. In direct response to Doling's comments, Breheny (1979), defends the spatial opportunity and, more specifically, the comparative profile approach to accessibility on the grounds that it offers a variety of measures dependent on the intended applications as well as inviting more analyst/decision-maker involvement than other approaches. The ability to disaggregate is seen as a further attribute of this approach and, whilst problems may arise in setting rigid standards, the assumptions implicit in aggregated, composite indices (not least concerning the origins and structures of trips) may be made explicit.

The graphic representation of disaggregated and largely value free information also enables the implications of using alternative definitions and measurements based on various assumptions to be compared. In view of this, it is felt that the expression of accessibility in a profile form provides enough flexibility for determining the implications of the assumption (implicit within all the above indices) that all trips are defined as being home-based, single-purpose journeys. Different profiles may be displayed showing accessibility provision for any combination of activities and from non-home origins (as will be explored in the subsequent text).

In comparison with other types of index the main advantages of the comparative profile approach lie in its simplicity, potential disaggregation, the explicit nature of the assumptions (through the setting of standards and the comparison of alternative profiles) and its adaptability to accommodate developments presently beyond the confines of existing accessibility measurement.

3.5. CONCLUSIONS

i) A diverse range of accessibility indices have been formulated over recent years for an equally diverse set of objectives and applications. Largely for this reason it is difficult to classify certain indices and, hence, only a broad classification system can be used in structuring a comprehensive review of accessibility measures.

ii) Indices based solely on interaction are felt to be only partial in their representation of accessibility in that some account should be taken of the availability of activities. However, they do provide a useful basis on which to determine the most appropriate separation measure as an input into an opportunity based index.

iii) The lack of any general agreement over the form of a generalised cost function (particularly the value of the coefficients) suggests that distance or time measures of interaction are more appropriate to accessibility measurement. It is felt that the precise nature of the measure should be determined with reference to the specific nature of the accessibility study in question.

iv) It is evident that composite measures of accessibility have been formulated with a view to expressing the interaction and activity elements of accessibility as one measure. However, it is felt that there is little intrinsic value in expressing accessibility in this form apart from the convenience of using a single unit measure of accessibility.

There is a danger that the index will be assumed, in most cases incorrectly, to have additive properties.

v) The level of complexity of existing indices varies considerably. Whilst certain measures purport to having a sound theoretical base derived from graph theory, economic theory or probability theory, they are often simply providing a more detailed mathematical expression of the same assumptions implicit in less sophisticated approaches. In order to operationalise accessibility indices, particularly with regard to determining transport or land-use policy, it is important that indices are easily intelligible to the decision-maker and that the measurement assumptions contained in the derivation of the index are not concealed and, hence, overlooked.

vi) It is recognised that aggregation is a necessary and significant stage in the measurement of accessibility. However, it is also recognised that aggregation is liable to distort and conceal information and is often undertaken without a full understanding of the assumptions implicit in taking such a step.

vii) Accessibility is a characteristic attributable to an individual as opposed to a place. In agreement with Jones (1976) it is felt that too much emphasis has been placed on the accessibility of areas rather than individuals. It can be argued that personal accessibility is of little use to policy decision-makers in a disaggregate form and that more aggregate measures are normally required; however, it is suggested that measures should be derived by aggregating personal accessibility (in order to reflect the distribution) rather than measuring place accessibility.

viii) In agreement with Breheny (1978) and others, behaviourally derived measures of accessibility are felt to be misleading in that they overlook the fact that an individual's behaviour is constrained by the system and are concerned only with expressed demand rather than preference. Transport or land-use changes to the system will alter the nature and level of constraints imposing on the individual and, hence, change his or her behaviour. Therefore, behavioural measures extrapolated into the future are likely to be self-fulfilling and may well amplify rather than reduce the existing differences in accessibility. On these grounds measures of opportunity potential are considered more appropriate in determining accessibility for evaluation purposes.

ix) Accessibility measures reflecting activity requirements (needs) rather than behaviour are considered to be more appropriate for deriving accessibility levels of individuals, population groups or geographic areas. Also, whilst considerable problems are likely to be encountered in identifying (defining) needs, it is noted that accessibility information, expressed in profile form, enables standards reflecting alternative value judgements derived from various sources to be compared. In order to determine the accessibility effects of transport and/or land-use changes it is necessary to identify not only individual preferences but also the nature of the constraints on those preferences and, hence, the underlying causal processes that give rise to travel decisions. In order to achieve this it is felt that accessibility should be viewed in a wider framework than is displayed in the majority of indices and that greater emphasis should be placed on disaggregate measures.

x) A fundamental deficiency of existing accessibility indices is considered to be in the definition of the trip origin location. All the indices summarised above make the assumption that the individual's trip origin is always his or her place of residence (or the zone centroid) and, hence, all trips are seen as single-purpose, home-based trips. Trip linkages and sequences are therefore overlooked in conventional accessibility measurement. Whilst a number of studies have recognised this deficiency including Ben-Akiva and Lerman (1978), Pirie (1979) and Koenig (1980) it is apparent that the importance and role of linked or multi-purpose trips in accessibility is unclear.

xi) The area providing most scope in the theoretical development of accessibility measurement is felt to be the elimination of definition assumptions concerning trip origins and journey structures. Also, scope is seen to exist for the formulation of accessibility indices in which the full implications of any valuation and aggregation assumptions can be understood.

xii) It is recommended that indices be developed, at least initially, in a disaggregated form but still offering the potential for aggregation. In this context the comparative index is seen as the most appropriate form of measurement in that it is essentially a method of displaying accessibility information which is relatively simple to interpret. The inclusion of values which are normally implicit within an index can initially be kept external to the index. The introduction of decision-maker values in the form of standards or constants will make the inherent assumptions explicit.

To summarise the main points from the above conclusions, it is felt that comparative accessibility indices provide a basis on which more specific measures can be developed given the precise objectives of the study. It is important that values and assumptions arising from aggregation and measurement procedures are made explicit. Whilst it would be beneficial to study the effects of aggregation and the development of personal accessibility indices, it is inevitable, in the practical context of the research, that in providing accessibility information on which policy decisions for a whole administrative area are taken, a certain degree of aggregation is necessary and, therefore, it is suggested that the analysis of linked trip-making offers the greatest scope for improving accessibility measurement. In order to relate linked trip-making to accessibility analysis it is necessary to establish a wider frame of reference, particularly as all destination locations must now be redefined as potential origin locations. Chapter Four, therefore, focuses on both the concept of linked trip-making in accessibility and the extent to which recent developments in disaggregate transport modelling can be used in establishing a wider framework for accessibility analysis.

CHAPTER FOUR

TRIP LINKAGES AND THEIR ROLE IN ACCESSIBILITY MEASUREMENT

4.1. INTRODUCTION

It has been established in Chapter Three that a major deficiency of existing accessibility indices is the simplification of journey structures. All trips are assumed to be home-based, that is, trips start and finish at the individual's place of residence and only one destination or aggregate destination (zone) is visited. The extensive use of this assumption is thought to be attributable to two factors. Firstly, the convenience of measurement - without the assumption, difficulties would arise in defining the trip origins and destinations. Secondly, the incidence and nature of more complex journey structures are not fully understood. It is likely that the trip complexity will vary with trip-purpose and between individual types.

Over recent years there has been a growing concern with the over-simplification of journey structures for use in transport planning, for instance, Hensher (1976) states that "there is a general lack of any theoretical framework to assist in understanding the causal processes that produce such journey structures". Also, it is now increasingly recognised that "activities at each end of - and in some cases, during - travel are the causal factors which determine the direction, intensity, pattern, timing and demand for travel of different types" (Morris and Wigan, 1979). Against this backcloth travel patterns have been examined in a wider framework that encompasses the temporal as well as spatial components of travel and, on this basis, greater attention can be given to the sequencing and continuity of trip-making. Whilst new developments have been explored in describing and modelling travel behaviour, less attention has been focussed on developing accessibility indices within this wider framework.

This chapter describes recent developments in behavioural travel modelling and explores their relevance to and potential utility in determining accessibility indicators that are able to take account of trips to more than one destination, that is, non-home based trips. Preceeding this it is felt necessary, firstly, to clarify the precise terminology to be used when referring to complex travel patterns and, secondly, to establish the concepts inherent in analysing accessibility in this wider framework.

4.2. TERMINOLOGY

Before investigating the role of complex journey structures in accessibility analysis it is important that the terminology is clarified. A number of studies have recognised the existence of trip linkages in travel behaviour but have used different terminologies to describe this action.

Jones (1976), defines a multi-trip journey as a "travel sequence which commences at the traveller's home and involves at least two trips before the last trip home is made (that is, it comprises three or more trips in all)". Hensher (1976) notes that non home-based trips are accommodated within this definition. A trip, in turn, is defined as "a one-way movement from an origin to a fundamental destination for a single purpose and may comprise a number of stages corresponding to the use of a sequence of modes (e.g. walk-bus-train-walk)". Although this definition is generally accepted, ambiguity is still inherent in the term single purpose as this is dependent on the classification of activities and needs.

In comparison with Jones' definition, Bentley et. al. (1977), similarly interpret the term trip as denoting "a movement between two consecutive activity locations". In addition the term journey is used to denote "a complete expedition starting and ending at home" and a multi-stage journey is one that comprises more than two trips. Alternatively, Hemmens (1970), amongst others, adopts the distinction between single and complex journeys with the latter comprising three or more trips. It is recognised that a journey consisting of three or more trips must involve the sequencing or linking of activities.

A distinction can be drawn between trips that are undertaken in order to participate in more than one activity at one or more destinations and trips that are undertaken in order to participate in one type of activity at more than one location. Gilbert et. al. (1972), refer to the latter as a linked trip and a number of studies have referred to the former as a multi-purpose trip.

In the light of the above terminology, the following text is concerned generally with trip linkages, that is multi-stage journeys and their effects on accessibility levels. The research concentrates on multi-purpose trips (as defined by Gilbert et. al. 1972), but refers to both mulit-purpose trips and trips to one activity undertaken at more than one destination as 'LINKED TRIPS'.

4.3. A CONCEPTUAL FRAMEWORK FOR UNDERSTANDING ACTIVITY PATTERNS

The conceptual framework developed in Chapter Two provides a basis on which to analyse accessibility indicators. Within this framework it has been established that conventional measures of accessibility overlook non-home based trips. However, Chapter Two, whilst identifying the inadequacy of existing indices does not provide a suitable framework in which to examine the sequential nature of activities and the resultant journey structures. It is considered, therefore, that a conceptual framework for understanding activity patterns is required. The two conceptual frameworks are seen as being complementary to one another in that the first provides a basis for measuring accessibility whilst the framework outlined in the following text provides a basis for investigating activity patterns by introducing additional concepts associated with the previously defined components of accessibility.

In order to explore the nature of complex journey structures it is felt necessary to view accessibility in an activity rather than a travel based framework. Reference can be made to recent developments in behavioural travel modelling as the concepts associated with these developments are also likely to be useful in analysing the role of linked trips in accessibility measurement.

The concepts forming the basis of an activity pattern's framework are derived from the rationale that accessibility is essentially a characteristic of an individual rather than a location. Each individual is obliged or desires to undertake a set of activities of which a proportion can only be pursued at specialised out-of-home facilities. Every activity can be assigned both spatial and temporal co-ordinates which, by their very nature, impose a number of constraints on the timing, amount, location and type of activities that may be undertaken in a certain time period. Other constraints can be attributed to the individual's personal and household characteristics and requirements.

It is apparent that the vast majority of existing accessibility indices are, in the words of Pirie (1979) "temporally naive" in that they reflect only the spatial dimension. In an activity based framework, the concept of time budgets has proved to be useful in reflecting the temporal dimension and, further to this, the concept of space-time budgets reflects the inseparability of both dimensions. In addition, space-time analysis provides a framework in which the constraints on activity participation can be taken into account. The following text, therefore, elaborates the concepts of time and space-time budgets and continues by identifying the types of constraints impinging on activity patterns.

4.3.1. Time Budgets

Time is seen as a scarce resource which is distributed equally between individuals in that everyone has 24 hours in the day. Each person, depending on their physiological and role requirements have a set of activities which they wish to perform during a day. A certain proportion of the time is allocated to certain activities in such a way that they gain maximum utility from performing those activities in the given time allowance.

In the transportation context a fundamental distinction can be drawn between within and without home activities. The latter necessitates the individual to allocate a proportion of time to travel in order to participate in the desired activity. Hence, in the sense that travel is essentially a derived demand and is rarely undertaken as an end in itself, it is seen as lost time. By minimising lost time, individuals are then able to participate in further activities or the same activities for longer periods of time. Clearly one way of minimising travel time is to link trips so that more than one activity is participated in before the individual returns home. This, of course, depends on the spatial distribution of the facilities catering for these particular activities.

Recent investigation into the concept of time budgets has given rise to the hypothesis that time budgets are constant over time. Given that individuals will participate in additional out-of-home activities if their total travel time associated with existing activities is reduced, it is argued that new travel time will be generated by these extra activities (Landrock, 1979, and Tanner, 1979).

In contrast, Downes and Morrell (1979) have found trip-rates and travel budgets to be dependent on household size and car-ownership. Goodwin (1979) believes also that travel opportunities, costs and various socio-economic and personal characteristics are important factors and argues that "we are likely to learn most about travel behaviour, mobility and the effect of alternative policies if the time and money allocated to travel are treated as variables, not behavioural constants". It is important to see travel as a derived demand and a means to undertaking out-of-home activities. It can be assumed that the individual aims to minimise the time spent travelling (the travel time budget) whilst maximising the utility of participating in a set of activities (the activity time budget). Linking trips is one of the many ways of moving nearer to this situation.

4.3.2. Space-Time Budgets

It is recognised that a proportion of those activities allocated time in the time budget are pursued out-of-home and, hence, it is important to focus attention on the spatial distribution of the facilities catering for these activities. In this context, the Transport Studies Unit (T.S.U.) (1980) state that "daily behaviour may be characterised as the outcome of a process in which people match activity 'demand' against facility 'supply' in both time and space". It is necessary, therefore, that individual activity patterns are seen in "a space-time continuum" (Anderson, 1971) as opposed to a simple time continuum.

The space-time representation of human activity has been pioneered by Hagerstrand (1973) who identifies both temporal and spatial attributes for every action and event comprising an individual's existence (Burns, 1980). A two-dimensional framework is utilised in which the spatial and temporal co-ordinates of a particular activity can be recorded. Given that certain activities can only be undertaken at a limited number of locations, it is generally recognised that individual's activity patterns and, hence, journey structures can be viewed more accurately with reference to space-time budgets as opposed to time budgets.

The space-time representation of human behaviour provides a basis on which to analyse the linked-trip concept. As stated above, it is evident that trip linkages have the potential ability to reduce the travel time element of the total time budget. This potential, however, is dependent on the spatial distribution of the facilities at which the desired activities may be undertaken.

Figures 4-1 and 4-2 display the spatial and temporal co-ordinates of two behavioural activity patterns. In both cases the same out-of home activities (X and Y) are undertaken at the same location and for the same duration of time. The linked trip journey indicates that travel time can be reduced (that is, $(tn^2 - tn^1) + (tn^4 - tn^3) + (tn^6 - tn^5)$ is less than $(ts^2 - ts^1) + (ts^4 - ts^3) + (ts^6 - ts^5) + (ts^8 - ts^7)$)and, hence, more time can be allocated to alternative activities, that is, tn^6 is less than ts^8.

It is apparent, however, that the two-dimensional representation is a simplification of the co-ordinates in that space itself is a two-dimensional surface. For this reason, Hagerstrand (1973) developed the space-time prism in which space forms a horizontal surface and time is represented by the vertical axis. Within this three-dimensional representation the influence of the spatial distribution of facilities on the potential to reduce total travel time by linking trips can be shown. Any movement in space is represented by a change in the horizontal surface co-ordinates whilst time is represented by a continuous change in the vertical co-ordinates. Therefore, any non-travel activity

━━━ Non-travel Activity

‒ ‒ ‒ ‒ Travel

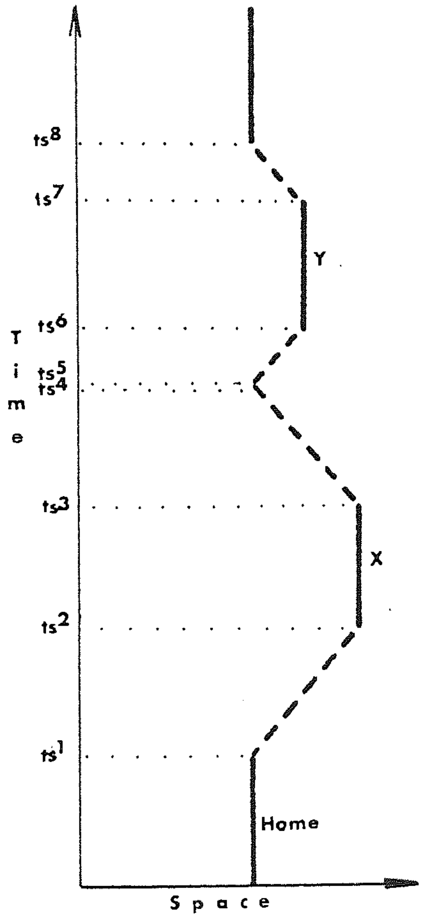


FIGURE 4 - 1 The Space-time Path of Two Single-Purpose Trips to Two Activities at Different Locations

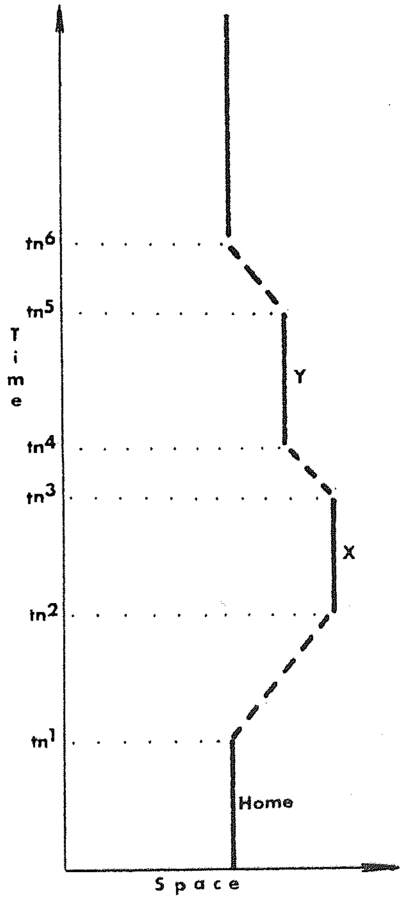


FIGURE 4 - 2 The Space-time Path of a Linked Trip to Two Activities at Different Locations

may be represented by vertical lines in the prism, the length of which represents the period of duration of that activity. Alternatively, travel may be represented by a diagonal line which traverses the three surfaces of the prism showing both the movement in space and the duration of the trip. Figures 4-3 and 4-4 show the locations in space (that is, on the horizontal surface) of home, activity X and activity Y for an individual. Due to their locations on this surface relative to one another the travel time and distance involved in linking trips to activities X and Y is considerably less in Figure 4-3 than for the equivalent linked trip in Figure 4-4. The spatial location of activities X and Y in comparison with the spatial location of activities X' and Y' provides for a greater reduction in travel time from linking trips.

Hemmens (1970) also represents the inter-relationship between time and space and activities as shown in Figure 4-5. The spatial distribution of facilities at which particular activities may be performed is considered to determine whether an activity is undertaken and the timing and duration of that activity. Similarly, both the time of day and the duration of activity participation will determine whether an activity is undertaken. Also for certain activities it is recognised that there is a minimum duration time and, hence, there is an element of interdependence. It is noted that by linking trips the duration of time spent travelling may be reduced and, with reference to Figure 4-5, the activity pattern is liable to change. It is felt that this representation is particularly useful in identifying the types of constraints on activity participation.

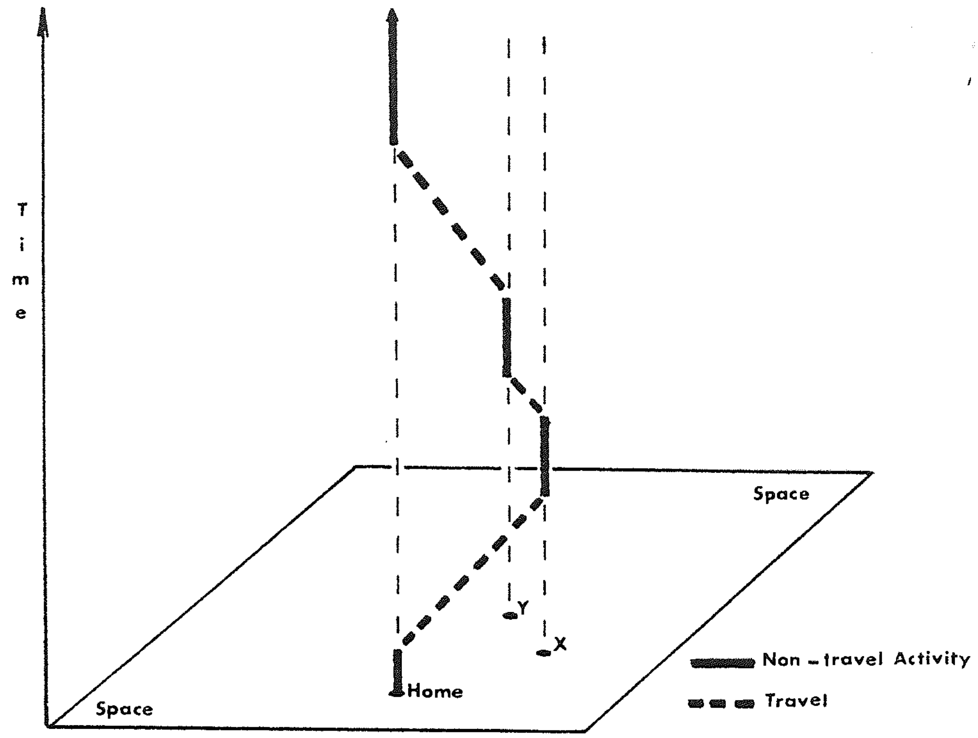


FIGURE 4 - 3 A Space-time Prism Showing a High Saving in Travel Disutility from Linking Trips

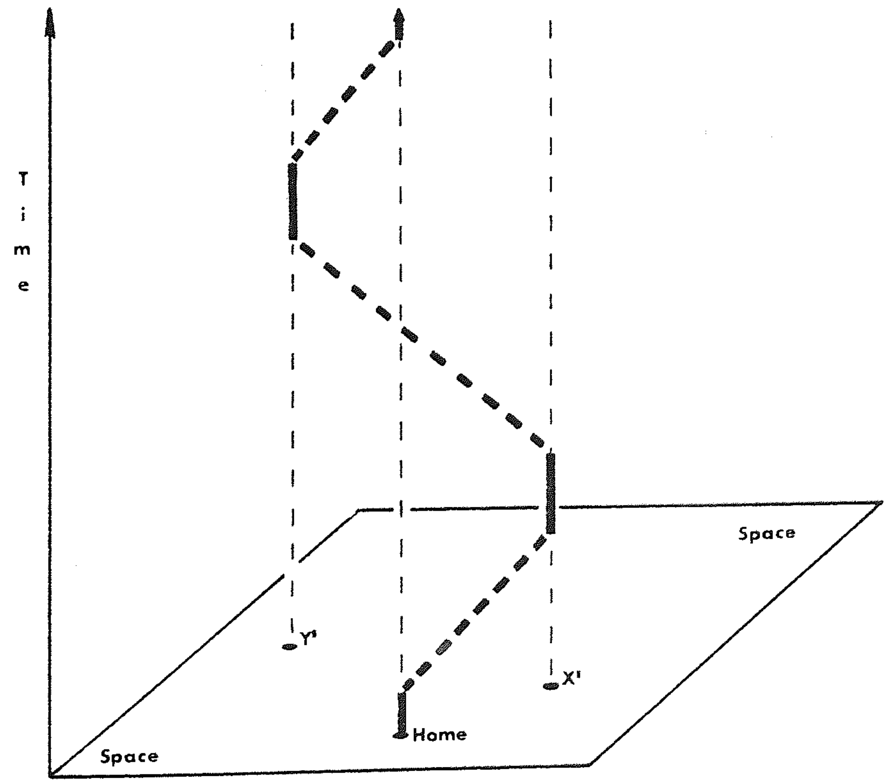


FIGURE 4 - 4 A Space-time Prism Showing a Low Saving in Travel Disutility from Linking Trips

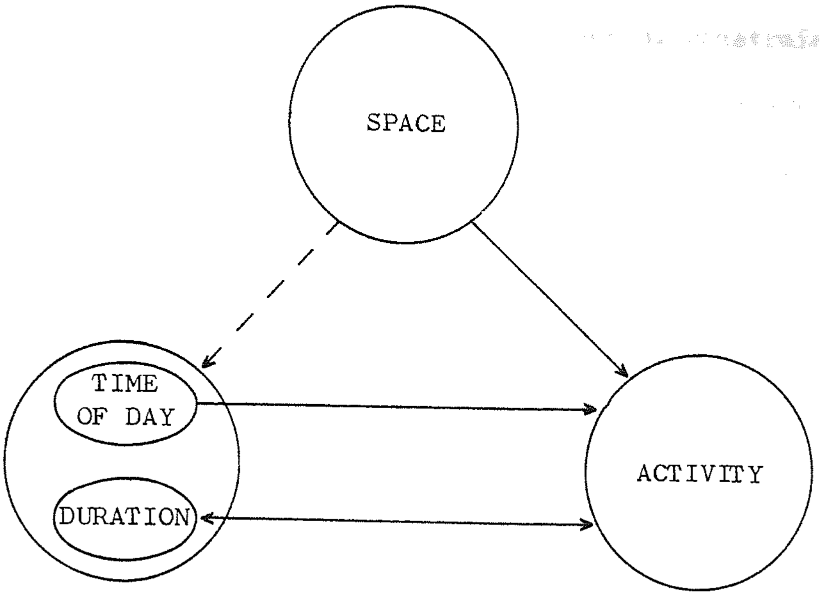


FIGURE 4-5 The Inter-Relationship between Time, Space and Activities (After Hemmens, 1970).

4.3.3. Constraints

The space-time representation of human behaviour indicates that by linking trips the total travel time can be reduced in certain circumstances, and, hence, further activities can be undertaken. It has also been shown that the potential to reduce total travel time is constrained by the spatial distribution of the facilities at which certain activities can be undertaken. It is recognised, however, that other constraints impinge on the structure of journeys and, hence, the ability to undertake linked trips. Hagerstrand (1973) identifies three sets of such constraints:

i. Capability constraints (for example, physical mobility).

ii. Coupling constraints (for example, the synchronisation of activities).

iii. Authority constraints (for example, limits and controls of access).

Similarly, T.S.U. (1980) identify four kinds of constraints which "prescribe limits on the kinds of activity which are available and the timing and location of activity participation". The four types of constraint can be summarised as:

i. Constraints imposed by the activity - in terms of the amount of time necessary to undertake an activity and the timing and ordering of activity participation.

ii. Constraints imposed by the facility; activities can only be undertaken at specific times and places.

iii. Constraints imposed by the household; the availability of shared resources and the obligation of household members to undertake activities at the same time and place as other household members.

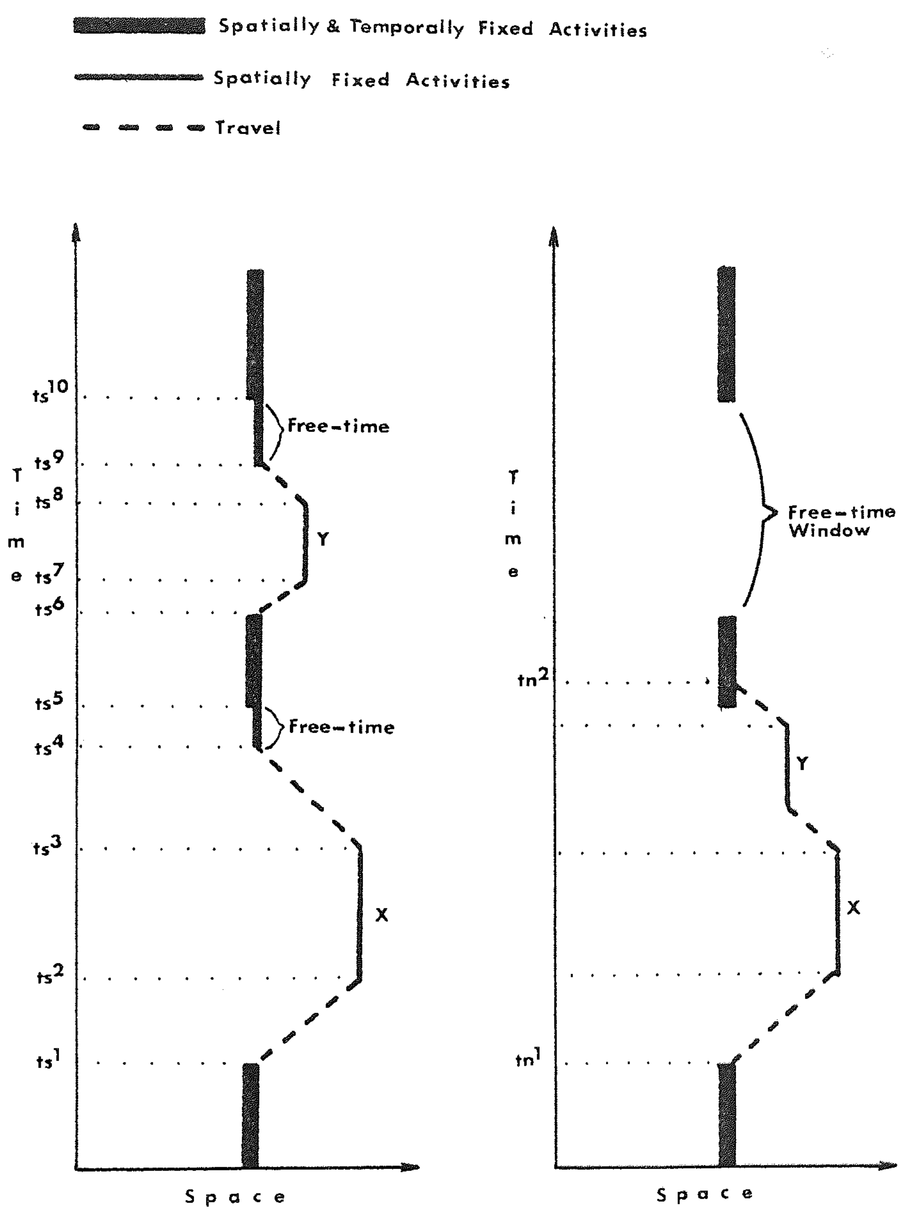
iv. Constraints imposed by the person; individuals are obliged to undertake certain activities and/or they may have incomplete knowledge of all options open to them and/or their behaviour may be governed by habit.

Further to this, T.S.U. note that, in considering the interactions between events and the household activity patterns rather than simply the activities of the individual, a series of scheduling constraints start to operate at:

- the individual level; and
- to allow for joint activities and linkages between household members.

With reference to Hemmens' (1970) representation of the space-time framework it is possible to indicate the effects of constraints on journey structure. Spatial constraints arise due to the fact that certain activities can only be undertaken at particular facility locations. Timing and duration constraints of activity participation are imposed by the necessity to undertake other activities (including travel) and by the nature of the activity (for instance, certain activities must be undertaken for a minimum or specified time period and between specified times).

The various constraints on an individual's journey structure can also be represented on the space-time graph. Given that a certain number of obligatory activities are fixed by their spatial and/or temporal co-ordinates, it is apparent that other activities can only be undertaken in the remaining space-time windows. For instance, in assuming that all other activities are fixed both spatially and temporally, the following graphs (Figures 4-6 and 4-7) indicate that an individual can undertake, by single-purpose trip, activity X over the time period $ts^3 - ts^2$ and activity Y in the time period $ts^8 - ts^7$ and that on each occasion a certain amount of free-time is available ($ts^5 - ts^4$ and $ts^{10} - ts^9$). Now without the constraining influence of these other activities it is shown that by visiting activity X and activity Y through linking trips the total duration time is less (that is, $(tn^2 - tn^1)$ is less than $(ts^4 - ts^1) + (ts^9 - ts^6)$) due to the decrease in total travel time. However, the nature of the constraints on home-based activity prevent trips from being linked as the duration time for both activities is greater than any of the available time windows (that is, $(tn^2 - tn^1)$ is greater than $(ts^5 - ts^1)$ or $(ts^{10} - ts^6)$). These time windows are, however, large enough to encompass single-purpose trips.



FIGURES 4 - 6 and 4 - 7 Space-time Graphs Showing the Constraints of Home Based Activities on Non-Home Based Activities

In summary it is evident that there are numerous constraints restricting the individual from taking the most 'efficient' path through the space-time prism and that in certain instances activities have to be foregone. The structure of any travel activity pattern is subject to these constraints and, hence, in order to measure accessibility their influence must be fully understood.

4.4. STRUCTURING AND MODELLING ACTIVITY PATTERNS

It has been established in the preceeding text that a space-time representation of human activity patterns provides a basis on which to understand the concept of trip linking. It has also been shown that the ability to link trips and the associated benefits depend on the nature of various constraints.

In order to account for linked trip-making in accessibility measurement it is necessary to quantify the likelihood that linked trips will be, or at least can be undertaken. In general terms, this can be seen as a function of the benefits to be gained from linking trips and the level of overall constraints. In the same way the conventional measures of accessibility have in the past been derived from transport modelling techniques, it is useful to explore the extent to which the space-time analysis of human travel behaviour provides a basis for developing new measures of accessibility. Within these terms of reference two areas of work can be investigated:

- the structuring of activity patterns; and
- the modelling of human behaviour.

4.4.1. The Structuring of Activity Patterns

The inclusion of linked trip-making in accessibility analysis requires that all desinations are seen as potential origins and, hence, trips may be made from origins other than the place of residence. In view of the fact that each individual undertakes a range of out-of-home activities over a given time period and that certain activities can be undertaken at more than one location, introducing an element of locational choice, it is desirable to simplify, or at least structure, activity patterns. The importance of linked trips to individuals can probably be better understood if certain activities can be assigned 'windows' in the space-time prism. The ability to participate in further activities can then be examined with reference to the remaining free windows.

The imposition of spatial and temporal constraints on the individual's activity patterns introduces the concept of flexibility in terms of how the individual is able to allocate his or her time to different activities throughout the day. Some activities are necessary and/or some activity locations are fixed by the amount of time and/or by the time of day. For instance, sleeping is normally fixed both spatially (home activity) and temporally both by the amount and, to some extent, the time of day. Work is also normally fixed both spatially and temporally. Likewise, all activities may be assessed according to the level and type of constraints associated with them.

It has been proposed that an hierarchial activity order can be constructed with the dominant trip-purpose at the top and lower levels expressing greater flexibility in their execution either in terms of their location or in their timing. More important, the sequential structure of multi-trip and multi-purpose journeys will depend, at least in part, on this dominance hypothesis. Brail and Chapin's (1973) reference to 'discretionary' and 'obligatory' activity classes, and likewise, Hagerstrand's

(1973) to 'obligatory' and 'non-obligatory', is an attempt to simplify the classification of trips (human activities). An extension of this argument is the distinction between fundamental and incidental trips - "a stop is incidental if it alters the spatial and temporal structure of the travel and non-travel activities in only a marginal way" (Hensher, 1976). However, the term 'marginal way' still requires definition. Furthermore, conceptual terms such as 'participation' and 'passive' have been used in order to codify the complex nature of activity patterns.

Yeung and Yeh (1976) argue that such attempts to categorise trips are "all partial analyses of the complex of human activities". A more systematic and objective approach to the simplification of activity patterns is the identification of all the factual components contributing to the decision process. Cullen and Godson (1972) list organised behaviour, the action space (that is, the framework structured by physical patterns and needs), priorities, constraints, flexibility of activities and scheduling. From this, it is suggested, therefore, that "in place of the simple fixed - unfixed dichotomy, a much more elaborate range of flexibility defined by the range of commitment to the activity and the time and space fixity of it" is needed (Cullen and Godson, 1972). Likewise, Morris and Wigan (1979), in response to the more traditional models of action-space, argue that we "must pay attention to not only the overall aggregation level typified by a time budget, but also to the frequency, sequence, synchronisation and substitutability of activities". It is evident, then, that accessibility measurement must take account of, or at least control for, the sequential nature of activities and the interrelationship between different activities and the activity patterns of individuals.

4.4.2. Modelling Human Behaviour

On the basis of structured activity patterns, a number of models have been developed in order to predict the travel behaviour of individuals. Any model requires simplifying assumptions about human behaviour and it is a fundamental dilemma to determine the level of complexity that can be handled by any modelling procedure.

Initially, it is worth noting that entropy maximising models (as described in Chapter Three) can be used to determine the most probable distribution of people to activities by taking account of the overall time budget constraints, and restrictions on the spatial and temporal availability of facilities. This is essentially an aggregate representation of human behaviour and not only randomly allocates people to activities but also takes no account of linkages between activity types. In contrast to this approach "the Markov process assumes dependence between an event and the immediately preceeding event" (Chorley and Haggett, 1967). The outcomes of an event are termed states and each state is linked to a preceeding state by a probability value termed the transition probability. On this basis, Markov chain models have been developed to determine the outcome state given the preceeding state and the transition probability.

With regard to complex travel patterns, it is recognised that several destinations may be visited in order to accomplish the purposes of a journey (Gilbert et. al. 1972). In this sense the facilities at these destinations can be defined as states and, given the preceeding state and the transition probability, the outcome state can be determined. In this context it is possible to model the journey structures of individuals within a system, for instance, Burnett (1974) utilises the Markovian principles in developing a model involving a number of discrete decisions as to whether or not to perform particular activities.

Markov chain models, however, are open to criticism in that a change from one state to another is undertaken in a series of discrete time intervals rather than through a change in spatial, as well as temporal, co-ordinates as indicated by the above space-time prisms. Also, as regards activity behaviour, the specification of the transition probability function is difficult to determine accurately in that the separation and opportunity functions should ideally be taken into account. In fact, the transition probabilities should essentially be accessibility measures themselves. Further to this, it is also noted that transition probabilities will vary over time, due to the changing needs of the individual. In response to these difficulties, Markov 'renewal' models have been developed in an attempt to take account of the time dimension in linked trip behaviour, and the variance of time spent in each activity. The 'sojourn' time spent in any one state is considered to be dependent on the type of activity and the next state to be visited. The travel time between any two states is assumed to comprise part of the sojourn time in the origin state. Markov renewal models can, therefore, take into account the fact that the time spent in state i is dependent not only on the activity at i but also upon j, the next state to be visited. The spatial dimension is, therefore, taken into account in that the physical separation between states i and j is reflected by the sojourn time in state i.

The use of Markov renewal theory is demonstrated by Gilbert et. al. (1972) in deriving transition probabilities, the number of trips per journey, sojourn times in each state and the number of visits to a state. This information, it is argued, may then be used in a policy-making context to make predictions about linked trip-making. Whilst the rationale underlying Markovian models contributes to the understanding and prediction of linked trip patterns it is still necessary to determine the precise form of the transition probability function. At a disaggregated level this and, hence, trip-making behaviour will be dependent on the characteristics of the constraints imposing on the individual as well as on the type of activity or the corresponding sojourn time.

In contrast to Markovian models, a number of models based on the space-time budget approach have been proposed in order to "encompass the joint requirements of spatial travel-choice modelling with a more appropriate activity framework" (Hensher, 1976). For instance, Stone (1972) emphasises the use of elasticity models where the competition between activities leads to a re-structuring of activity patterns. Alternatively, Evans (1972), and de Donnea(1971) attach monetary values to activity types and assume that individuals maximise utility by choosing the 'best' set of activities subject to money and time constraints.

Within an accessibility context greater importance can be attached to the work of the Lund school of geography. P.E.S.A.S.P. (Program for Evaluating the Set of Alternative Sample Paths) model (Lenntorp, 1976) provides a disaggregate simulation which places emphasis on the constraints and linkages of activities and can be used to determine the opportunities open to individuals according to their situation. The model assumes that a given proportion of all activities are followed by other specific activities and that people can be randomly allocated to given activity locations in the first instance (Morris and Wigan, 1979).

The P.E.S.A.S.P. model has been criticised for assuming that locational decisions of activity participation are stable over time and that, in allocating links between activities, the quality of alternative locations catering for an activity are the same. Westilieus (1972), largely in light of these criticisms, has developed a model that takes into account an individual's need to access certain activities. The level of need for activity participation rises to a threshold with time from when the activity was last undertaken. Where the opportunity arises for participation in this activity "a new chain of activities is automatically instigated" (Morris and Wigan, 1979).

More recently, research into disaggregate behavioural travel modelling has identified individuals activity behaviour as being highly adaptable (see, for instance, Pirie, 1979). T.S.U. (1980) argue that "P.E.S.A.S.P. is used essentially as a model of an urban environment rather than as a model of human behaviour" and, in contrast, develop C.A.R.L.A. (Combinatorial Algorithm for Rescheduling Lists of Activities). Whilst P.E.S.A.S.P. is concerned with the opportunities available to hypothetical individuals, C.A.R.L.A. aims to predict the impact of a proposed policy on observed activity schedules. The model comprises a hierarchy of sub-models that represent different types of response to change. At the simplest level, only the rescheduling of activities is recorded unless a satisfactory activity pattern cannot be developed. In this situation, greater complexity can be introduced by modelling changes in both the location of activities and the actual set of activities undertaken.

It is felt that the understanding of trip linkages and, for that matter, any characteristic of activity of travel patterns must be set in this type of framework in which the causal processes giving rise to behaviour can be simulated. Whilst C.A.R.L.A. highlights the complexity of travel behaviour it serves to provide more realistic guidelines as to what constitutes 'good' or 'bad' accessibility. T.S.U. (1980), in using C.A.R.L.A. to determine an objective function to measure the response to change in terms of activity behaviour, suggest that the maximisation of free-time or the minimisation of travel disutility (that is, the separation element of accessibility) may be adopted. Both can be seen as indicators of accessibility in that any change in out-of-home activity behaviour will be in response to a change in accessibility.

On the basis of this it is now appropriate to consider how the properties of the above behavioural models and the concepts on which they are based assist in incorporating linked trips into accessibility measurement.

4.5. INCORPORATING TRIP LINKAGES INTO ACCESSIBILITY MEASUREMENT

The space-time representation of accessibility measurement infers that each travel decision is inter-related and that activity involvement must be seen as a continuous, sequential process. It is apparent, then, that in order to measure accessibility to one type, or a set of, activities it is necessary to specify the temporal and spatial co-ordinates of participation in all other activities undertaken in a given time period. In the case of compulsory or obligatory activities such as education and employment this is likely to be possible in that their co-ordinates can be assumed to be fixed (at least in the short term). For all other activities, however, it may be argued that a certain amount of flexibility exists regarding both the timing and location of activity participation. As stated above, the problems of including linked trips into accessibility measurement stem from the fact that every destination becomes a potential origin. The definition of that origin is, therefore, difficult to determine in terms of both the type of facility and its location.

In the models described in the preceeding text, the temporal and spatial co-ordinates of activities are specified according to the actual behaviour of individuals. On this basis, accessibility can be measured in terms of either the total amount of travel disutility (separation) or the amount of free-time available after a given set of activities have been participated in. It is necessary, however, to draw a distinction between accessibility to a set of activities and accessibility to one particular activity type. The latter assumes significance where, in a practical context, the accessibility to a specific facility or activity type is an issue and, therefore, necessitates some form of policy responsive accessibility analysis. Whilst the above measures are appropriate for determining total accessibility, a less aggregated interpretation of activity patterns is required for determining the accessibility to a particular activity or set of activity types. It is suggested, therefore, that accessibility to a particular activity type Y can be measured by the level of additional travel disutility (that is, the detour) required to participate in this activity. With reference to Figures 4-1 and 4-2 (p. 125), the travel disutility in terms of time associated with participating in activity Y as a single-purpose, home-based trip is given as $(ts^8 - ts^7) + (ts^6 - ts^5)$ and as a linked trip (combined with activity X) is given as $(tn^6 - tn^5) + (tn^4 - tn^3) - (tn^2 - tn^1)$.

The potential of accessibility indices to take account of trip linkages depends on their ability to encompass the sequential nature of activities and, more specifically, recognise trip origins other than the individual's home. With reference to Chapter Three, it is concluded that potential opportunity measures have several advantages over behavioural measures in that, amongst other reasons, behaviour in itself is constrained by accessibility provision and does not necessarily reflect accessibility needs. In attempting to take account of the role of linked trip-making in accessibility measurement it is, therefore, considered appropriate to determine the potential opportunity available for different trip origins and observe how individuals behave in this given supply situation rather than simply rely on behaviour as the sole indicator of accessibility levels.

Potential opportunity measures of accessibility are required that reflect the availability of opportunities from non-home locations as well as home locations. Assuming that all possible origin locations and the availability of activity locations can be defined, it is possible to express accessibility information for different trip structures in a composite form of accessibility measure. However, the combination of the measure of accessibility provision from home locations with that from non-home locations requires a value judgement as to the relative utility of each. Thus, in addition to the valuation and aggregation assumptions implicit in combining the separation and opportunity variables, additional assumptions must be incorporated in valuing and aggregating accessibility levels from different locations. As noted in Chapter Three, composite measures, in producing a single unit measure, tend to shroud these assumptions and, therefore, do not present accessibility information in a form that is helpful to our understanding of the influence of linked trip-making on accessibility levels.

Comparative accessibility profiles, showing the potential availability of opportunity, provide a basis on which to represent accessibility information which is largely free of value judgements and assumptions often implicit in more complex indices. Given that the potential to link trips is essentially an unexplored area of accessibility measurement, it is important that information is assembled through which different interpretations and assumptions about journey structures and the relative utility of the availability of opportunity from linking trips can be investigated. Comparative accessibility profiles are taken, therefore, to be the most appropriate method of accessibility measurement in which to encompass linked trip-making.

The potential opportunity available to an individual can be measured by indicating the extent to which the availability of opportunity increases with the travel disutility from the facility location of activity X as well as the individual's home location. This can be expressed in a very simplified form by the following space-time graphs (Figures 4-8 and 4-9) where $Y^1 - Y^p$ represents the nearest to pth nearest facilities for activity type Y from the individual's home location and $Y'^1 - Y'^p$ represents the nearest to pth nearest facility for activity type Y from activity X.

Given then that Figure 4-8 represents the space-time paths for a single-purpose trip and Figure 4-9 for linked trips and that the travel disutility attributable to participation in activity Y^p for a single-purpose trip is tsY^p and for a linked trip is tnY'^p respectively, then a cumulative opportunity profile may be drawn as in Figure 4-10. It is also noted that only those opportunities that can be accessed within the temporal and spatial constraints impinging on the individual should be recorded on the profile.

Whilst the above method of measurement takes account of the

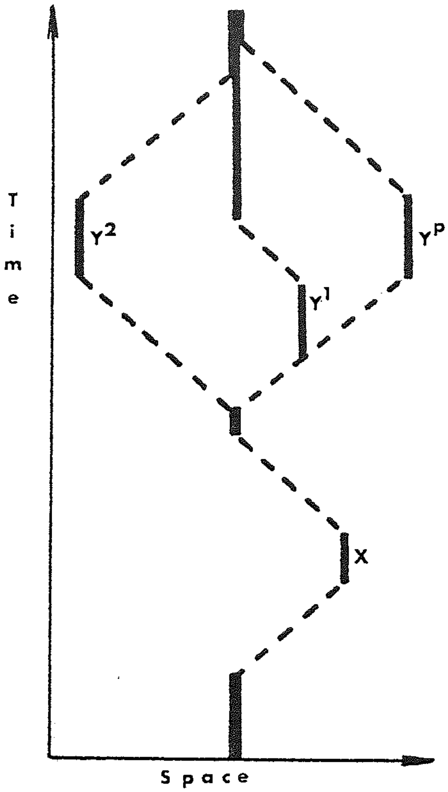


FIGURE 4 - 8 The Space-time Representation of Potential Opportunity for Participating in Activity Y from Single-Purpose Trips

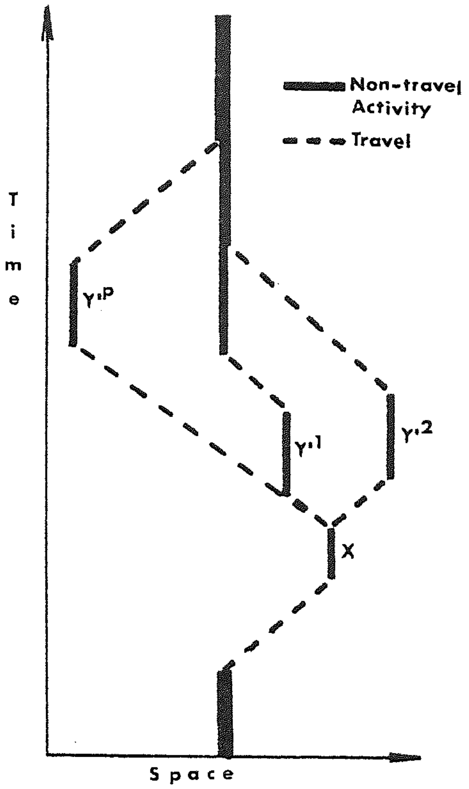


FIGURE 4 - 9 The Space-time Representation of Potential Opportunity for Participating in Activity Y from Linking Trips

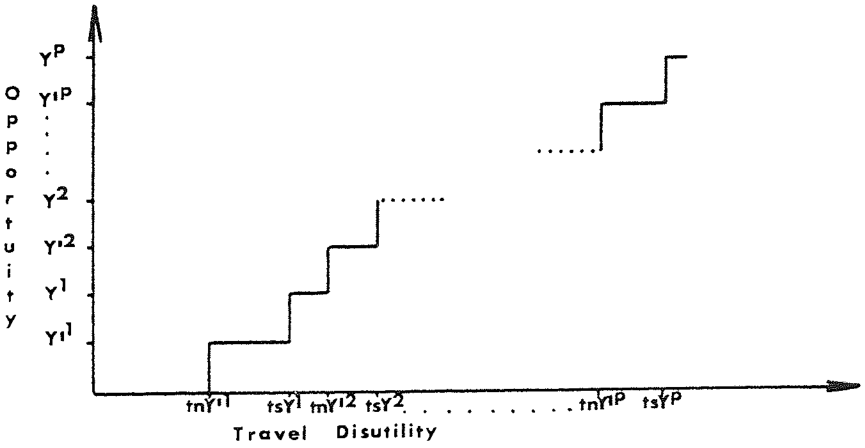


FIGURE 4 - 10 A Potential Opportunity Profile Showing the Increasing Availability of Activity Y with Travel Disutility from Both Single-Purpose and Linked Trips

potential opportunities available for participating in the activity type to which accessibility is being determined, it is apparent that the spatial and temporal co-ordinates of the remaining activity set are still derived from behaviour. It is suggested, therefore, that a true potential opportunity measure of accessibility must take into account the potential availability of all activities within the activity set. Again this can be illustrated by comparing the graphs in Figures 4-8 and 4-9 with the graphs in Figures 4-11 and 4-12.

Not only are there a number of alternative locations for participating in activity Y but there are also a number of potential destinations for participating in activity set X. It is noted, therefore, that a potential opportunity measure must take account of the separation level for all possible combinations of activity locations in calculating the accessibility by both single-purpose and linked trips, provided they are within the limitations imposed by constraining factors. Profiles showing the potential opportunity for activity set Y, activity set X and activity set X + Y from single purpose trips and from linked trips may take the form of the profile displayed in Figure 4-13.

This type of approach to accessibility measurement is simply a development of the cumulative opportunity measure described in Chapter Three and seemingly provides a basis for accounting for trip linkages in accessibility indices. Profiles taking this form are, therefore, utilised in the experimental design stage of this research (Chapter Five) and the investigation of the

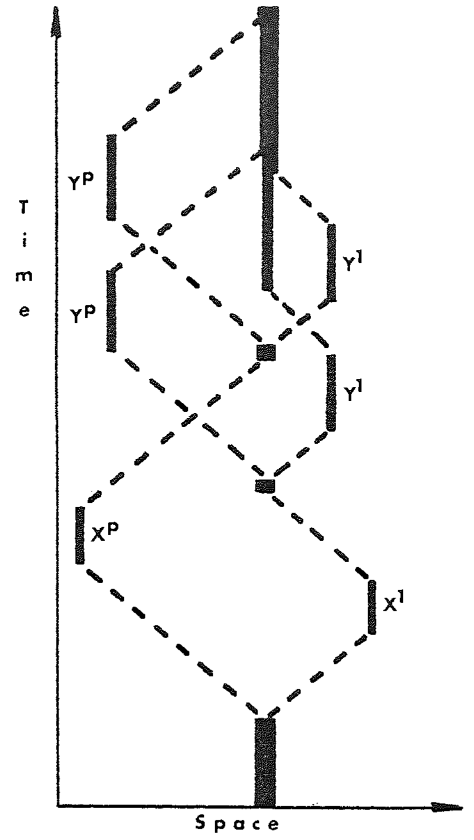


FIGURE 4 - 11 The Space-time Representation of Potential Opportunity for Participating in Activities X and Y from Single-Purpose Trips

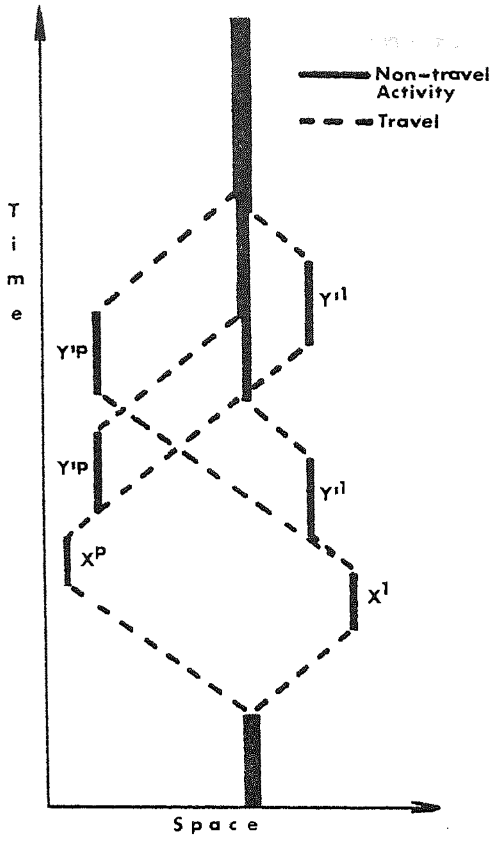


FIGURE 4 - 12 The Space-time Representation of Potential Opportunity for Participating in Activities X and Y from Linked Trips

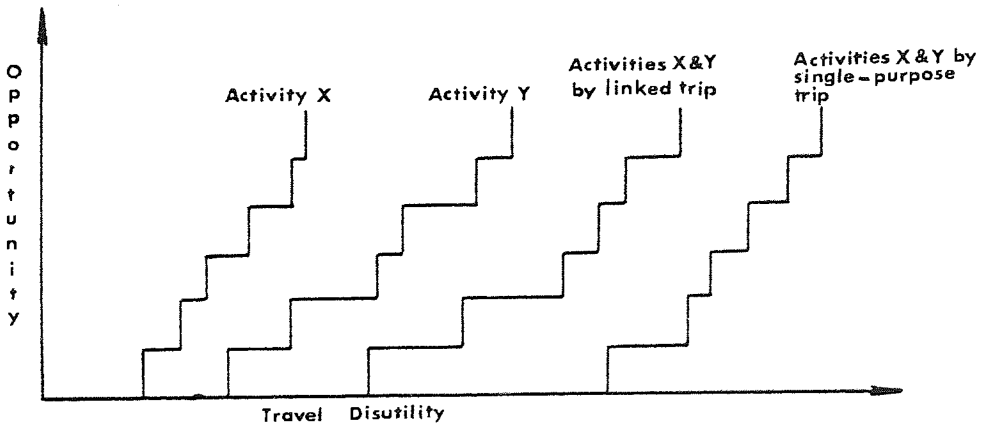


FIGURE 4 - 13 A Potential Opportunity Profile Showing the Increasing Availability of Activities X and Y from Both Single-Purpose and Linked Trips

relationship between trip linking and accessibility measurement.

4.6. CONCLUSIONS

i. Conventional measures of accessibility have been developed in a framework that is unable to take account of the sequential and linked nature of travel and non-travel activities. It is necessary that, in order for accessibility measurement to take cognisance of linked trip-making, wider terms of reference must be established.

ii. The notions of time, and more specifically space-time, budgets extend the conventional accessibility framework. The temporal dimension, particularly as regards the timing and duration of activities, contributes to our understanding of the relationship between accessibility and linked trip-making.

iii. An individual's accessibility level must be determined in the light of a number of constraints restricting travel and activity participation. Constraints such as the spatial location of facilities, the provision and quality of transport facilities and the mobility characteristics of the individual are, in some cases, implicit within several of the accessibility measures described in Chapter Three. However, it has been suggested that other constraints such as the temporal availability of facilities, the duration time associated with participating in certain activities and the obligation to undertake activities with or for other people (particularly household members) are equally significant in restricting an individual's degree of accessibility.

iv. Recent trends have directed behavioural transport modelling towards the development of more disaggregated causal models that focus on the individual, the interrelationships between travel and non-travel aspects of human behaviour and trip sequences and linkages (see T.S.U., 1980). Whilst this type of model is still in very much of an experimental stage, it is concluded that, the underlying rationale applies equally to accessibility measurement. Within this context, journey structures and travel decisions are recognised as being considerably more complicated than is portrayed by both conventional models of human behaviour and accessibility indices.

v. The linking of trips comprises one element in the complexity of travel behaviour. The fact that non-home based trips have not been incorporated in accessibility indices in the past is recognised as stemming from the convenience associated with assuming all trips to be single-purpose, two-way movements and, hence, undertaken from the individual's place of residence. The above text demonstrates that, whilst a number of possibilities exist for representing trip linkages in accessibility measurement, a number of behavioural assumptions have to be taken on board.

As concluded in Chapter Three, comparative accessibility profiles provide a basis on which the assumptions normally implicit in accessibility measurement can be made explicit.

In attempting to incorporate the potential to link trips in accessibility measurements it is apparent that a number of behavioural assumptions will be required. In order that the affect of these assumptions can be appreciated, comparative profiles showing how the availability of opportunity accumulates with travel disutility are utilised. The information displayed in these profiles provides the foundations on which to further our understanding of the role of trip linking in accessibility measurement and to determine the most appropriate method of measuring potential accessibility from linked trips.

CHAPTER FIVE

EXPERIMENTAL DESIGN AND CASE STUDY SELECTION

5.1. INTRODUCTION

It has been established (in Chapters Two and Three) that a major theoretical deficiency of existing accessibility measurement is the inability of indices to take into account the potential to link trips between activities. Chapter Four has, therefore, explored an extended framework of accessibility with relation to activity patterns and current developments in disaggregate behavioural modelling with a view to determining how complex travel patterns can be encompassed in accessibility indices. In addition to the linked trip problem other deficiencies of accessibility measurement are identified as the aggregation of information and the relative valuation of different variables and components of accessibility. The assumptions implicit in each stage are, on the evidence of Chapters Two and Three, often overlooked or concealed within the final form of the index. As also concluded in Chapter Three, comparative accessibility profiles are considered to provide the most scope for overcoming the above measurement and specification problems and enable disaggregate and largely value-free information to be presented.

In reverting to the practical context as outlined in Chapter One, the use of accessibility measurement by local authorities and in this case the London Borough of Hammersmith and Fulham for transport and land-use planning requires that particular issues (problems) can be addressed and that the accessibility of different individuals and areas within the administrative boundary can be compared. With respect to implementing transport and land-use policies it is, perhaps, particularly important that areas with poor accessibility (measured in terms of policy responsive variables) are identified.

The following section of this chapter outlines a series of experiments designed to determine the importance and extent of the theoretical deficiencies and at the same time meet the practical requirements of the research. An appropriate case study through which the experiments can be undertaken is outlined in the remaining text of this chapter.

5.2. EXPERIMENTAL DESIGN

An experimental design is required that addresses the theoretical problems of accessibility measurement as identified in the preceeding chapters and that provides accessibility information of use to the London Borough of Hammersmith and Fulham.

5.2.1. The Areas of Investigation

The theoretical content to the research requires that the empirical study should focus on:

i. Determining the extent to which comparative profiles form an appropriate basis on which to represent accessibility information.

ii. Assessing the differences in accessibility levels that can be attributed to the use of alternative values and changes in the level and type of aggregation.

iii. Investigating techniques for accounting for trip linkages in accessibility measurement and attempting to develop appropriate indices or profiles.

iv. Assessing the likely extent of the distortions in conventional accessibility indices with regard to the failure to account for trip linkages.

Alternatively, the practical content to the research requires that the empirical study should focus on:

v. Developing accessibility profiles that address an accessibility issue within the London Borough of Hammersmith, enable a geographic comparison to be made between areas within the Borough and identify those areas and individuals with the lowest levels of accessibility.

vi. Examining the significance and policy implications of trip linking as a means by which individuals can gain maximum utility from a specified accessibility situation.

5.2.2. The Method of Investigation

The method of investigation comprises the following stages and experiments:

i. The formulation of accessibility profiles by zone enabling accessibility comparisons between both areas and individuals within the London Borough of Hammersmith and Fulham; and showing the potential accessibility from undertaking non-home based as well as home-based trips.

ii. The interpretation of the accessibility information displayed in the accessibility profiles by investigating the extent to which different interpretations of the same data (as displayed in the profiles) differ in the resultant measurement of accessibility. This is undertaken by:

- Examining the sensitivity of the information presented in the profiles to alternative forms and levels of valuations and aggregations as applied to the accessibility information presented in the profiles and, more specifically, testing the hypothesis that - the rank order of zones according to their accessibility level varies with the use of different values and levels of aggregation (H.1.).
- Assessing the extent to which measures of the potential accessibility from linking trips differ from home-based conventional measures and, more specifically, testing the hypothesis that - the rank order of zones according to their accessibility level changes when the potential to link trips is taken into account (H.2.).

  In testing both hypotheses (H.1. and H.2.) rank orders are compared for similarity using the Spearman rank correlation coefficient (see Appendix C).

iii. A survey of travel patterns providing data on the incidence of trip linkages, their role in overall journey structures and the principal factors giving rise to trip linking.

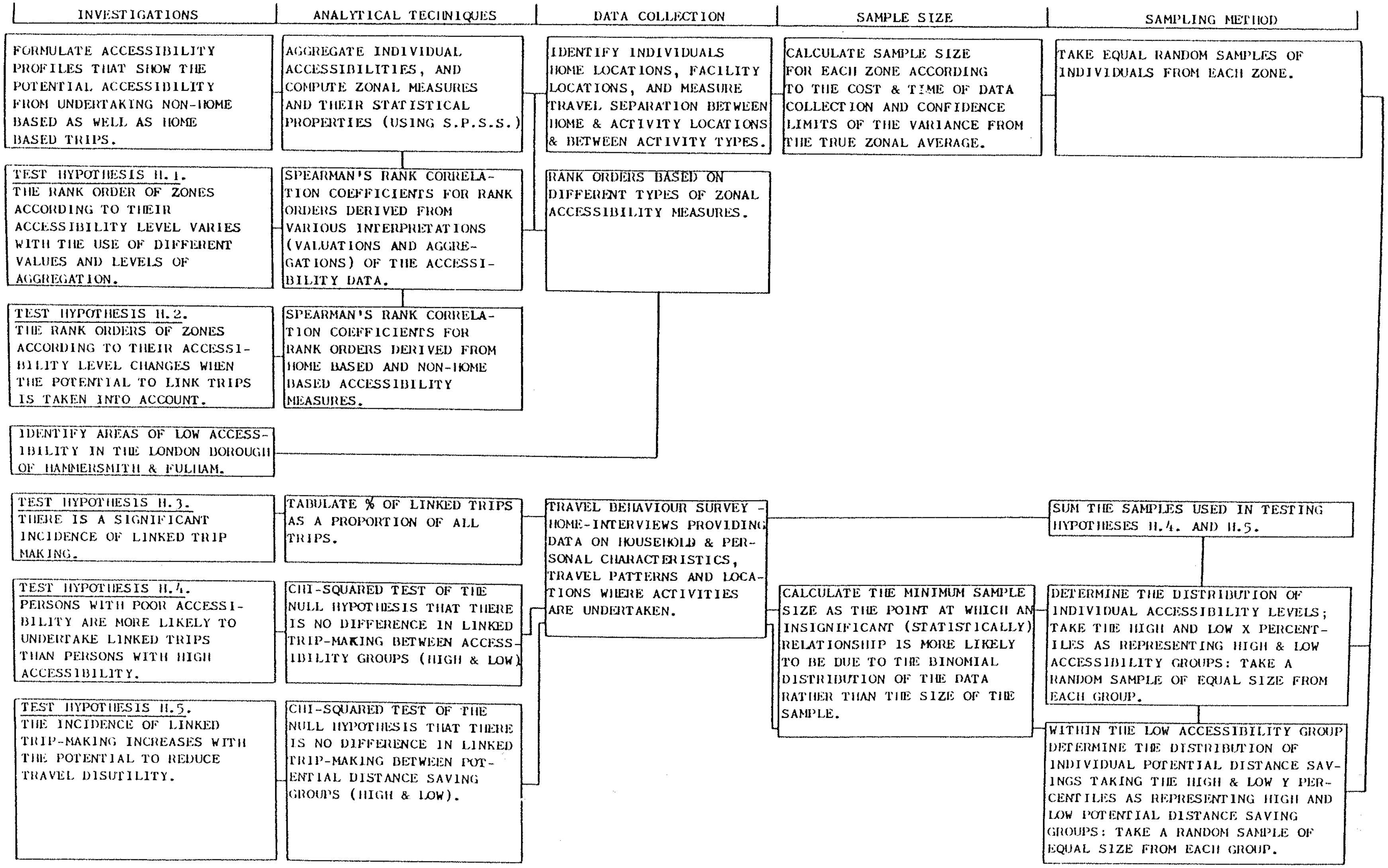
iv. The analysis of trip linking and its role in accessibility measurement by (on the evidence of the travel survey) determining:

- The proportion of trips that are linked and, hence, the likely extent of the deficiency of existing accessibility measures to take account of multi-purpose trips. The hypothesis that <u>there is a significant incidence of linked trip making (H.3.) is examined simply by tabulating the proportion of trips that are linked</u>.
- Whether the potential to link trips increases in importance as accessibility declines. More specifically, this is examined by testing the hypothesis that <u>persons with poor accessibility are more likely to undertake linked trips than persons with high accessibility (H.4.).</u>
- Whether the saving in travel disutility is the major determinant of journey structures. The hypothesis that <u>the incidence of linked trip making increases with the potential to reduce travel disutility (H.5.)</u> is examined.

  Hypotheses H.4. and H.5. are tested for statistical significance using Chi-squared analysis (see Appendix D).

v. In the light of the above analysis, a re-examination of the profiles previously formulated in order to determine the most appropriate interpretation and the extent to which linked trips are adequately reflected; to suggest alternative and, perhaps, more appropriate methods of encompassing the potential to link trips into accessibility indices and to determine the policy implications of the results for the London Borough of Hammersmith and Fulham.

The experimental design, as outlined above, is summarised in Figure 5-1 showing for each stage of the empirical research the analytical techniques, data collection and sampling methods (these are described more fully in Chapters Six and Seven). Stages a and b and, hence, hypotheses H.1. and H.2. are examined in Chapter Six whilst stages c, d, and e and, hence, hypotheses H.3., H.4. and H.5. are investigated in Chapter Seven. However, in order to operationalise this experimental design a case study approach is adopted in which the accessibility of one particular population group to a specific set of activities is analysed. The remainder of this chapter is devoted to describing the selection of a case study within the practical context of the research.



INVESTIGATIONS

ANALYTICAL TECHNIQUES

DATA COLLECTION

SAMPLE SIZE

SAMPLING METHOD

FORMULATE ACCESSIBILITY PROFILES THAT SHOW THE POTENTIAL ACCESSIBILITY FROM UNDERTAKING NON-HOME BASED AS WELL AS HOME BASED TRIPS.

AGGREGATE INDIVIDUAL ACCESSIBILITIES, AND COMPUTE ZONAL MEASURES AND THEIR STATISTICAL PROPERTIES (USING S.P.S.S.)

IDENTIFY INDIVIDUALS HOME LOCATIONS, FACILITY LOCATIONS, AND MEASURE TRAVEL SEPARATION BETWEEN HOME & ACTIVITY LOCATIONS & BETWEEN ACTIVITY TYPES.

CALCULATE SAMPLE SIZE FOR EACH ZONE ACCORDING TO THE COST & TIME OF DATA COLLECTION AND CONFIDENCE LIMITS OF THE VARIANCE FROM THE TRUE ZONAL AVERAGE.

TAKE EQUAL RANDOM SAMPLES OF INDIVIDUALS FROM EACH ZONE.

TEST HYPOTHESIS H.1.
THE RANK ORDER OF ZONES ACCORDING TO THEIR ACCESSIBILITY LEVEL VARIES WITH THE USE OF DIFFERENT VALUES AND LEVELS OF AGGREGATION.

SPEARMAN'S RANK CORRELATION COEFFICIENTS FOR RANK ORDERS DERIVED FROM VARIOUS INTERPRETATIONS (VALUATIONS AND AGGREGATIONS) OF THE ACCESSIBILITY DATA.

RANK ORDERS BASED ON DIFFERENT TYPES OF ZONAL ACCESSIBILITY MEASURES.

TEST HYPOTHESIS H.2.
THE RANK ORDERS OF ZONES ACCORDING TO THEIR ACCESSIBILITY LEVEL CHANGES WHEN THE POTENTIAL TO LINK TRIPS IS TAKEN INTO ACCOUNT.

SPEARMAN'S RANK CORRELATION COEFFICIENTS FOR RANK ORDERS DERIVED FROM HOME BASED AND NON-HOME BASED ACCESSIBILITY MEASURES.

IDENTIFY AREAS OF LOW ACCESSIBILITY IN THE LONDON BOROUGH OF HAMMERSMITH & FULHAM.

TEST HYPOTHESIS H.3.
THERE IS A SIGNIFICANT INCIDENCE OF LINKED TRIP MAKING.

TABULATE % OF LINKED TRIPS AS A PROPORTION OF ALL TRIPS.

TRAVEL BEHAVIOUR SURVEY - HOME-INTERVIEWS PROVIDING DATA ON HOUSEHOLD & PERSONAL CHARACTERISTICS, TRAVEL PATTERNS AND LOCATIONS WHERE ACTIVITIES ARE UNDERTAKEN.

SUM THE SAMPLES USED IN TESTING HYPOTHESES H.4. AND H.5.

TEST HYPOTHESIS H.4.
PERSONS WITH POOR ACCESSIBILITY ARE MORE LIKELY TO UNDERTAKE LINKED TRIPS THAN PERSONS WITH HIGH ACCESSIBILITY.

CHI-SQUARED TEST OF THE NULL HYPOTHESIS THAT THERE IS NO DIFFERENCE IN LINKED TRIP-MAKING BETWEEN ACCESSIBILITY GROUPS (HIGH & LOW)

CALCULATE THE MINIMUM SAMPLE SIZE AS THE POINT AT WHICH AN INSIGNIFICANT (STATISTICALLY) RELATIONSHIP IS MORE LIKELY TO BE DUE TO THE BINOMIAL DISTRIBUTION OF THE DATA RATHER THAN THE SIZE OF THE SAMPLE.

DETERMINE THE DISTRIBUTION OF INDIVIDUAL ACCESSIBILITY LEVELS; TAKE THE HIGH AND LOW X PERCENTILES AS REPRESENTING HIGH & LOW ACCESSIBILITY GROUPS: TAKE A RANDOM SAMPLE OF EQUAL SIZE FROM EACH GROUP.

TEST HYPOTHESIS H.5.
THE INCIDENCE OF LINKED TRIP-MAKING INCREASES WITH THE POTENTIAL TO REDUCE TRAVEL DISUTILITY.

CHI-SQUARED TEST OF THE NULL HYPOTHESIS THAT THERE IS NO DIFFERENCE IN LINKED TRIP-MAKING BETWEEN POTENTIAL DISTANCE SAVING GROUPS (HIGH & LOW).

WITHIN THE LOW ACCESSIBILITY GROUP DETERMINE THE DISTRIBUTION OF INDIVIDUAL POTENTIAL DISTANCE SAVINGS TAKING THE HIGH & LOW Y PERCENTILES AS REPRESENTING HIGH AND LOW POTENTIAL DISTANCE SAVING GROUPS: TAKE A RANDOM SAMPLE OF EQUAL SIZE FROM EACH GROUP.

FIGURE 5-1 Experimental Design

5.3. CASE STUDY SELECTION

With regard to both the theoretical and practical content of the experimental design a case study approach in which accessibility data for one population group to a specified set of activities is utilised. This type of case study approach is necessary due to the limited resources available for data collection but, more importantly, is appropriate for the following reasons:

- To ensure that the activity requirements of the study population are similar and to avoid the complexities associated with valuing and aggregating the accessibility levels of different social groups in comparable terms. The case study is, therefore, confined to investigating the accessibility levels and travel patterns of one particular sector of the population defined as being relatively homogeneous in their activity requirements.
- In relation to the theoretical context of the work, to limit the set of activities for which trip-linkages are investigated and, hence, minimise the complexity of the analytical framework. Certain types of activity are more or less likely to be sequential depending on the frequency, timing and duration of participation.
- In relation to the practical context of the work, to address a relevant issue (problem) within the London Borough of Hammersmith and Fulham. Clearly, the accessibility levels of certain population groups to particular activity types are more of an issue and

are more responsive to local authority transport and land-use policies than other population groups/activity types. As a second-tier authority in the Greater London area, the London Borough of Hammersmith and Fulham has direct responsibility for certain services while other services are under the control of the Greater London Council. Table 5-1 summarises the division of functions between the two-tiers of local government.

FUNCTIONS

INNER LONDON BOROUGHS	GREATER LONDON COUNCIL
TRANSPORTATION - Minor Road Maintenance (right to claim maintenance powers in relation to unclassified roads) - Footpaths and Bridleways	TRANSPORTATION - Major Roads and Road Building - Public Transport (London Transport - Traffic - Parking - Road Safety
PLANNING - Local Plans - Most Development Control Decisions - Acquisition and Disposal of Land for Planning Purposes - Development or Redevelopment	PLANNING - Structure Plans - Strategic Development Control Decisions
OTHER - Housing (G.L.C. also has powers) - Social Services - Libraries - Parks and Recreation - Museums and Galleries - Environmental Health - Refuse Collection - Clean Air	OTHER - Housing - Parks and Recreation - Museums and Galleries - Fire - Refuse Disposal

Education is the responsibility of the Inner London Education Authority (I.L.E.A.).

TABLE 5-1 The Split in Functions Between the Inner London Boroughs and the Greater London Council

In an accessibility context it is noted that the two major policy areas are transportation (influencing the interaction component) and land-use planning (influencing the activity component). Firstly, as regards transportation, the London Borough of Hammersmith and Fulham has direct responsibility for minor road improvements, whilst transport and major highway improvements are under the control of the G.L.C. In practice, however, the London Boroughs undertake an influential role in liaising with the G.L.C. and London Transport on public transport provision (through, for instance, in the case of Hammersmith and Fulham, the Abbey district bus management team, that covers the whole of West Central London) and by providing the initiative or by acting as agents for the G.L.C. on highway changes and improvements. Also, the London Boroughs role in transport provision for certain groups of the population is further enhanced through their responsibility for social services and their co-ordinating role in local community and voluntary transport schemes.

In contrast to transportation, the majority of land-use planning policy decisions are undertaken by the London Boroughs through development control procedures and local plans. Similarly, the Boroughs' responsibility for social services and housing (con-

> current with the G.L.C.) enables them to have some influence over the location of population groups as well as activities.
>
> Given the limited responsibilities of the Borough as regards transportation, it is important to ensure that the accessibility study addresses a problem that is potentially responsive to Local Authority policies.

Whilst the results of the empirical research will be directly applicable only to the population group, location and activity types for which data is collected and analysed, the investigation of the theoretical deficiencies of accessibility measurement may be interpreted so as to determine the implications for accessibility measurement in general. The actual specification of the population group and the specification of activities, however, may be undertaken in relation to the practical context of the research. As noted in Chapter Two, any precise practical criteria can only be determined in the light of the intended application of the accessibility analysis. Therefore, given the experimental design, a series of practical criteria derived from the guidelines set out in the practical framework (Chapter Two) can be utilised in specifying the population group and activities for which accessibility information is collected and analysed.

5.3.1. The Specification of a Population Group

In determining a particular sector of the population on which to focus a fundamental distinction can be drawn between those persons likely to have regular access to private transport and those who are largely dependent on public transport. Studies such as that undertaken by Wachs and Kumagai (1973) indicate that private transport availability is an important contributing factor to an individual's level of accessibility. As those persons who have access to private transport are also able to use public transport then their level of potential accessibility will always be higher than for public transport dependents. Given that the Local Authority are primarily concerned with accessibility problems (issues) within the Borough and the formulation of policies to alleviate these problems, then it is considered more useful to focus attention on population groups who are likely to have low accessibility relative to the population of the area as a whole rather than those with high accessibility levels.

The identification of transport disadvantaged groups in terms of car availability is normally derived from household car-ownership levels (for instance, see Pritchard, 1974; Black, 1977; Kinley, 1973; and Vickerman, 1974). However, WYTConsult (1977) also take into account the possession of a personal driving licence. Irrespective of any car availability classification it is generally recognised that certain sections of the population are transport disadvantaged due to:

i. Authority Constraints

Persons under 17 years of age are, by law, unable to drive a car. Also, a proportion of elderly persons are either advised or unable to drive due to failing health and disabilities.

ii. Income Constraints

Low or non-wage earners are unable to afford to own a car.

iii. Timing and Synchronisation Constraints

Whilst one (or in some cases more than one) car may be owned by a household, the availability of that vehicle to an individual is restricted due to its usage by other household members (this is particularly true for housewives whose husbands use the car for the journey to work).

With reference to these constraints, three population groups can be identified as displaying low levels of car availability:

- the young;
- economically inactive adults (housewives); and
- the elderly.

As stated in the practical framework (Chapter Two), precise criteria on which to assess accessibility indices can only be developed in light of the intended application of the index. In addition, with reference to the experimental design, it is possible to list practical criteria by which the final choice of population group, forming the subject of the case study, may be determined:

i. It is recognised that the accessibility indices should be related to transport policy variables. It is necessary, therefore, that the population group are responsive to policy changes. As noted above, the London Borough of Hammersmith and Fulham, as a second-tier local authority in the Greater London area, has a greater control over certain accessibility factors than others.

ii. In order that the survey results are useful to the Local Authority, the accessibility levels of the population group must be a policy issue within the Borough.

iii. The population group must be definable by location in order that adequate data collection can be carried out.

iv. The group should have a clearly defined set of activities in which they participate. The activities must be definable by location and temporal availability.

v. It is likely that survey methods may be undertaken in the form of interviews or questionnaires; the study must not, therefore, be based on information liable to be incorrect or under-reported.

vi. Most importantly, the population group must be recognised as being likely to, or at least having the potential to, undertake linked trips.

The three transport disadvantaged groups outlined above can each be assessed in the light of these criteria.

The Young

Education, as the dominant activity of the young, is well defined by its location, temporal availability and frequency of participation. Data collection is, therefore, possible as school children may be located at the place of education. The availability and provision of education and other activities for the young is likely to be an accessibility issue. However, transport policy areas having a direct influence, including school transport service levels, concessionary fare schemes and traffic management schemes (for instance, cycle access only) are not, certainly as regards the first two, directly under the control of the Inner London Boroughs (as indicated by Table 5-1). Moreover, the likelihood of multi-purpose trips being undertaken is questionable when it is considered that, besides education, only leisure activities are significant to the needs of this group. This is supported by Morris et. al. (1979) who provide evidence (Figure 5-2) to show that the majority of trips undertaken by school children are two-stage journeys. Moreover, leisure activities are likely to be undertaken on non-school days - either weekends or holidays - due to a number of intangible constraints (for example, homework and family requirements) on school days.

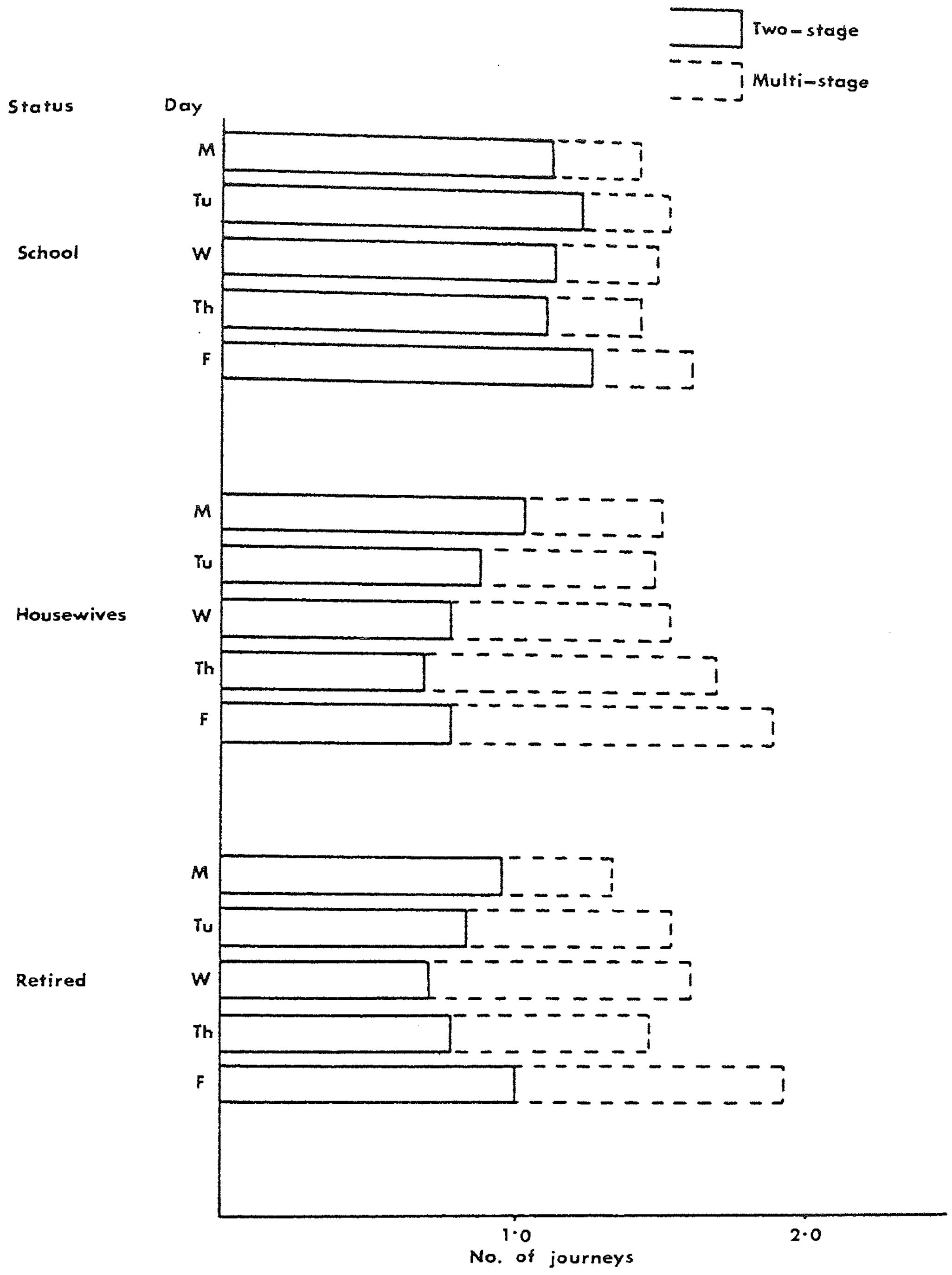


FIGURE 5 - 2 The Incidence of Journey Making and Trip Structure From a Study in Ballerat (from Morris et al., 1979)

In conclusion then, it is recognised that school children's activity patterns are likely to be dominated by education and additional constraints may further reduce the likelihood of non-home based trips being undertaken.

Housewives

This group have the attraction of being the least studied social group in terms of accessibility measurement whilst also being the group most likely to undertake linked trips on the evidence given in Figure 5-2. However, problems exist in locating housewives and it is difficult to envisage what policies might be implemented to improve their accessibility levels apart from general improvements to the off-peak transport service and the relocation of facilities. More significantly, trips and activity participation undertaken by the housewife are often in response to the needs of the household rather than the individual and, thus, their activity needs are ill-defined. The high level of trip substitution between housewives and other household members implies that the inaccessibility of housewives may not be seen as an issue by decision-makers because low levels of accessibility for the individual may be counter-balanced by high levels of accessibility for the household as a whole.

Housewives daily activity patterns may vary considerably due to the potential influence of employment (either part-time work undertaken by the housewife or the work of the husband).

In conclusion, although it is recognised that the accessibility of housewives is a relatively unexplored area of research, particularly as regards the incidence of trip-linking, the ill-defined nature of their activity needs and the importance of household and other factors pose severe restraints on the use of an accessibility study of this particular population group.

The Elderly

Much attention has focussed on the problems of the elderly in recent years. Hillman (1978) states that "pensioners have been the subject of more numerous studies than have young women and are often seen as a disadvantaged or dependent group in terms of social contact, housing, income or health. Yet few have investigated the part which mobility and accessibility play in their relative deprivation". In the light of this, Hillman (1978) looks more extensively at the influence of these factors on the elderly's travel patterns and Skelton (1978) has also undertaken research in this area. Other studies have recognised that the factors determining old people's mobility are more complex than previously assumed. For instance, Gillan and Wachs (1976), amongst others, note the importance of physical and economic limitations, Hopkin et. al. (1978a)stress the role of social characteristics and in particular past life style, while Falcocchio and Cantilli (1974) argue that it is often a question of the elderly overcoming psychological rather than physical barriers to mobility. All these factors are recognised as contributing to a decline in the life style of the elderly.

Attention has also focussed on identifying the needs of the elderly and the extent to which these needs are met (for instance, Markovitz, 1971). Paaswell and Edelstein (1976) note that the elderly have needs that are both distinct and coincident with the rest of the population but "often find it difficult to reach their needs without some penalty". Moreover, Wachs (1979), in noting the diversity of their life-styles, recognises that the needs of the elderly are also changing. In addition, there is a growing awareness of the extent of accessibility substitution (Hunt, 1978), that is, where facilities are brought to the elderly rather than vice-versa (for example, visits by the doctor). Hence, in view of all these factors there is still considerable debate over what constitutes the transport and accessibility needs of the elderly.

The extent of the elderly's transport problems are highlighted by the fact that, on the evidence of the 1975-76 National Travel Survey data, 69% of elderly persons live in households without a car (compared with 37% for the whole population). Also ill-health and car availability have been shown to have an important effect on travel behaviour (Hopkin et. al., 1978b). The number of elderly persons is presently growing and, more significantly, is increasing in proportion to the population as a whole. With reference to the Greater London Council Population Projections (1979), approximately 25,000 persons of pensionable age reside in the London Borough of Hammersmith and Fulham representing an above average proportion of the total population of the Borough as compared with the country as a whole. Also relative to the population structures of other Inner London Boroughs, Hammersmith and Fulham has the highest proportion of persons over 75 years of age and the second highest proportion of persons over 65 years of age (Campbell and Pettit, 1979).

The accessibility problems of the elderly in general have been addressed through a variety of policies including concessionary-fare schemes, voluntary transport services, location policies and innovations in vehicle design (see for instance, Norman, 1977). However, in view of the functions of the London Boroughs and within the bounds of the research, it is evident that the London Borough of Hammersmith and Fulham has greater control over the accessibility provision for the elderly through policies concerning local traffic management and minor improvements to the network (in particular the pedestrian network), land-use planning and social services. Recent literature (for example, Ashford and Bell, 1978) argues that the integration of alternative policy options provides the greatest scope for improving the accessibility of the elderly. Norman (1977) notes that possible action open to local authorities to improve the availability of transport to the elderly include liaising with transport operators in order to co-ordinate services, increasing the utilisation of social service transport and encouraging and co-ordinating social car services and voluntary service provisions. Also, Garden (1978) argues that, for existing policies to be effective, better integration is needed between the transport, social service and land-use planning functions of the decision-making process. In this context an investigation of the potential to improve accessibility levels through the linking of activities may provide the basis on which to formulate effective and integrated transport and land-use policy alternatives.

Having established the accessibility of the elderly to be both a problem in the London Borough of Hammersmith and Fulham and responsive to policy decisions, it is important to determine the likelihood of the elderly undertaking linked trips. Reverting back to the principle objective of the case study, that is, to investigate the relationship between accessibility and linked trips, the main criterion for specifying the population group is their likelihood to undertake linked trips. In comparison with housewives, Figure 5-2 indicates that the elderly make slightly less multi-stage journeys. However, given aggregate definitions of trip-purposes, the activity requirements of the elderly are limited to shopping and personal business, health and social and leisure. Alternatively, housewives are specified as having a more diverse range largely because, as stated above, they are likely to undertake a greater proportion of trips to satisfy household rather than individual requirements.

It has been shown that the variations in overall travel patterns between the elderly and the remainder of the population are almost completely explained by less participation in employment (and the associated travel) activity and the resultant temporal flexibility of activity participation (Hanson, 1977).

Moreover, if trip-purposes are disaggregated further by, for instance, types of shop or service facilities, then the incidence of multi-purpose journeys is likely to increase.

Due largely to the composition of their households (that is, the average number of persons is less) the elderly are likely to undertake a greater proportion of trips purely for their own requirements, although it is recognised that a difference in activity patterns will occur between the elderly living alone and the elderly living within a family household. In the latter situation there is likely to be a significant proportion of trips undertaken for the elderly. It is also questionable to what extent elderly persons living with a family are transport disadvantaged in that they are able to rely heavily on the household resources and in particular the availability of a car and driver. For these reasons it is felt necessary to draw a distinction between those elderly persons living alone or with other elderly persons and elderly persons living within a family household. It is considered that the former group are more likely to be disadvantaged and are, therefore, seen as being a more appropriate subject for a case study.

Finally, it is noted that in relation to the practical criteria, the only possible problems with focussing on the elderly stem from availability of data. As with housewives, problems exist in locating the elderly. However, as will be shown later, a number of existing data sources can be identified.

Problems are also likely to be encountered in presenting the elderly with lengthy and detailed questionnaires or interviews requiring the recollection of activity participation over a period of time.

It is concluded that, whilst the problems associated with choosing the elderly are essentially practical in terms of data requirements, the argument against choosing housewives is a more fundamental and conceptual one central to the objectives of the study. It is felt, therefore, that the elderly provide the most suitable population group in light of the research objectives.

5.3.2. The Specification of Activities

Having identified the elderly as the subject of the accessibility analysis it is necessary to establish the activities to which accessibility should and can be measured. As noted in the preceeding text it is considered necessary to select a pair of activities in investigating trip linkages as the inclusion of any more would create too complex an analytical framework. It has been stated previously that the elderly's activity requirements broadly comprise shopping, personal business, health, leisure and social activities. With reference to the criteria used in selecting the population group, it is important that the location and temporal availability of activities must be capable of being defined and that there is a likelihood of, or at least the potential for, linked trips being undertaken. In light of this and in relation to the practical criteria (as stated in Chapter Two) it is important that accessibility is measured to those activities for which the elderly have a regular and frequent need. Similarly, their spatial distribution must be seen as an issue within the Borough in as much as a significant variation in accessibility and in the potential to link trips should exist.

Reference to existing literature on the travel behaviour of the elderly assists in identifying the activities of most importance to them. (It is to be noted, however, that travel behaviour overlooks any latent demand for activities). Vickerman (1972), using National Travel Survey data, identifies shopping and personal business followed by social, as the main activity types for which demand by elderly persons is highest. More recently, however, Hopkin et. al. (1978a) show that from 1975/6 N.T.S. data for carless households, the average number of non-work trips per day is highest for shopping (0.55) followed by recreation (0.29), social (0.26) and personal business (0.23). Hopkin et. al. justify shopping and medical facilities and social contact as important trip-purposes on the basis that social characteristics developed during working life can influence mobility in old age - these factors interact with personal characteristics which change as people grow older and which may constrain their mobility - their importance is established only when they affect the desired accessibility of old people.

Leisure and recreation facilities can be seen as satisfying desires rather than need and, thus, within this context there is a high degree of trip elasticity and substitution of activities. Also, social destinations are ill-defined by both their spatial and temporal availability and it is, therefore, difficult to measure accessibility to them. Further refinement is possible by sub-dividing shopping and personal business facilities into:

- convenience shops
- durable shops
- services
  - post offices
  - banks
- health
  - chemists
  - doctor/dentists
  - health clinic
  - hospital

In the light of the experimental design and the objectives of the research and with reference to the practical criteria, it is necessary (as noted above) to select activities for which there is the most regular and frequent need. The above list can, therefore, be reduced to:

- convenience shops
- post offices
- chemists

Grocers are selected as a specific example of convenience shops for which there is a frequent and fundamental need (that is for food). It is recognised that other shops may also be visited and that grocers may only partially satisfy the needs of the individual for food, however, the range of products offered by grocers infers that they are the most important types of food shop. Secondly, elderly persons drawing state pensions need to visit the post office on a regular basis and are also likely to require other services such as the issue of stamps, postal orders, etc. Thirdly, in proportion to the total population, the elderly have a greater and more frequent need for health facilities. It is assumed, therefore, that the elderly need and visit, amongst other health facilities, chemists - the regularity and frequency of visits depending on their condition of health. The definitions of these three facilities gives rise to a number of problems. The specification of grocery shops as a facility type fails to distinguish between the small corner store and the large supermarket. With regard to opportunity, differences in the choice and price of commodities may be significant. The range of commodities for sale at chemists are not exclusive to this facility type. Medical commodities can be obtained from doctors and health clinics whilst non-medical items are occasionally sold in supermarkets. Moreover, it is questionable whether elderly people have a need, as opposed to a desire, for these non-medical items. Furthermore, it is likely that the demand for such commodities is dependent to some extent on expendable income.

With reference to the supply of these facility types, it is apparent that there is a much lower provision of post offices than chemists or grocers. Harding (1979), in analysing the census of distribution, gives the following figures:-

	Population per shop
Grocers	512
Chemists	3,375
Post-Offices	15,384

It is likely, therefore, that there will be a significant variation in the spatial separation between persons and post offices and between grocers and post offices. Hence, it is also likely that there will be a significant difference in the potential to undertake linked trips. This difference in the distribution of facilities is supported by Bruce (1974) who finds that the size of centre for the predicted occurrence of one example of that shop type is for:-

Grocers ≈ under 30 shops

Post-Offices ≈ 73 shops

(no information is given for Chemists)

On this basis it is considered appropriate to select post offices and grocers as the facility pair to which accessibility will be measured. It is assumed that the elderly have a specific and regular need for the commodities and services provided at these facilities.

5.4. CONCLUSIONS

i. To summarise, a series of experiments are outlined that examine the existing deficiencies in accessibility indices and attempt to extend the conventional framework of accessibility measurement by:

- Analysing the sensitivity of accessibility information to the aggregation and valuation stages of the formulative process of accessibility indices;
- investigating the variance in accessibility levels measured for different trip structures; and
- determining ways in which the potential opportunity from linking trips can be encompassed into accessibility indices.

These experiments may be undertaken by utilising information contained in accessibility profiles and through a survey of travel patterns.

ii. A case study is selected in which the experimental design can be implemented. Elderly persons who live alone or with other elderly persons are chosen as the subject of the study on the grounds that they are a transport disadvantaged group, their travel requirements are an issue within the London Borough of Hammersmith and Fulham and they are likely to undertake a significant proportion of linked trips. In turn, their accessibility is measured to post offices and grocers on the premise that the elderly have a frequent and fundamental need for the commodities and services provided at these facilities and that, because of their common temporal availability, trips are likely to be linked between these two facility types.

iii. In addition to exploring the theoretical deficiencies of accessibility measurement, the study also serves a practical use by providing information on the accessibility of the elderly in the Hammersmith and Fulham areas of London. Consequently this information assists in identifying areas of relatively poor accessibility and possible policies for alleviating the present constraints on the accessibility levels of the elderly.

iv. A case study approach is necessary due largely to resource and time constraints, however, the methodology could equally be applied to alternative locations, population groups and activities. Moreover, the results are used to indicate the implications of trip linkages to accessibility measurement in general.

CHAPTER SIX

FORMULATING AND INTERPRETING ACCESSIBILITY PROFILES

6.1. INTRODUCTION

The experimental design outlined in Chapter Five comprises essentially two stages. The first stage forming the content of this chapter focuses on formulating accessibility profiles and, on the basis of the information contained in these profiles, investigating the sensitivity of accessibility to different value judgements, aggregations and trip structures. The second stage focuses on investigating the nature and incidence of linked trip-making and its relationship to levels of accessibility and is undertaken in Chapter Seven.

Before describing the data collection involved in formulating accessibility profiles for twenty-three zones in the London Borough of Hammersmith and Fulham, consideration is given to determining the form of the profiles and, in this context, the various methods by which the accessibility information may be valued and aggregated. Further consideration is also given to the representation of linked trip and single-purpose trip accessibility data in profile form (as proposed initially in Chapter Four).

Following the analysis of the sensitivity of accessibility to valuation, aggregation and trip structures, the implications of the results for accessibility measurement in general, together with the practical and policy implications, are discussed.

6.2. DETERMINING THE FORM OF ACCESSIBILITY PROFILES

It will be recalled that in reviewing accessibility indices (Chapter Three) the comparative approach was considered to be the most appropriate method of representing accessibility information. The disaggregate form of this type of index is seen as providing a basis on which to make explicit those definition, measurement, valuation and aggregation assumptions often implicit in other forms of index. Moreover, as described in Chapter Four, comparative profiles provide the greatest scope for investigating the potential distortion inherent in accessibility measures that overlook the sequential and complex structure of travel patterns.

Within the theoretical dimension of the research, comparative accessibility profiles are required that provide information on which to examine (as outlined in the experimental design) the sensitivity of alternative valuations and aggregations on accessibility levels and to assess the potential improvement in accessibility levels from trip linking (that is, hypotheses H.1. and H.2. of the experimental design). Alternatively, with reference to the practical dimension of the research (that is, the practical context in Chapter One, the practical framework in Chapter Two and the case study selection in Chapter Five) accessibility information is required that addresses accessibility issues (the accessibility of the elderly to post offices and grocers) within the London Borough of Hammersmith and Fulham and enables a geographic comparison to be made between different areas of the Borough whilst also revealing personal accessibility levels.

The aggregation of individual accessibilities to a zonal level is necessary in that most conventional transport and land-use policies improve or redistribute accessibility provision by area rather than by individuals (for example, the provision of new facilities). It is apparent, therefore, that in compiling zonal accessibility profiles a certain level of aggregation is necessary.

With regard to these research requirements the precise form of the accessibility profiles can be determined. Three dimensions (axes) to accessibility (as noted by Breheny, (1978) and described in Chapter Three) forming the basis of comparative indices are identified as separation, opportunity and population. Profiles are formulated by representing the way in which one dimension varies in relation to another. Hence, by holding each dimension constant, profiles can be developed showing:

- For a given population set how the availability of opportunity varies with separation (population constant).
- How the proportion of the population having access to a specified level of opportunity varies with separation (opportunity constant).
- How the proportion of the population having access to a specified level of separation varies with the availability of opportunity (separation constant).

This latter type of profile, however, is not formulated in that within the practical context of the research (that is, the accessibility of the elderly to local facilities) separation and population are more significant and sensitive variables, in terms of identifying differences in accessibility provision, than the level of opportunity. Moreover, if required, the information may be derived from the two former profiles.

Consequently, accessibility information for specified zones may be displayed in two profiles as shown in Figure 6-1. However, before describing the data collection and computations undertaken in formulating these profiles showing the accessibility of the elderly in the London Borough of Hammersmith and Fulham to post offices and grocers it is necessary to consider, firstly, methods by which different values and aggregations can be used to interpret the profile information (and, hence, test hypothesis H.1.) and, secondly, how accessibility levels from linked trips can be compared with accessibility levels from single-purpose trips (and, hence, test hypothesis H.2.).

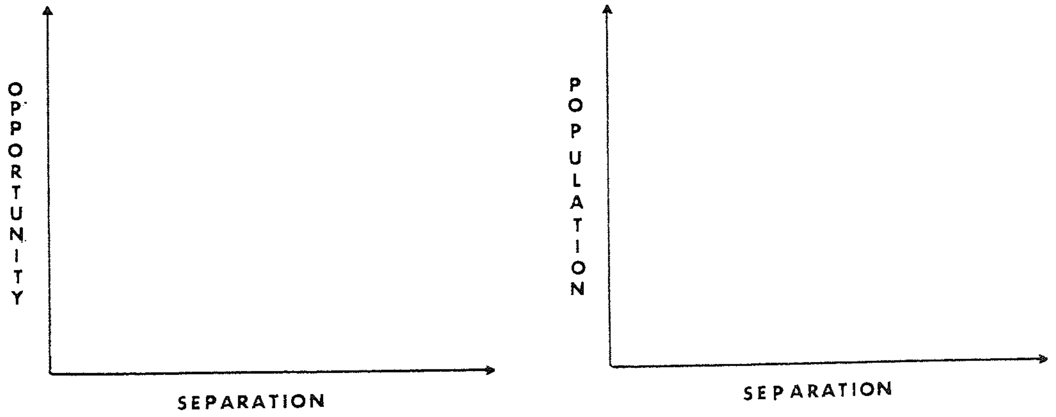


FIGURE 6-1 The Two Types of Profile Utilised in Displaying Accessibility Information

6.3. METHODS OF VALUING AND AGGREGATING ACCESSIBILITY PROFILE INFORMATION

With reference to the four stages of the measurement process (as described in the theoretical framework in Chapter Two), the definition and measurement stages are undertaken in deriving comparative accessibility profiles and in this form provide the basic accessibility data on which to investigate hypothesis H.1.. The valuation and aggregation stages of the measurement process provide the means of interpreting the accessibility information presented in the profiles and enable a single score of accessibility to be derived.

Firstly, in order to express accessibility in terms of one dimension, a second dimension must be held constant necessitating value judgements as to the level of the constant. Diagramatically this can be represented by drawing a vertical or horizontal line on each of the two types of profile as shown above (section 6.2.) Different value judgements can, therefore, be represented by holding different dimensions constant (that is, deciding which cross-section of the profile is the most relevant) and by varying the level of the same constant.

Secondly, the inclusion of the population dimension in developing zonal accessibility profiles represents aggregation in that accessibility is measured as a characteristic of the individual rather than the zone. The aggregation process is essentially one of averaging, the accuracy of which is dependent on the distribution of individual accessibilities around the mean average and the sample size used in estimating this average. Aggregation can be undertaken in a number of different ways depending on which component is aggregated and the method of averaging (see later text).

It is apparent then, that a range of accessibility measures can be derived from the same basic set of accessibility data by:-

- expressing (measuring) accessibility in terms of separation, opportunity or population by holding the remaining two dimensions constant;
- varying the value at which the two fixed dimensions are held; and
- varying the level and form of aggregation.

The decision as to which dimensions to hold constant, the actual value of the constants and the level of aggregation must be taken in the light of the population group (the elderly) and activities (post offices and grocers) for which accessibility is being measured and the intended application of the measure (as specified in Chapter Five). However, in the general case a number of guidelines can be given.

6.3.1. Choice of Constants

i. Opportunity Constant

This is appropriate where the utility gained from increasing opportunity reaches a known threshold or cut-off point. In this context the cut-off point for activities where choice or quality is not significantly different between facilities (for example, post offices) may be reached at the point of the first facility (or opportunity).

ii. Separation Constant

This is appropriate where upper or lower limits to separation are implicit within land-use and transport policies (for instance, travel concessions for persons over a certain distance from a given level of opportunity).

iii. Population Constant

Both the level and form of aggregation is expressed through this dimension. It is considered appropriate to hold the population dimension constant in establishing average measures (such as the mean, median and percentiles) of accessibility for a population set or sample of that set.

In holding two of the above dimensions constant accessibility is expressed in terms of the third dimension. It is apparent then that opportunity measures are appropriate where choice of opportunity is significant. In contrast, separation measures are appropriate where a specific facility can be identified as the most accessible location for participating in a particular activity and where choice of opportunity is not significant. Alternatively, population measures expressed in terms of the proportion or number of individuals having access to a set amount of opportunity in a given level of separation are appropriate in determining the distribution of accessibility within population sets and assists in identifying individuals with low (and high) accessibility (that is, the extreme percentiles).

6.3.2. Specification of Constant Values

In order to produce single measures of accessibility it is necessary to specify the point at which two of the three dimensions described above are held constant. Whilst a number of values are implicit within the choice of separation and opportunity units, it is recognised that the values determining which of the dimensions to hold constant are made explicit by expressing accessibility in a comparative form. With reference to the valuation stage of the theoretical framework (Chapter Two) it is noted that there are a number of ways of deriving these values:

- Decision-maker values based on the opinions of a group of experts or elected representatives. Problems arise in that standards are often derived arbitrarily and without understanding the full implications. However, in determining accessibility relative to other zones, standards may be taken as the average for the whole area. This is particularly useful where the redistribution of accessibility is of significance rather than the absolute level.
- Population values based on the subjective values of the population group for whom accessibility is being measured. This sort of approach, however, is likely to set wide ranging standards that vary greatly between individuals depending on their past and present life-styles and future expectations.
- User-group values as reflected by actual behaviour. The observation of individuals in particular situations offers

guidelines as to the specification of separation and opportunity values (for example, by observing the average distance travelled by the elderly to the post office).

6.3.3. Specification of the Form and Level of Aggregation

In order to derive zonal measures of accessibility some form of aggregation must be undertaken. Average measures of accessibility expressed in terms of opportunity or separation must be derived by summing individual accessibilities for a given population set grouped according to residential location. The specification of zones depends largely on the form of the required data but should reflect some form of homogeneity in terms of socio-economic, land-use or transport characteristics depending on the intended application of the index.

True zonal averages are given only where a 100% sample of the population set is taken or where the distribution of sampled individual accessibilities around the mean reflect the true distribution. Thus, the margin of error incurred in deriving zonal averages increases with a reduction in the sample size and an increase in the variance in the distribution of accessibility levels of individuals within the zone. This distribution is concealed by aggregate zonal measures but is revealed by plotting comparative zonal profiles showing how the proportion of the zonal population having access to a given level of opportunity varies with the level of separation.

Other forms of aggregation may also be applied to the basic accessibility data set. Zonal measures may be derived by averaging across origin and destination locations (producing zone centroids) and/or by combining trip-purposes.

The extent to which the choice of constants, the values of the constants (standards) and the form and level of aggregation influences the resultant accessibility level (that is, hypothesis H.1.) is investigated later in this chapter.

6.4. COMPARING ACCESSIBILITY PROFILE INFORMATION FOR DIFFERENT TRIP STRUCTURES

The inclusion of information on the potential opportunity available from linking trips in the two types of profile described in the preceeding text (section 6.2.) is a definition and measurement problem rather than a valuation or aggregation problem in that it is dependent on the definition of all trip destinations as potential trip origins and vice-versa and, hence, necessitates the measurement of separation between these points. As outlined in Chapter Four, these linked trip measurements may be plotted on the comparative accessibility profiles showing how the availability of any combination of two different activities (in this case post offices and grocers) increases with separation (that is, the total travel disutility incurred in undertaking the linked trip). That is, for each individual the linked trip separation Cl is given by:

$$Cl = Cip + Cpg + Cgi$$

where Cip = the separation between the individual's home and the post office;

Cpg = the separation between the post office and the grocers; and

Cgi = the separation between the grocers and the individual's home.

Given that zonal accessibility profiles are required, then the linked trip measurements may be summed and divided by the number of individuals giving a mean average linked trip separation for each zone. The proportion of the zonal population having access to a given level of opportunity from undertaking linked trips may also be displayed in the population/separation profile.

In order to show the difference between accessibility from two separate single-purpose trips and linked trips accessibility, measurements may also be plotted in a comparative form showing how the availability of any combination of post offices and grocers increases with the total travel disutility incurred in undertaking these single-purpose trips. That is, for each individual the single-purpose trip separation Cs is given by:-

$$Cs = Cip \times 2 + Cig \times 2$$

Likewise, the information for each individual may be aggregated to a zonal average and the proportion of the zonal population having access to a given level of opportunity from undertaking two separate single-purpose trips may be displayed in the population/separation profile.

The linked trip and single-purpose trip accessibility information (as described above) together with accessibility information for post offices (that is, $Cp = Cip \times 2$) and grocers (that is, $Cg = Cig \times 2$) may be expressed as four separate curves in each of the two types of profile shown in Figures 6-2 and 6-3.

On the basis of the information contained in these profiles the influence of linked trips on accessibility levels may be investigated. In this context, three properties of the profiles are worthy of note. Firstly, the single-purpose trip profile represents the sum of the post office and grocer profiles, that is, with reference to Figure 6-2 $Cg^1 + Cp^1 = Cs^1$. Similarly,

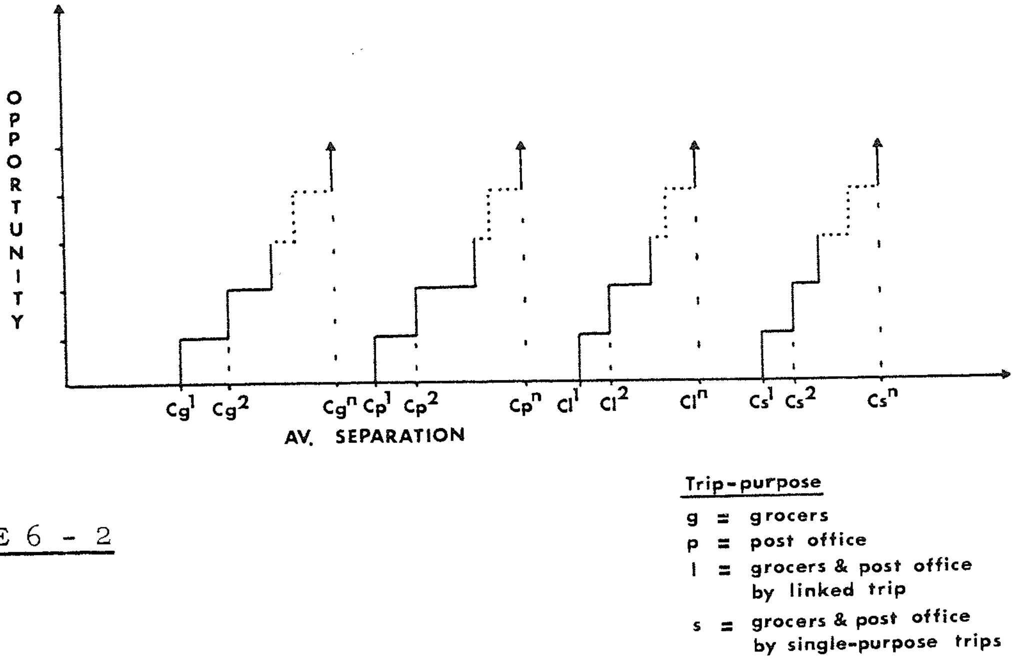


FIGURE 6 - 2

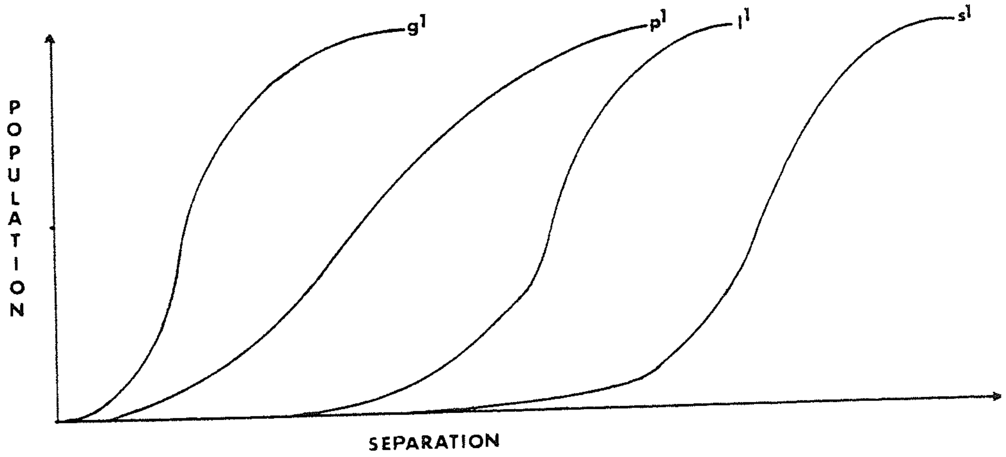


FIGURE 6 - 3

FIGURES 6-2 and 6-3 Accessibility Profiles Displaying the Potential Availability of Combinations of Facilities from Undertaking Linked and Single-Purpose Trips

$Cs^2 = Cg^2 + Cp^1$ or $Cs^2 = Cg^1 + Cp^2$ depending on which one gives the lower value.

Secondly, the difference between the single-purpose trip profile and the linked trip profile represents the potential travel saving attributable to trip linking. That is, with reference to Figure 6-3, potential travel saving = Cs - Cl.

Thirdly, the difference between the grocer trip and linked trip profiles (that is, Cl - Cg) indicates the travel detour associated with visiting the post office given that a trip is linked to the grocers. Likewise, the difference between the post office and linked trip profiles (Cl - Cp) indicates the travel detour associated with visiting the grocer given that the trip is linked with a post office trip.

Information on the accessibility of the elderly resident in the London Borough of Hammersmith and Fulham to post offices and grocers presented in the above form is utilised in examining (in the latter part of this chapter) the differences in accessibility levels measured for linked trips and single purpose trips (that is, hypothesis H.1.) and assists in investigating the relationship between linked trip-making and accessibility provision (Chapter Seven).

6.5. FORMULATING ACCESSIBILITY PROFILES

Within the practical context of the research and in the light of the methods by which hypotheses H.1. and H.2. can be investigated, comparative accessibility profiles (by zone) showing, for the elderly resident in the London Borough of Hammersmith and Fulham, how the availability of post offices and grocers increases with separation and how the proportion of the zonal population having access to a given level of opportunity varies with separation were developed. The precise form of the data and the computations necessary for compiling zonal profiles were determined as follows:

6.5.1. The Measurement of Separation

As concluded in Chapter Three, it is possible to state the precise form of separation measure only in relation to the specific objectives of the study. In view of the fact that the elderly are a time surplus group it was felt that they were more likely to perceive travel disutility in terms of effort and/or monetary cost rather than time. Also, given that the case study focuses on accessibility to essentially local facilities it was considered likely that the large majority of trips would be made on foot. Hillman and Whalley (1979) shows that 80% of journeys by women pensioners in households without a car (the majority) are made on foot and Hopkin et. al. (1978b) indicate that just over half of all journeys undertaken by the elderly are made on foot.

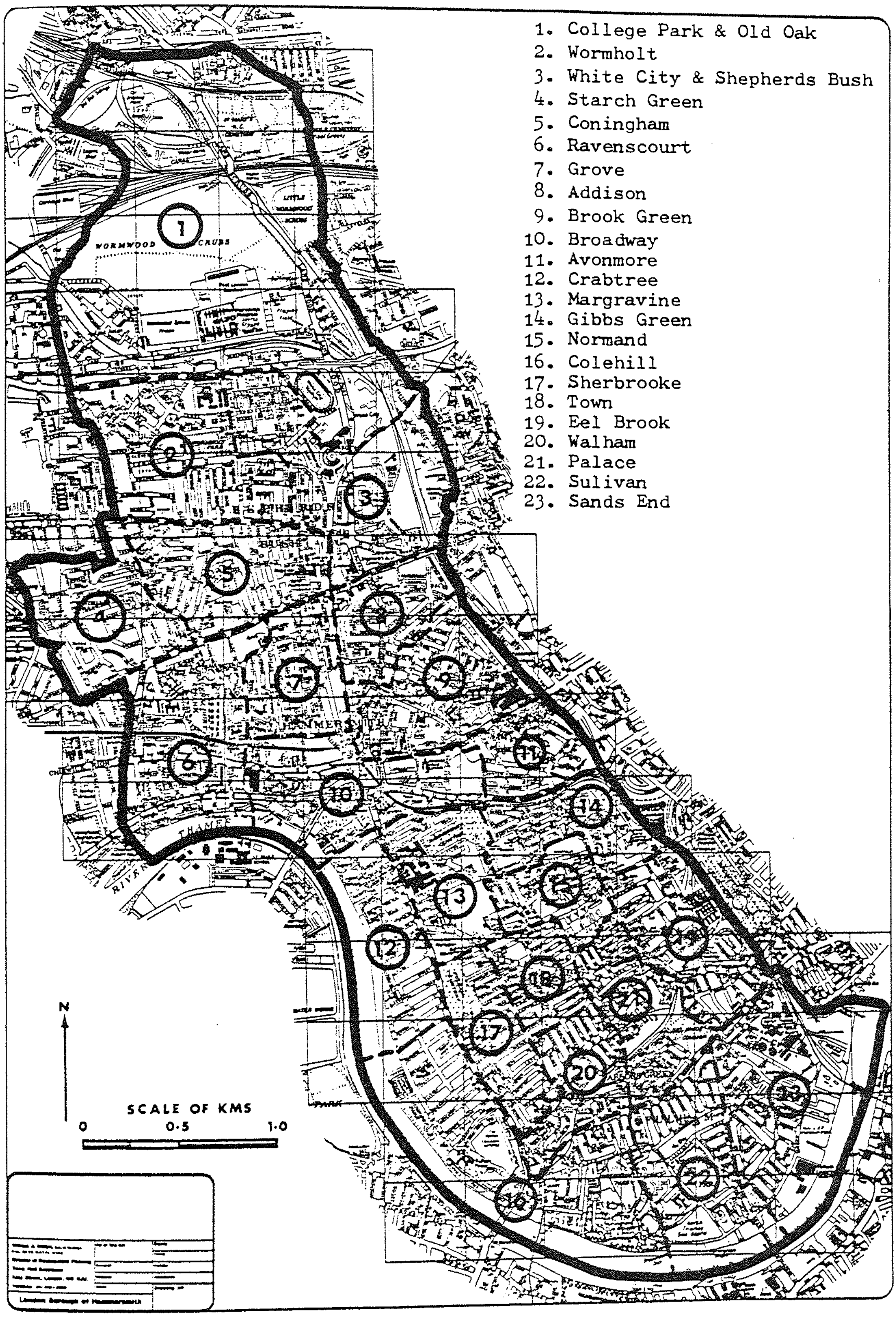
In the light of this evidence and taking into account the requirements and availability of data, network distance was used as the measure of separation and, more specifically, as a representation of the effort attributable to walking.

6.5.2. The Measurement of Opportunity

It is recognised that there is almost complete uniformity in the services provided by post offices whilst, in contrast, significant differences can be identified in the opportunities provided by grocers particularly in terms of the quality, choice and price of goods. However, because of the constraints on data availability and the complexities associated with measuring the differences in opportunities provided by grocers, it was necessary to measure opportunities simply in terms of the number of facilities. Post offices were defined to include both main and sub-post offices whilst grocers were defined to include 'corner shops' providing general food provisions, as well as supermarkets and grocers.

6.5.3. Specification of Zone Size

Information on the residential location of the elderly was derived from the electoral register (as described below) which is documented by enumeration district. Zones based on enumeration district boundaries were felt to be too small due to the large variation in the number of elderly persons in each. Larger zones were derived, therefore, by aggregating enumeration districts to administrative ward level. Hence, twenty three zones were established corresponding to the administrative ward boundaries (see Map 6-1). In this sense the aggregation of individual accessibilities to a zonal level is determined by the availability of data rather than by any accessibility characteristics.



MAP 6 - 1 Accessibility Study Zones in the London Borough of Hammersmith and Fulham

It is important, therefore, to assess the significance of this constraint on the level of disaggregation by determining the similarity between accessibility levels within zones as compared to the variance between zones.

6.5.4. Sample Size

The sample size required to give mean zonal average accessibility measures within a certain percentage of the true zonal accessibility level within a 95% probability was calculated on the basis of a pilot sample of the network distance to the nearest post office for individuals taken from 6 of the 23 zones. The statistical calculation required to estimate the true mean separation to the nearest post office within ± 5% (with a 95% probability) of the sample size (see Appendix E) is based on the assumption that there is a normal distribution of individual accessibilities within a zone. It is evident, however, that the location of elderly persons throughout a zone is not an even spatial distribution but tends to be biased by the physical and socio-economic structure of the zone (for example, type and age of housing) and, hence, the distribution of individual accessibilities within a zone is liable to be skewed. However, by calculating the sample size necessary to give the proportion of the zonal population having access to at least one facility in a specified level of separation with ± 10% of the true proportion with a 95% probability and in light of the practical limitations as to the amount of data that could be collected, the maximum feasible sample size for each zone was estimated to be in the region of 100 elderly persons for each zone (giving a total of 2300 for the whole Borough). It is estimated that in assuming a normal distribution (and on the basis of the best estimate of the standard deviation and sample mean) this sample size gives a zonal accessibility level in terms of the mean separation to the nearest post office, within ± 11% of the true zonal accessibility level within a 95% probability.

6.5.5. Data Collection

In order to develop comparative accessibility indices three basic sets of data were collected:

i. The Residential Location of the Elderly Within the London Borough of Hammersmith and Fulham.

The Electoral Register (unpublished version) identifies all those persons over 65 due to their ineligibility for jury service. The information is listed by individual's name, house number and street name (alphabetically) for each enumeration district and was used, therefore, to identify elderly persons living alone or with other elderly persons by name and address. A sample of 100 persons from this population for each of the 23 zones was derived using random number selection.

ii. The Location of Facilities.

Facilities within the Borough boundaries were located from the land-use data collected by the Authority between November 1978 and September 1979. The data gives the address and the classification by use(s) for each establishment. Facilities in outlying areas up to 1500m (network distance) from the Borough boundaries were located by a separate survey undertaken specifically for this research.

iii. Network Distances

Distances were measured in 50 metre intervals from ordinance survey maps (scale 1:1250). The network was defined in terms of pedestrian access rather than vehicular access and, hence, links were based on footpaths and pavements. In certain instances it was necessary to visit a particular location in order to clarify whether pedestrian access was possible.

The residential locations of the sample elderly population and the locations of all post offices and grocers within the study area were plotted on the map and referenced accordingly. Network distances were then measured for each individual to all post offices within 1250m and all grocers within 1000m. However, irrespective of these limits, for each individual network distances were recorded to at least the five nearest post offices and ten nearest grocers. Network distances of up to 1250m were also measured between grocers and post offices. Hence, three basic measures of network distances were recorded:

diPj(p) = network distance for an individual at residential location i to the pth nearest post office (P) at location j where p = 1....5.

diGk(g) = network distance for an individual at residential location i to the gth nearest grocer (G) at location k where g = 1....10.

dPjGk = network distance between post office (P) at location j and grocer (G) at location k.

6.5.6. Computations

The above measures were utilised in calculating and computing individual accessibilities and from these zonal accessibilities were derived. Individual accessibilities were calculated manually whilst zonal accessibilities and the associated statistics were computed using Statistical Package for the Social Sciences (S.P.S.S.) as described in Appendix F.

a) Individual Accessibilities

In each zone for each individual $n = 1 \ldots\ldots n = 100$ the following measures were calculated in terms of network distance (d) using the three basic measures as defined above.

Post Office accessibility	$AniPj(p) = diPj(p) \times 2$
Grocer accessibility	$AniGk(g) = diGk(g) \times 2$

Return trip network distances were recorded in order that the measures are comparable with linked trip measures (as specified below).

Single purpose trip accessibility to Post Offices and Grocers (two separate trips) (AniS(s)). For the sth nearest combination of post offices and grocers $s = 1 \ldots s = 5$

$$AniS(s) = (diPj(p) \times 2) + (diGk(g) \times 2)$$

Linked trip accessibility to Post Offices and Grocers (AniL(l)). For the lth nearest combination of post offices and grocers $l = 1 \ldots$ $l = 5$

$$AniL(l) = diPj(p) + diGk(g) + dPjGk$$

b) Zonal Accessibilities

Given the above measures for each individual, zonal accessibilities were calculated giving the mean average distance to each of the five nearest post offices, single-purpose and linked trip combinations of post offices and grocers, and the ten nearest grocers. Hence, for each zone z = 1...... z = 23

$$AzP(p) = \sum_{n=1}^{n=100} AniPj(p)$$

$$AzG(g) = \sum_{n=1}^{n=100} AniGk(g)$$

$$AzS(s) = \sum_{n=1}^{n=100} AniS(s)$$

$$AzL(1) = \sum_{n=1}^{n=100} AniL(1)$$

Accessibility profiles for the four different facilities (or combinations of facilities) were subsequently produced by plotting the mean average network distance for each zone (Az) along the horizontal axis and the number of facilities (that is, p, g, s, l) along the vertical axis. Also in order to show the distribution of individual accessibilities within a zone the cumulative percentages of the zonal population having access to the nearest facility (or combination of facilities) with increasing network distance were computed. For each zone, therefore, a second accessibility profile was developed by plotting individual network distances to the nearest facilities (that is, p, g, s, l = 1) along the horizontal axis and the cumulative percentage of the population having access to the facility (n/100) along the vertical axis.

6.5.7. Results

On the basis of the computations described above, accessibility profiles for each of the 23 zones showing how the availability of facilities increases with the network distance and how the cumulative proportion of the population having access to one facility increases with network distance, were compiled. The profiles for each zone are displayed in Appendix G, whilst the profiles for the Borough as a whole are displayed in Figures 6-4 and 6-5.

The accessibility profiles provide information on which the sensitivity of valuation and aggregation and the influence of trip linking on accessibility levels can be tested. Whilst displaying accessibility information the profiles do not, however, provide a measure of the relative or absolute level of accessibility. It is clear that the gradient of the curves and the distance from the origin are partial determinants of accessibility - the former indicating how the availability of facilities increases with distance and the latter indicating the network distance to the first facility. However, the precise interpretation of the profiles requires further elaboration and is dependent on the results of hypotheses H.1. and H.2. (see the following text). Moreover, the significance that can be attached to the linked trip profiles is dependent on the results of (hypotheses H.3., H.4. and H.5.) a survey or individual's travel patterns (Chapter Seven). Before proceeding with the hypothesis testing and in relation to the data analysis the following characteristics of the accessibility profile information are worthy of note.

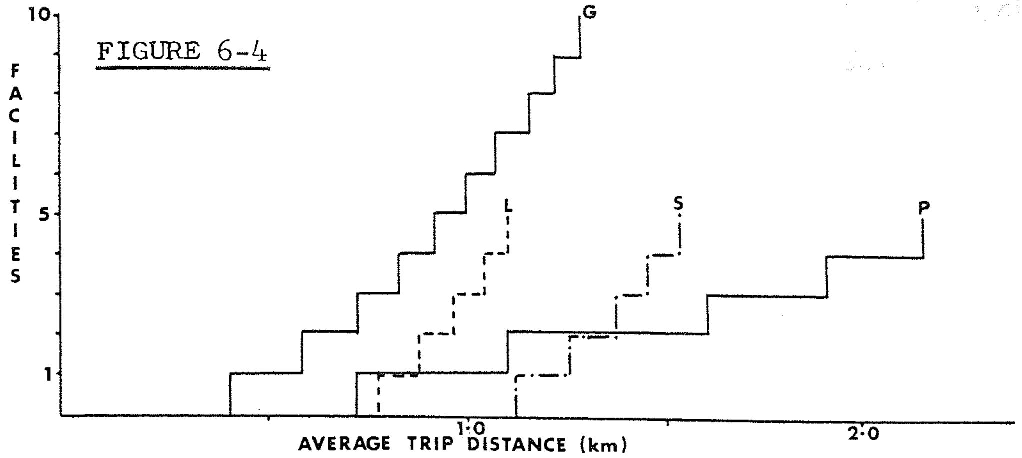


FIGURE 6-4

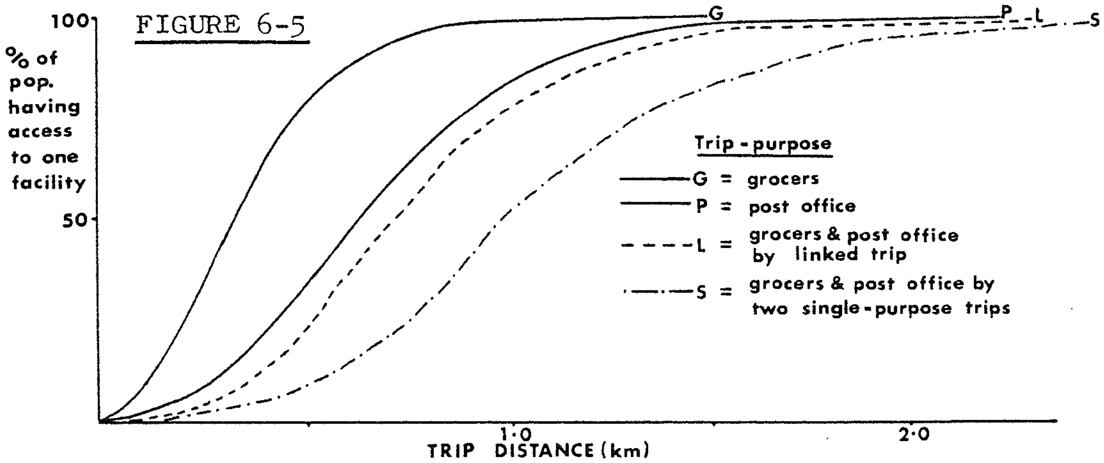


FIGURE 6-5

FIGURES 6-4 and 6-5 Accessibility Profiles of the Elderly for the London Borough of Hammersmith and Fulham

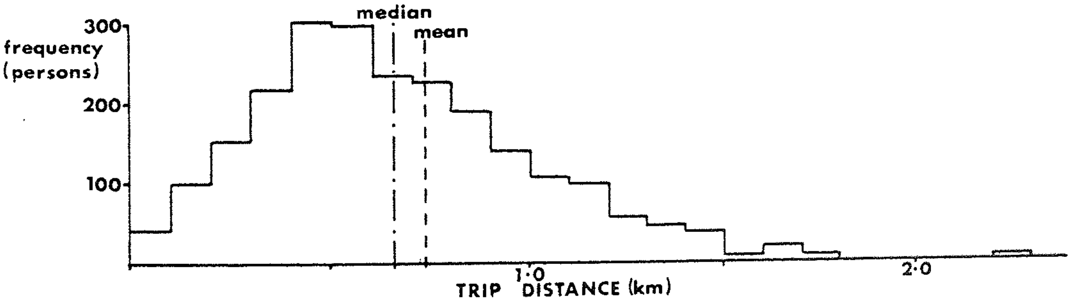


FIGURE 6-6 The Frequency Distribution of Individual Accessibilities to the Nearest Post Office - All Zones

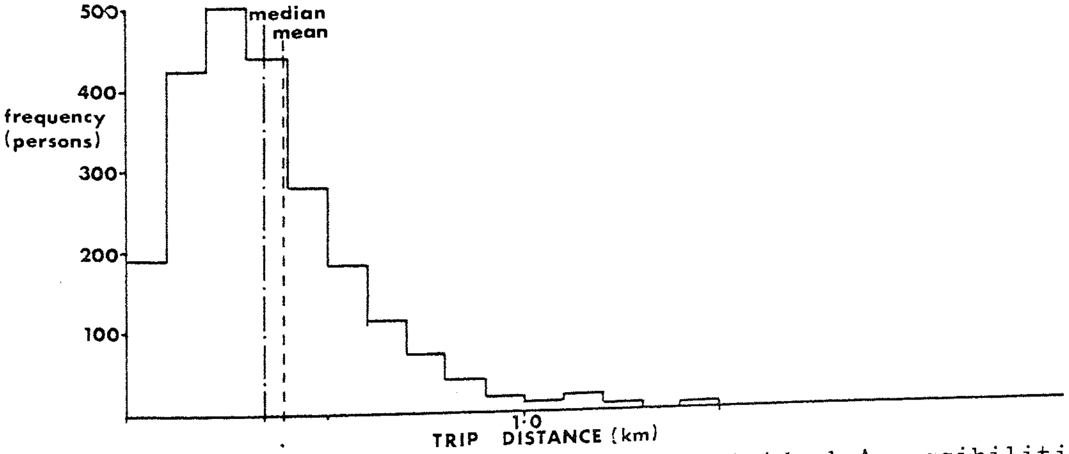


FIGURE 6-7 The Frequency Distribution of Individual Accessibilities to the Nearest Grocers - All Zones

With reference to Figure 6-4, the mean average network distance to the nearest post office is 720m (return trip) and 400m to the nearest grocers. On average the availability of grocers increases at the rate of one facility per 130m and at the lower rate of one facility per 430m for post offices. Referring to Figure 6-5, the median average distance to the nearest post office (that is, the point at which 50% of the sample population have access to at least one facility) is 660m and 360m for grocers. It is, perhaps, also useful to note that the profile indicates that 10% of the sample population do not have access to a post office in 1100m and a grocers in 600m.

The degree to which information is concealed by aggregation and the accuracy of aggregating individual accessibilities depends for each zone on the extent of the variance from the mean average network distance and the skewness of the distribution. The gradient of the curves in Figures 6-5 indicates the variance from the mean in that the lower the gradient the greater the variance. This can be seen more clearly by plotting the frequency distribution of the network distance to the nearest post office and grocer (as shown in Figures 6-6 and 6-7). The variance from the mean may be measured in terms of the standard deviation (σ) where:-

$$\sigma = \sqrt{\frac{\sum(x - \bar{x})^2}{n}}$$

where for each individual 1....n, x = network distance

$\bar{x}$ = the mean average network distance.

It is evident from Figures 6-5, 6-6 and 6-7 that this variance is greater for the network distance to the nearest post office ($\sigma = 3.41$) than for the nearest grocer ($\sigma = 2.4$).

Similarly, the difference between the mean and the median averages is reflected in a measure of the skewness of the distribution of individual network distances to the nearest facilities; where skewness $= \sum_{1=1}^{n} \frac{[(x1 - \bar{x})/\hat{\sigma}]^3}{n}$ with x, $\bar{x}$,$\hat{\sigma}$ and n defined as above.

For the distribution of individual accessibilities as indicated in Figures 6-5, 6-6 and 6-7, the coefficient of skewness = +0.564 for post offices and +1.119 for grocers. The positive sign indicates that the distribution tails off to the right side of the mean (as shown in Figures 6-6 and 6-7) and, vice-versa, a negative sign indicates that the distribution tails off to the left of the mean. The utility of these statistical properties of the profiles for each zone becomes evident in examining the sensitivity of accessibility levels to valuation and aggregation procedures (see the following text).

In turning to the accessibility profiles for combinations of post offices and grocers (from linked and single-purpose trips), Figure 6-4 indicates that the average potential distance saving from linking trips is approximately 350m (that is, 30% of the total distance travelled). For the shortest linked trip and grocers trip the minimum average travel detour attributed to visiting the post office when visiting the grocers is 380m (that is, the difference in network distance between the grocers and linked trip profiles). Similarly, the equivalent minimum average travel detour attributed to visiting the grocers when visiting the post office is just 60m (that is, the difference between the post office and linked trip profiles).

Further reference is made to the characteristics of the zonal linked trip and single-purpose trip profiles in examining the difference in accessibility levels between the two journey structures (see later in this chapter) and in investigating the role of linked trips in accessibility measurement (Chapter Seven).

6.6. INTERPRETING THE ACCESSIBILITY PROFILES

The various means by which accessibility profile information can be valued and aggregated and methods of comparing accessibility profile information for linked trips as well as single-purpose trips have been established earlier in this chapter. The analysis and interpretation of accessibility profiles and, more specifically, the testing of hypotheses H.1. and H.2. can be undertaken on the basis of the information provided in the zonal accessibility profiles (as displayed in Appendix G).

The significance of differences in zonal accessibility levels attributable to different values, aggregations and trip structures (that is, linked or single-purpose trips) is felt to be most appropriately represented by differences in zone rankings on the grounds that, from a practical view point, the various interpretations of the accessibility profiles are required for identifying areas (zones) of poor accessibility and that any policy decisions aimed at redistributing accessibility are dependent on being able to identify the relative accessibility provision as distributed throughout the London Borough of Hammersmith and Fulham.

On this basis, the sensitivity of accessibility levels to the valuation and aggregation stages in accessibility measurement and the differences in accessibility levels between two single-purpose trips and linked trips are examined by testing the two hypotheses (H.1. and H.2. as outlined in the experimental design):

H.1. - The rank order of zones according to their accessibility level varies with the use of different values and levels of aggregation.

H.2. - The rank order of zones according to their accessibility level changes when the potential to link trips is taken into account.

The first hypothesis is tested by comparing zone rankings resulting from various different interpretations of post office and grocer accessibility profiles as measured from single-purpose trip data. The second hypothesis is tested by comparing zone rankings for similar interpretations of post office and grocer combined profiles representing, on the one hand, accessibility to post offices and grocers by two separate single-purpose trips and, on the other hand, accessibility by a linked trip.

6.6.1. The Sensitivity of Accessibility to Valuation and Aggregation - Testing Hypothesis One (H.1.)

On the basis of the profile information presented in Appendix G different values and aggregations (as outlined in the preceeding text) are introduced giving a series of different accessibility scores for each zone. A series of zone rankings is then derived and by comparing pairs of rankings the sensitivity of accessibility to valuation and aggregation is revealed. Two forms of sensitivity test are adopted.

Firstly, a statistical test of correlation between rank orders using the Spearman rank correlation coefficient (see Appendix C) is undertaken. However, the following text reveals that, in all cases, there is a high positive correlation between different rank orders. This is to be expected in that the accessibility scores on which the rank orders are based are all functions of the spatial distribution of post offices and grocers and the residential locations of the elderly in the London Borough of Hammersmith and Fulham. Moreover, the degree of statistical correlation between the rank orders is shown to be sensitive to the number of pairs of correlation (see Appendix H). It is important, therefore, to note the limitations of interpreting differences in rank order using statistical methods such as the Spearman rank correlation coefficient. However, the correlation coefficient still has a limited use in checking the extent of the positive relationship between rank orders and is, therefore, utilised in analysing differences in the rank order of zones based on different levels and types of valuation and aggregation.

Secondly, with reference to the practical and policy context of the research and, more specifically, the identification of zones with relatively poor accessibility, 'commonsense' interpretation of the meanings and implications of the differences in rank order is, perhaps, more useful than any statistical measure of the degree of correlation. Within this context slight differences in rank order are not seen as being significant, however, large differences may lead to an inconsistent classification of zones between three fundamental categories of accessibility, that is, below average, average and above average. Given that there are twenty-three zones and that in a relative context they can be divided equally between the above three categories of accessibility, a change in rank order of more than seven places will give rise to a change in the category of accessibility into which the zone is placed.

a) The Sensitivity of Accessibility to Valuation

As indicated in section 6.3. the inclusion of value judgements in accessibility measurement is represented in part by the decision as to which cross-section of the accessibility profile is the most relevant. Various ways of determining the most relevant section were also outlined in section 6.3. From the zonal profiles displayed in Appendix G, a range of zonal rankings were developed by measuring accessibility at different points on the profiles. These points were determined by setting different opportunity, separation and population standards as a means of representing the input of alternative values.

i. Opportunity Standards

For each zone the mean average distance to one facility and five facilities for post offices and one, five and ten grocers were calculated from the opportunity/separation profiles. For each measure the zones were ranked as revealed in Table 6-1. It is evident that, in comparing rankings for different opportunity standards for both post office and grocer accessibilities, the difference in rankings is, in a number of cases, considerable. Despite this, a statistical measure of the correlation between the rank order of two sets of data (the Spearman rank correlation coefficient) indicates that there is a positive relationship between all relevant rank order comarisons at least at a 99% significance level (see Table 6-2).

ZONES	RANK ORDER ACCORDING TO THE MEAN AVERAGE DISTANCE TO:				
	NEAREST POST OFFICE (a)	5TH NEAREST POST OFFICE (b)	NEAREST GROCER (c)	5TH NEAREST GROCER (d)	10TH NEAREST GROCER (e)
1	13th	23rd	19th	18th	23rd
2	18th	9th	22nd	15th	12th
3	6th	11th	10th	22nd	17th
4	2nd	6th	9th	2nd	2nd
5	21st	15th	17th	16th	11th
6	10th	13th	21st	19th	21st
7	4th	3rd	14th	13th	14th
8	7th	1st	5th	6th	4th
9	15th	14th	15th	11th	13th
10	8th	10th	18th	21st	22nd
11	22nd	20th	16th	5th	7th
12	23rd	21st	13th	17th	19th
13	11th	17th	12th	14th	16th
14	3rd	19th	1st	1st	1st
15	14th	7th	8th	10th	9th
16	20th	16th	20th	23rd	20th
17	9th	4th	4th	8th	8th
18	5th	5th	2nd	3rd	3rd
19	16th	12th	7th	7th	10th
20	1st	2nd	3rd	4th	5th=
21	19th	8th	11th	9th	5th=
22	12th	18th	23rd	20th	18th
23	17th	22nd	6th	12th	15th

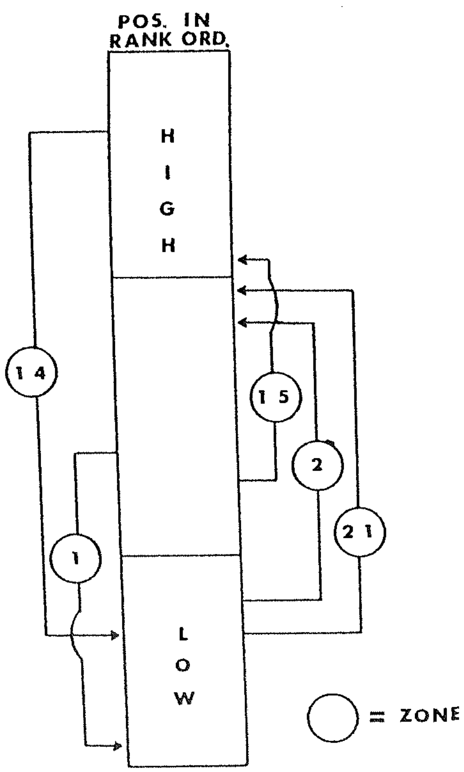
TABLE 6-1 Rank Order Positions Based on Accessibility Levels Using Different Opportunity Standards

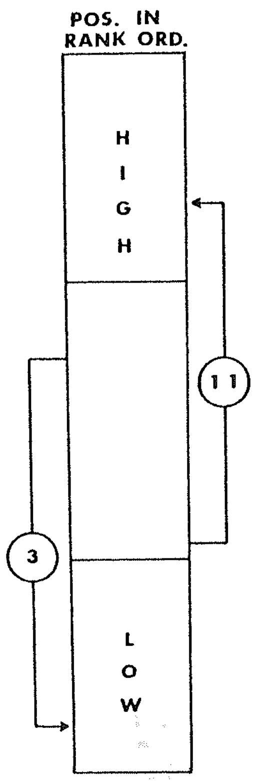
RANK ORDER COMPARISONS BETWEEN COLUMNS:	SPEARMAN'S RANK CORRELATION COEFFICIENT (r_s)	SIGNIFICANCE LEVEL (%)
a - b	0.576	99.5
c - d	0.824	99.9
c - e	0.721	99.9
d - e	0.921	99.9

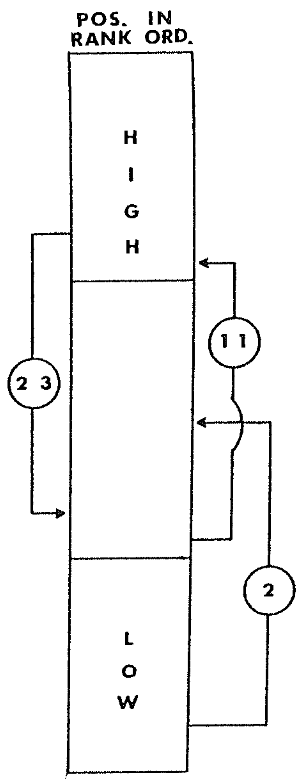
TABLE 6-2 Spearman's Rank Correlation Coefficients for Comparisons Between Rank Orders Based on Different Opportunity Standards

In reverting to the second sensitivity test it is shown that, in comparing post office accessibility measures, zones one, two, fourteen and fifteen and twenty-one all show differences of over seven places in rank order (see Figure 6-8). The difference is particularly significant for zone fourteen where the ranking reflects relatively high accessibility to the nearest facility on the one hand and relatively low accessibility on the other hand. The differences in rank order are less for grocer accessibility measures but show an increase with the divergence in opportunity standards. Changes in rank order of over 7 places are revealed by zones three and eleven when comparing accessibility to the nearest and fifth nearest facility (see Figure 6-9) and zones two, eleven and twenty-three when comparing accessibility to the nearest and tenth nearest facility (see Figure 6-10). A comparison between zonal accessibility to the fifth and tenth nearest facility shows there to be no significant variations in rank order.

With reference to the accessibility profiles (Appendix G) the reason for certain zones to change markedly in rank order for different opportunity standards stems from the spatial distribution of facilities relative to the zone. In certain cases the elderly have relatively high accessibility to the nearest facility but have relatively little choice of facilities (as indicated by the average network distance measures to post offices for zone fourteen and as shown in Map 6-2). In contrast, the opposite case is true for certain







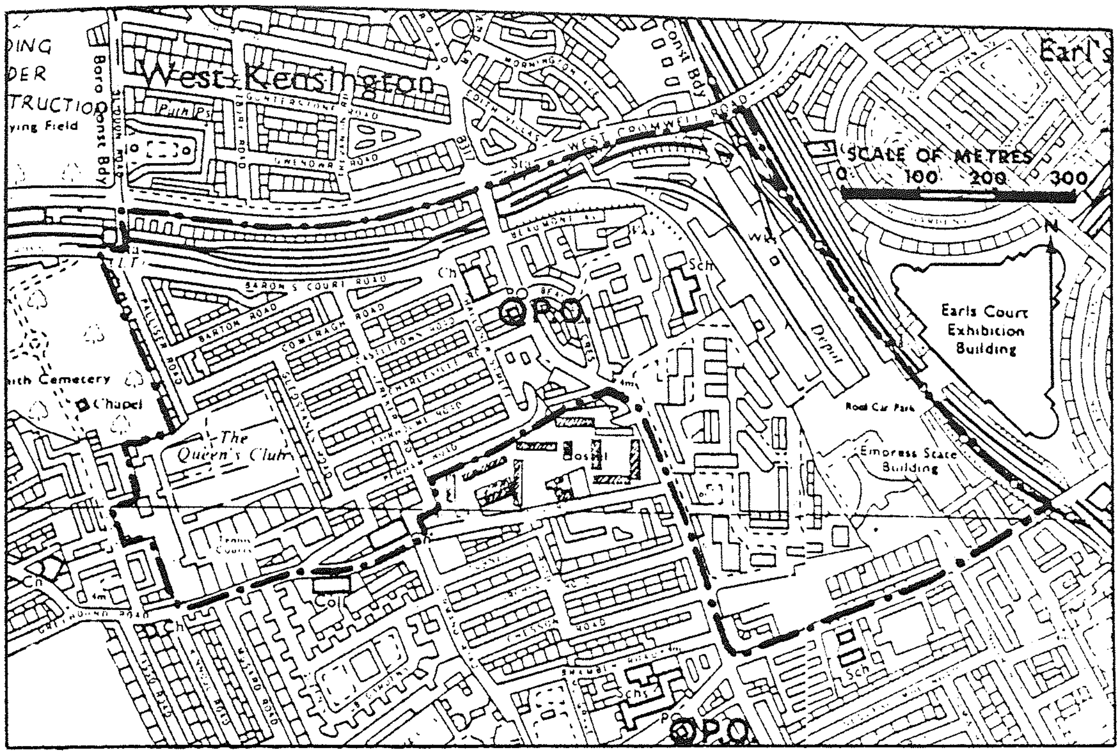
RANK ORDER COMPARISONS BETWEEN:

FIGURE 6-8
Mean Distance to Nearest P.O./Mean Distance to Fifth Nearest P.O.

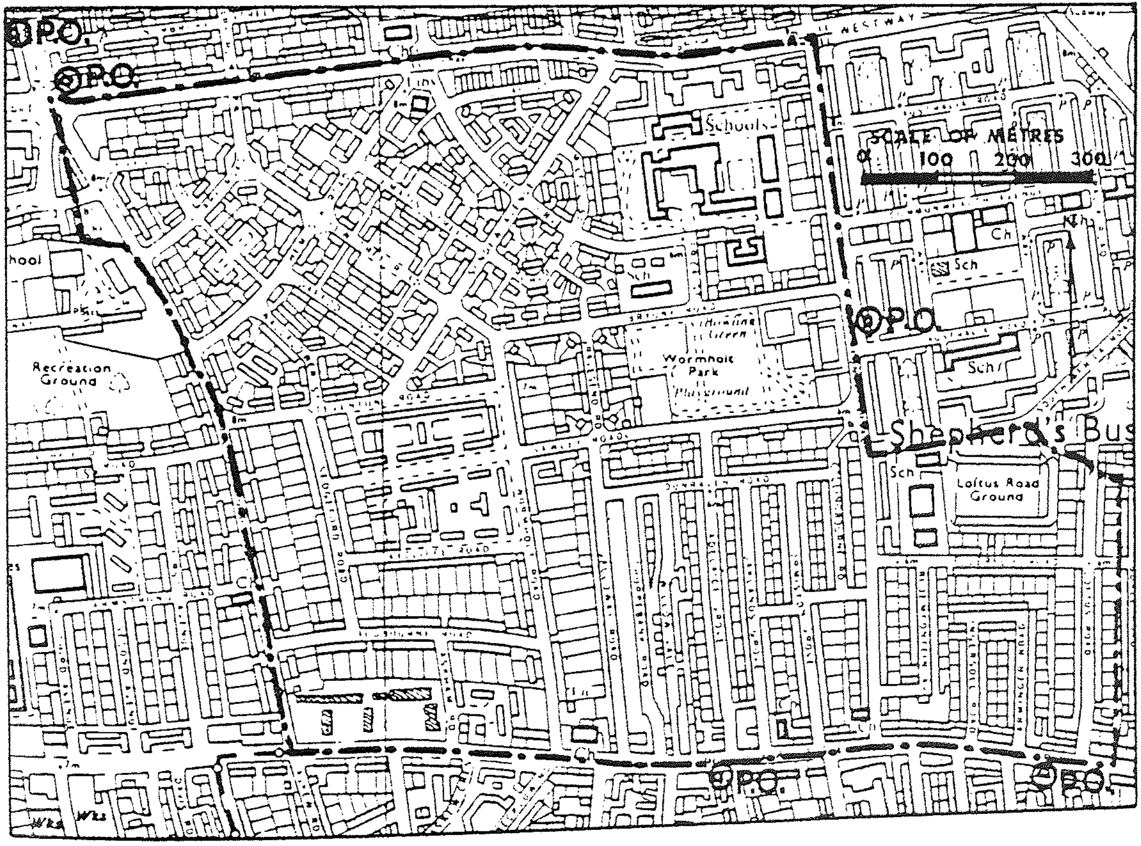
FIGURE 6-9
Mean Distance to Nearest Grocers/ Mean Distance to Fifth Nearest Grocers.

FIGURE 6-10
Mean Distance to Nearest Grocers/ Mean Distance to Tenth Nearest Grocers.

FIGURES 6-8 to 6-10 Significant Changes in the Rank Order of Zones for Comparisons Between Accessibility Levels Based on Different Opportunity Standards

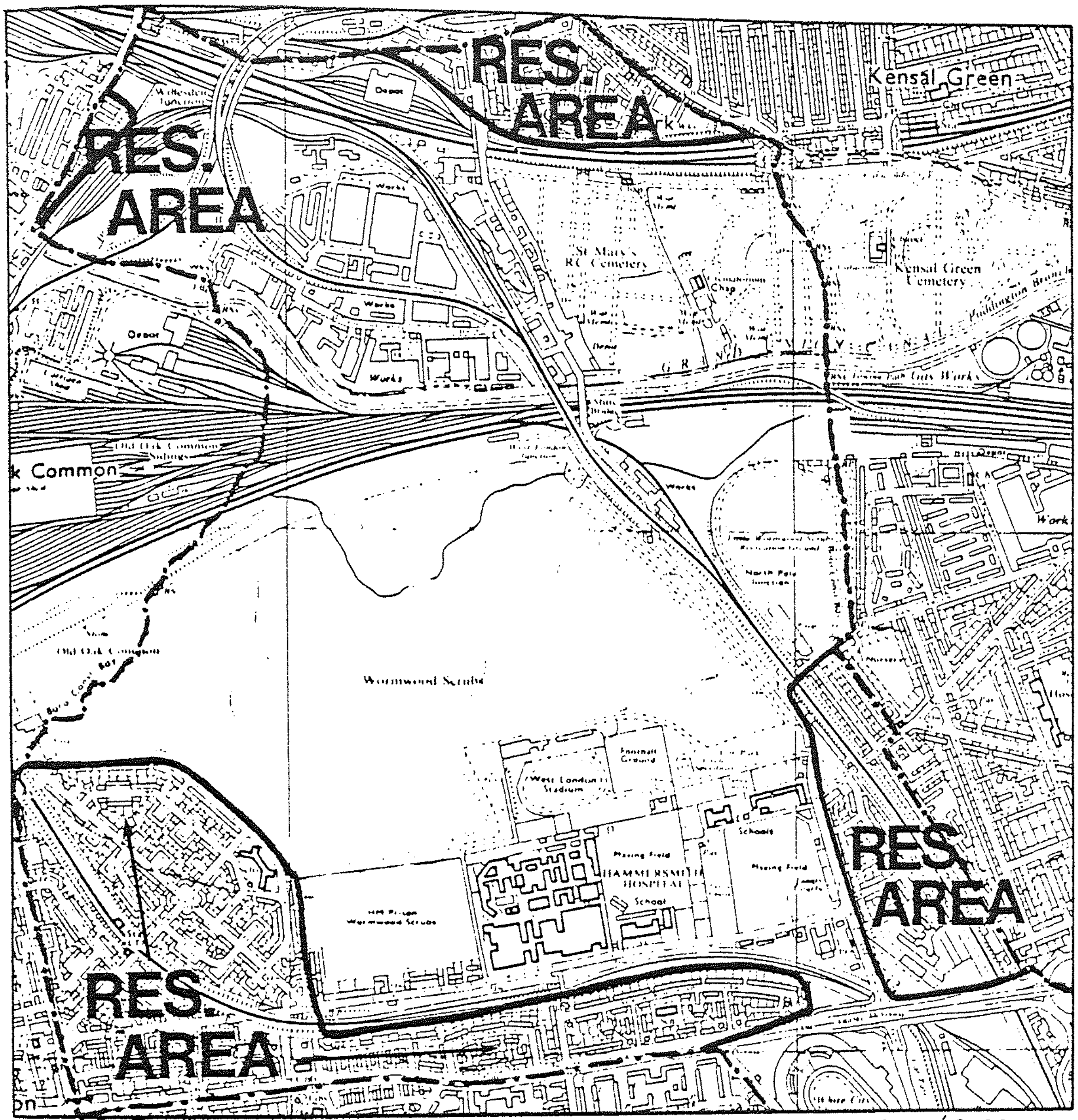


MAP 6 - 2 The Location of Post Offices in the Gibbs Green Area (Zone Fourteen) of the Borough

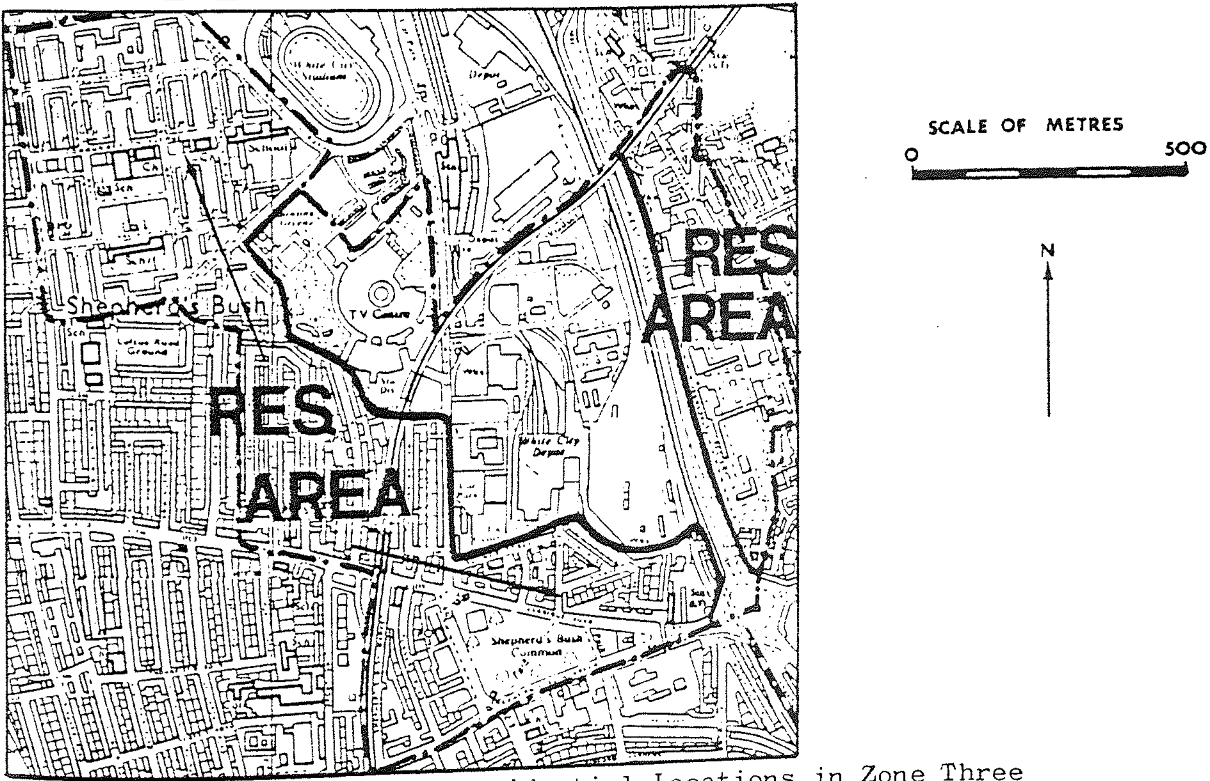


MAP 6 - 3 The Location of Post Offices in the Wormholt Area (Zone Two) of the Borough zones where the provision of local facilities is relatively poor but the range of choice compares favourably with other zones (as indicated by the average network distance measures to post offices and grocers for zone two, and as shown in Map 6-3).

Alternatively, the differences in rank order may also be explained in certain circumstances where a wide variance in the distribution of individual accessibilities from the mean average (as indicated by the gradient of the curves in the separation/population profiles in Appendix G). In this situation, the average may be significantly influenced by a proportion of the individuals within a zone who have a particularly high or low level of accessibility to a given number of facilities relative to the majority of the individuals within the zone. This variance may be attributed to the size of the zone (for example, zone one - see Map 6 - 4) and, in relation to this, the diversity of the spatial distribution of individuals within the zone (for example, zone three - see Map 6-5). Accessibility levels may, therefore, be sensitive to zone specification and size in that the greater the variance in the spatial distribution of individuals within the zone, the greater the likelihood of there being a difference between the rank order positions for different interpretations of the profile information. The practical and policy implications of these results are discussed later in this chapter.



MAP 6-4 The Diversity of Residential Locations in Zone One (College Park and Old Oak)



MAP 6-5 The Diversity of Residential Locations in Zone Three (White City and Shepherds Bush)

ii. Separation Standards

For each zone the percentage of the population having access to one post office in 400m, 700m and 1000m (two-way distance) was calculated from the population/separation profiles and zone rankings were derived accordingly. Equivalent rankings based on accessibility measures for grocers were not compared in this case, in that previous comparisons had already shown there to be greater variations in rank order for post office measures indicating a more diverse spatial distribution of post offices within the Borough.

The separation level of 700m is the approximate of the mean average and median distance (rounded to the nearest 100m) to the nearest post office for the local authority area as a whole (see Figures 6-4 and 6-5 p.206) and, hence, any zone with less than 50% of the population having access to at least one post office can be interpreted as having below average accessibility. Alternatively, the separation level of 1000m was taken to represent an arbitrary standard at which distance the elderly might be expected to walk to a post office in an urban area such as Hammersmith and Fulham. Hence, those individuals below this level might be deemed as having 'poor' accessibility and may comprise the target group for transport policy objectives. In contrast the 400m separation level assists in identifying the distribution of individuals between zones with 'high' accessibility.

The measure of the correlation between the rank orders using Spearman's rank correlation coefficient again, not surprisingly, reveals a positive correlation significant at least at the 97.5% level (Table 6-4). As with opportunity standards it is considered more meaningful to interpret a significant difference in accessibility to be represented by a change of over seven places in rank order. Table 6-3 indicates that when comparing rankings based on the 400m and 700m separation standards, zones one, three, eighteen and nineteen all change in ranking by at least eight places with the two latter zones showing a particularly marked variation of fifteen and fourteen places respectively (see Figure 6-11). Slightly smaller differences in rank order are revealed between rank orders based on separation standards of 700m and 1000m with only zone twenty-one changing rank significantly (see Figure 6-12). A comparison between the rank orders based on the low (400m) and high 1000m) separation standards, not surprisingly, shows the greatest variance with 8 out of the 23 zones (zones one, three, eight, ten, seventeen, eighteen, nineteen and twenty-one) showing a difference in rank order of over seven places (see Figure 6-13).

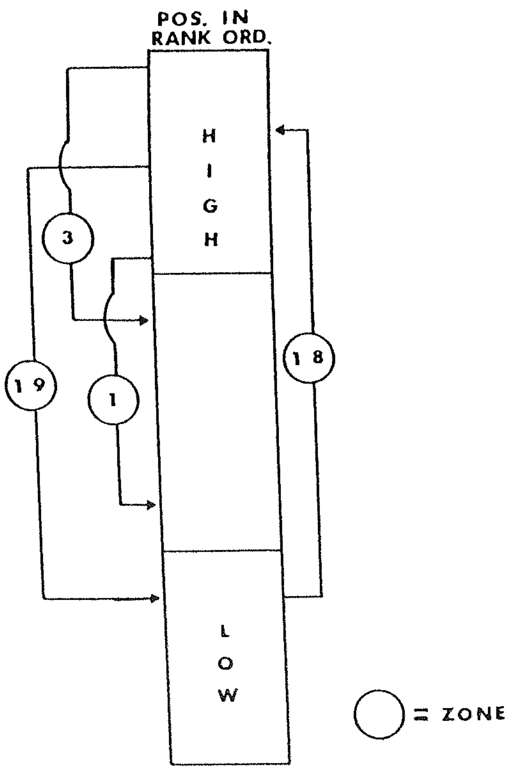
These significant differences in rank order for separation standards can, as with the differences in rank order for opportunity standards, be attributed to the distribution of individual accessibilities within the zones. Given the distribution for all zones (that is, effectively, the average of all zones) as shown in Figure 6-14, then the

ZONES	POSITIONS IN THE RANK ORDER ACCORDING TO THE % OF THE POPULATION HAVING ACCESS TO AT LEAST ONE POST OFFICE IN:		
	400m (f)	700m (g)	1000m (h)
1	7th	15th =	14th
2	19th	17th	19th
3	1st	9th	9th
4	5th	2nd	5th
5	20th	20th	20th
6	9th	12th	6th
7	11th	5th	7th
8	12th	6th	3rd
9	17th	14th	18th
10	2nd	7th	10th
11	23rd	22nd	22nd
12	22nd	23rd	23rd
13	10th	13th	12th
14	6th	4th	8th
15	8th	10th =	15th
16	15th	18th =	21st
17	14th	8th	4th
18	18th	3rd	2nd
19	4th	18th =	13th
20	3rd	1st	1st
21	21st	21st	11th
22	13th	10th =	16th
23	16th	15th =	17th

TABLE 6-3 Rank Order Positions Based on Accessibility Levels Using Different Separation Standards

RANK ORDER COMPARISONS BETWEEN COLUMNS:	SPEARMAN'S RANK CORRELATION COEFFICIENT (r_s)	SIGNIFICANCE LEVEL (%)
f - g	0.583	99.0
f - h	0.528	97.5
g - h	0.857	99.9

TABLE 6-4 Spearman's Rank Correlation Coefficients for Comparisons Between Rank Orders Based on Different Separation Standards



RANK ORDER COMPARISONS BETWEEN:

FIGURE 6-11
The % of the pop. having access to at least one P.O. in: 400m/700m.

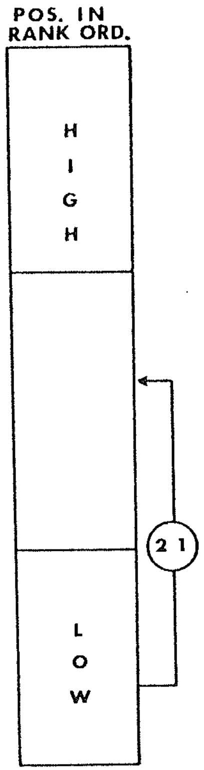


FIGURE 6-12
The % of the pop. having access to at least one P.O. in: 700m/1000m.

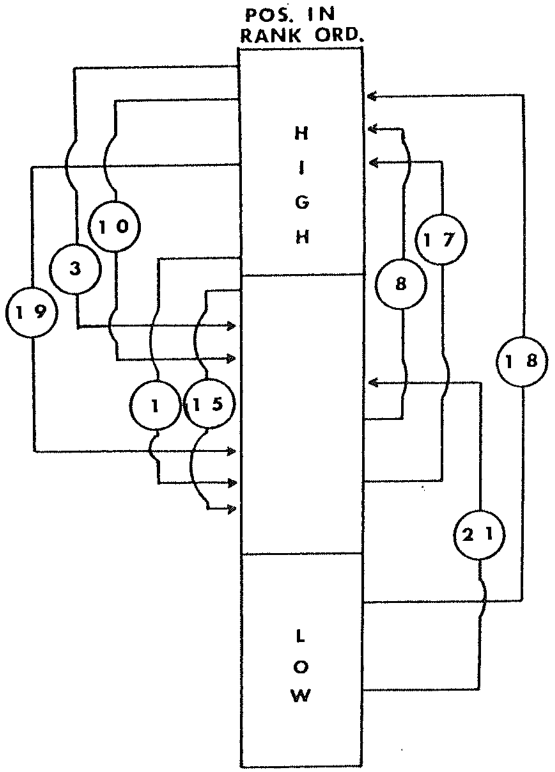


FIGURE 6-13
The % of the pop. having access to at least one P.O. in: 400m/1000m.

FIGURES 6-11 to 6-13 Significant Changes in the Rank Order of Zones for Comparisons Between Accessibility Levels Based on Different Separation Standards greater the divergence between this distribution and the distribution of individual accessibilities within a zone the greater the likelihood of there being a significant difference in the zone rankings. For example, zones one, three and eighteen all vary significantly in rank order for different separation standards but as illustrated below these changes in rank order occur for different reasons. Firstly, the distribution of individual network distances to the nearest post office for zone one reveals a similar skewness to the distribution for the Borough as a whole but differs markedly as regards the variance from the mean (Figure 6-15). Secondly, zone eighteen has a similar variance but a negatively skewed distribution in contrast to the positive skewed distribution for the Borough as a whole. (Figure 6-16). Thirdly, zone three has a symmetric distribution around the mean and median rather than a positive skewed distribution and a greater variance from the mean (Figure 6-17). In turn the distributional characteristics of these zones can be attributed to either the zone size (that is, the greater the size the greater the variance) and/or a clustered spatial distribution of the sample populations residential location within the zone. As noted in relation to the pilot survey (undertaken to determine the sample size) the spatial distribution of the elderlys' residential locations is biased by the physical and socio-economic structure of the zone and, hence, the sample comprises groups of individuals located within the same residential

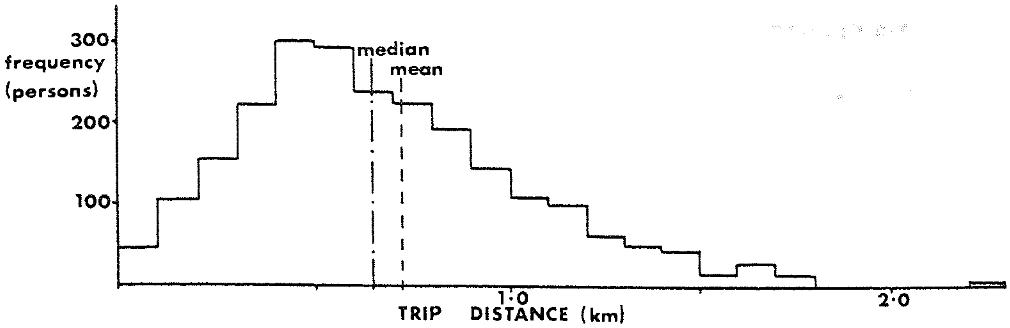


FIGURE 6-14 All Zones

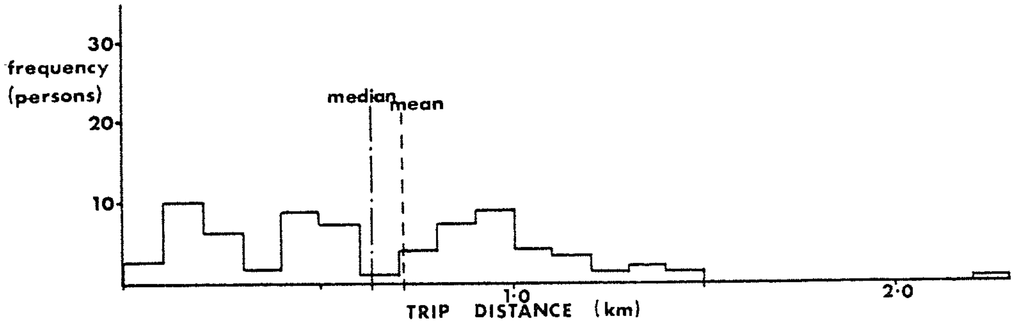


FIGURE 6-15 Zone One - College Park and Old Oak

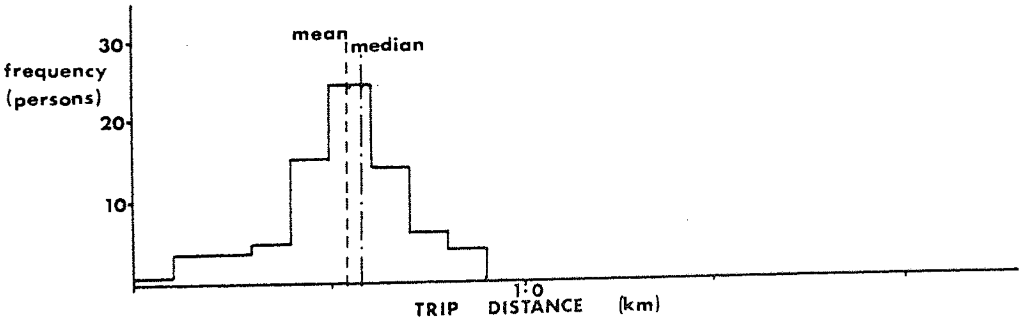


FIGURE 6-16 Zone Eighteen - Sherbrooke

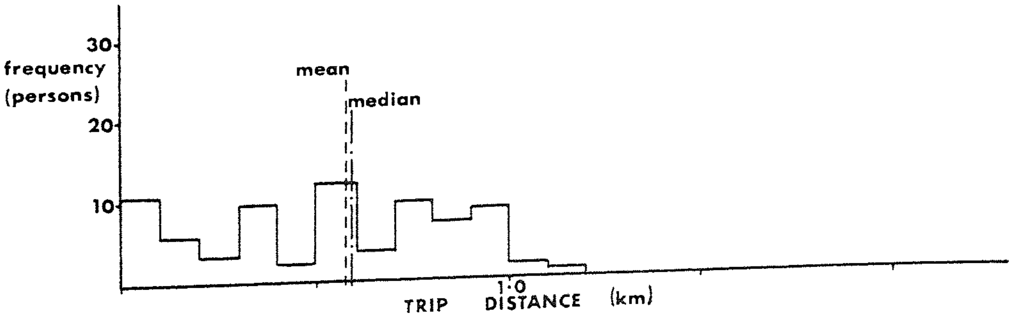


FIGURE 6-17 Zone Three - White City and Shepherds Bush

FIGURES 6-14 to 6-17 A Comparison of the Frequency Distributions of Individual Accessibilities to the Nearest Post Office for Selected Zones area rather than an even spatial distribution throughout the zone. This is particularly evident in zones one and three as indicated by Maps 6-4 and 6-5 (p.219). The influence of zone size and the spatial distribution of individuals within the zone on accessibility levels has implications for the definition of zones and is discussed in relation to the sensitivity of accessibility to aggregation (section 6.6.1.b). As with the sensitivity of accessibility to opportunity standards the practical and policy implications of these results are discussed later in this chapter.

iii. Population Standards

For each zone the distance at which 50%, 75% and 90% of the population have access to at least one post office was calculated from the separation/population profiles and zones ranked accordingly (see Table 6-5). The 50% level represents the median average distance to post offices whilst the 75% and 90% levels assist in identifying the minimum levels of accessibility for the majority of the zonal populations. In this context the 75 and 90 percentiles represent zonal average accessibility levels that exclude a minority of the population that may be unrepresentative of the majority of individuals, thus biasing the average level of accessibility for the zone. Again the relationships can be seen to be statistically significant in terms of Spearman's rank correlation coefficient at the 99.9% level (see Table 6-6.).

	POSITIONS IN THE RANK ORDER ACCORDING TO THE DISTANCE AT WHICH % OF THE POPULATION HAVE ACCESS TO AT LEAST ONE POST OFFICE:		
ZONES	= 50% (i)	= 75% (j)	= 90% (k)
1	12th	17th	15th
2	17th	15th =	18th
3	6th	9th	9th
4	1st	3rd	2nd
5	20th	20th	21st
6	15th	11th	10th
7	4th	6th	6th
8	8th	5th	5th
9	14th	12th =	13th
10	10th =	10th	8th
11	22nd	21st	20th
12	23rd	23rd	23rd
13	13th	8th	17th
14	2nd	1st	4th
15	10th =	12th =	14th
16	21st	22nd	22nd
17	9th	7th	7th
18	5th	4th	3rd
19	18th	18th	12th
20	3rd	2nd	1st
21	19th	14th	11th
22	7th	19th	16th
23	16th	15th =	19th

TABLE 6-5 Rank Order Positions Based on Accessibility Levels Using Different Population Standards

RANK ORDER COMPARISONS BETWEEN COLUMNS:	SPEARMAN'S RANK CORRELATION COEFFICIENT (r_s)	SIGNIFICANCE LEVEL (%)
i - j	0.860	99.9
i - k	0.848	99.9
j - k	0.907	99.9

TABLE 6-6 Spearman's Rank Correlation Coefficients for Comparisons Between Rank Orders Based on Different Population Standards

Table 6-5 shows that zone rankings are reasonably similar when comparing accessibility levels at the median with the 75 and 90 percentiles. A variance of greater than 7 places occurs only in zone twenty-two in the case of the former (see Figure 6-18) and in zones twenty-one and twenty-two in the latter comparison (see Figure 6-19). As with the separation standards these significant changes in rank order can be explained by the distribution of individual accessibilities within the zone in terms of the difference in the variance and/or skewness as compared with the distribution for the Borough as a whole. Again the practical and policy implications are discussed later in this chapter.

iv. Different Types of Standard

On the basis of the above rankings it is also possible to investigate the sensitivity of accessibility levels to different types of standard as opposed to different levels of the same standard. Table 6-7 shows the rank order of zones based on the mean average distance to the nearest post office, that is, the sum of the distances for each individual in the zone divided by the number of individuals (as shown previously in Table 6-1.p.214) the percentage of the population having access to one post office in 700m (as shown in Table 6-3.p.222) and the median average distance to the nearest post office, that is, the distance at which 50% of the population have access to at least one facility (as shown in Table 6-5.p.227). A comparison between the rank orders reveals a close similarity.

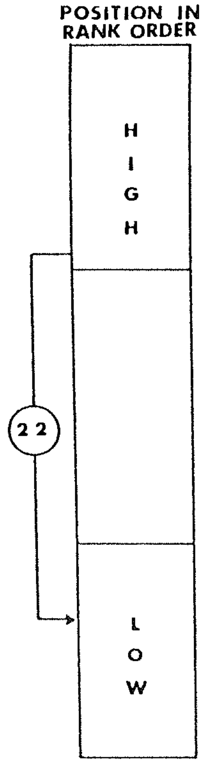
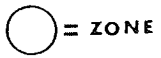


FIGURE 6-18

RANK ORDER COMPARISONS BETWEEN: The distance at which 50% of the pop. have access to at least one P.O./the distance at which 75% of the pop. have access to at least one P.O.



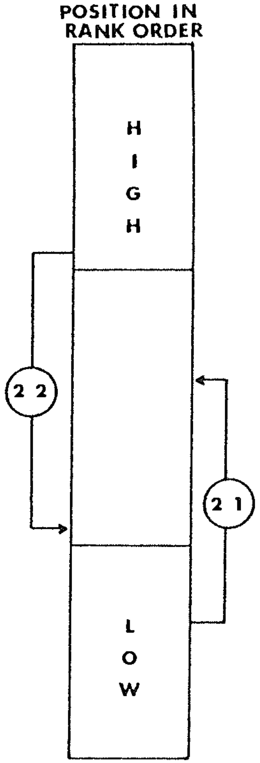


FIGURE 6-19

The distance at which 50% of the pop. have access to at least one P.O./the distance at which 90% of the pop. have access to at least one P.O.

FIGURES 6-18 and 6-19 Significant Changes in the Rank Order of Zones for Comparisons Between Accessibility Levels Based on Different Population Standards

	RANK ORDER ACCORDING TO:		
ZONES	MEAN AVERAGE DISTANCE TO THE NEAREST POST OFFICE (a)	% OF THE POPULATION HAVING ACCESS TO AT LEAST ONE POST OFFICE IN 700m (g)	MEDIAN AVERAGE DISTANCE TO THE NEAREST POST OFFICE (i)
1	13th	15th=	12th
2	18th	17th	17th
3	6th	9th	6th
4	2nd	2nd	1st
5	21st	20th	20th
6	10th	12th	15th
7	4th	5th	4th
8	7th	6th	8th
9	15th	14th	14th
10	8th	7th	10th=
11	22nd	22nd	22nd
12	23rd	23rd	23rd
13	11th	13th	13th
14	3rd	4th	2nd
15	14th	10th=	10th=
16	20th	18th=	21st
17	9th	8th	9th
18	5th	3rd	5th
19	16th	18th=	18th
20	1st	1st	3rd
21	19th	21st	19th
22	12th	10th=	7th
23	17th	15th=	16th

TABLE 6-7 Rank Order Positions Based on Accessibility Levels Using Different Types of Standard

RANK ORDER COMPARISONS BETWEEN COLUMNS:	SPEARMAN'S RANK CORRELATION COEFFICIENT (r_s)	SIGNIFICANCE LEVEL (%)
a - g	0.966	99.9
a - i	0.955	99.9
g - i	0.961	99.9
h - j	0.883	99.9

TABLE 6-8 Spearman's Rank Correlation Coefficients for Comparisons Between Rank Orders Based on Different Types of Standards

The largest difference in rank order between the mean and median average distances and the percentage of the population having access to one post office within 700m is four places (zone fifteen) and three places respectively. Similarly, the only difference worthy of note in comparing the mean with the median average occurs in zone twenty-two (five places). Table 6-8 shows the high level of significance that can be attached to the correlation of rank orders.

Further analysis is undertaken in order to check whether any more significant changes in rank order occur when these different types of standards are applied to the extremes of the profile rather than around the mean and median. In placing emphasis on identifying individuals and zones with poor accessibility it is appropriate to compare two types of standard utilised in the preceeding analysis:-

- the percentage of the population having access to at least one facility in 1000m; and
- the network distance at which 75% of the population have access to at least one facility.

A comparison of the rank orders, however, still reveals no significant changes as indicated by Tables 6-8 and 6-9.

In summary, the change in accessibility (in terms of rank order) due to different types and levels of valuation is shown to be statistically insignificant in that a positive correlation

	RANK ORDER ACCORDING TO:	
ZONES	% OF THE POPULATION HAVING ACCESS TO AT LEAST ONE POST OFFICE IN 1000m (h)	THE DISTANCE AT WHICH 75% OF THE POPULATION HAVE ACCESS TO AT LEAST ONE POST OFFICE (j)
1	14th	17th
2	19th	15th=
3	9th	9th
4	8th	3rd
5	20th	20th
6	6th	11th
7	7th	6th
8	3rd	5th
9	18th	12th=
10	10th	10th
11	22nd	21st
12	23rd	23rd
13	12th	8th
14	8th	1st
15	15th	12th=
16	21st	22nd
17	4th	7th
18	2nd	4th
19	13th	18th
20	1st	2nd
21	11th	14th
22	16th	19th
23	17th	15th=

TABLE 6-9 Rank Order Positions Based on Accessibility Levels Using Different Types of Standard

exists for rank orders based on different values. However, a more meaningful interpretation of the sensitivity of accessibility levels to the valuation process, given the practical context of the research, is undertaken by identifying those zones that change by more than seven places in rank order. A change of seven places is appropriate in that, given there are 23 zones and hence 23 rankings, it indicates a change from one of three fundamental accessibility categories (below average, average and above average accessibility). This analysis reveals, on the evidence of the information contained in the accessibility profiles in Appendix G that the greatest variations in rank order occur for changes in separation standards (values) with slightly smaller variations for opportunity and population standards. The major differences in rank order reflect the problems of interpreting accessibility profiles at one particular point (cross-section) and, for those zones showing the greatest change, the point of the curve at which the information is derived is unrepresentative of the curve as a whole. The likelihood of this point being unrepresentative is dependent on the extent to which the distribution of the individual accessibilities comprising the zonal measure is skewed and the variance from the mean. In turn, the skewness and degree of variance is dependent on the spatial distribution of the sample population within the zone and the zone size as well as the availability of facilities.

The fact that zones in the middle order of the rankings are more closely grouped in terms of their accessibility levels suggests that these zones will show the greatest changes in rank order. Hence, for the same difference in the accessibility level, a greater change in rank order is likely to occur for a zone in the middle of the rank order as compared to a zone to either extreme of the rank order. It is important, therefore, to determine whether a variance in rank order is merely attributable to the position of the zone in the rank order or whether the degree of skewness, variance in the distribution of individual accessibilities or the spatial distribution of the local facilities are important contributory factors. With reference to Figures 6-8 to 6-13, 6-18 and 6-19, showing the significant changes in rank order, it is evident that the changes occur in the middle order positions (for example, zone one in Figures 6-11 and 6-13p.223). However, other zones consistently occupying middle rank positions (for example, zones six and nine, do not change significantly). Moreover, in some cases, zones occupying a high or low position in rank order change position significantly (for example, zone fourteen in Figure 6-8 and zone eighteen in Figure 6-13.). By comparing the skewness and nature of the distribution of the individual accessibilities within the zones it is evident that changes in the rank order of zones can be explained by the skewness and variance in the distributions but greater changes in rank order are likely when the zone occupies a middle-order position.

Finally, the rank order of zones is shown to be relatively insensitive to the type of value implying that greater significance should be attached to deciding which cross-section of the profile is relevant rather than deciding in which units to express the accessibility level. The relevance of these results for accessibility measurement in general and their practical and policy implications are discussed later in this chapter.

b) The Sensitivity of Accessibility to Aggregation

The basic accessibility data set as previously described allows for a number of different forms of aggregation (as outlined in Section 6.3 of this chapter).

i. Individual Accessibilities

Throughout this research accessibility has been measured as a characteristic of the individual and, hence, aggregation is inherent in producing zonal measures of accessibility. By referring to the previous tests and, more specifically, to the distributional characteristics of individual accessibilities (that is, the standard deviation and skewness), an indication of the extent to which aggregation distorts accessibility measurement is revealed. It is recognised that in deriving zonal measures the distribution of individual accessibilities within the zones are concealed. If all zones displayed a normal distribution then the zonal median average distance to the nearest facility would be equal to the zonal mean average and, more significantly, zonal rankings would be the same for each measure.

Referring back to Table 6-7 (p230), the rank orders of zones based on the mean and median average distance to the nearest post office are compared in testing the sensitivity of different types of values. Whilst there is a certain amount of variation between the rankings, thus, indicating that there is not a totally normally distribution of individual accessibilities within each zone, this is shown not to be statistically significant but instead there is a high degree of positive correlation between the two rank orders. The extent to which the distribution data varies from the normal distribution is revealed by Table 6-10 showing the skewness for each zone. It will be seen that the greater the skewness the greater the difference between the mean and the median averages. Zones one, eleven, thirteen and fourteen display an above average skewed distribution which is reflected by both the variance between the rankings and the shape of the curves for the separation/population profiles. In this situation, therefore, the distribution of individual accessibilities is concealed in that, depending on whether the skewness is positive or negative, the accessibility levels for more than 50% of the population lies to the left or right hand side of the mean.

It is apparent that the configuration and size of zones determines the level and nature of the spatial aggregation of individual accessibilities. The greater the zone size the greater the likely variance and skewness in the distribution of individual accessibilities in that the accessibility levels of different groups of individuals within the zone will be functions of independent factors (that is, different parts of the pedestrian network and

ZONES	SKEWNESS OF DISTANCE TO THE NEAREST POST OFFICE	% VARIANCE FROM THE TRUE MEAN AVERAGE DISTANCE TO THE NEAREST POST OFFICE WITHIN 95% CONFIDENCE LEVEL
1	0.636	± 11.8
2	0.241	± 7.9
3	0.046	± 11.2
4	0.391	± 7.5
5	0.255	± 5.5
6	-0.272	± 8.6
7	0.234	± 8.7
8	-0.234	± 6.4
9	0.151	± 7.9
10	0.493	± 9.8
11	-0.652	± 5.3
12	-0.169	± 6.8
13	1.128	± 10.2
14	0.673	± 7.9
15	0.476	± 9.4
16	0.111	± 10.3
17	-0.370	± 7.4
18	-0.195	± 6.0
19	0.200	± 9.4
20	-0.344	± 6.5
21	0.062	± 5.9
22	0.135	± 9.7
23	0.387	± 8.6
All Zones	0.564	± 2.0

TABLE 6-10 The Skewness of and % Variance From the True Mean Average Distance to the Nearest Post Office for Each Zone

the location of different facilities). It is concluded, therefore, that without the data availability constraints on the zone specification, the variance in the accessibility levels of individuals within zones could be minimised by reducing the zone size. Similarly, a more even spatial distribution could be achieved by re-specifying the zone configurations so that the accessibility levels of all individuals within the zone are dependent on the same factors. Those changes in rank order attributable to the variance or skewness of the individual accessibilities may, therefore, be largely eliminated and, hence, the extent to which aggregation and averaging conceals or distorts information may be minimised.

A second aspect to the aggregation of individual accessibilities is that in order to derive a true zonal average the total population set in question should be taken into account. As specified in Chapter Five a sample of 100 elderly persons for each zone was selected and, thus, by the nature of the aggregation process employed the zonal averages are only estimates. The extent to which this estimated zonal average can be taken to reflect the true zonal average is, therefore, investigated with regard to the distribution and standard deviation from the mean of individual accessibilities for each zone.

By calculating the standard error inherent in estimating the mean distance to the nearest facility for each zone (see Appendix E) the range in which the true mean lies is derived at a 95% confidence limit (see Table 6-10). It is seen that for the total sample the true mean lies within 2% either side of the sample mean and, hence, the true mean distance to the nearest post office for the elderly in the London Borough of Hammersmith and Fulham lies between 700m and 730m with a 95% probability. However, in taking a sample of only 100 individuals for each zone the true mean averages for each zone may, in some cases (as shown by Table 6-10), be at least 10% lower or higher than the sample mean averages. More significantly, given that a 10% variation in the mean average is enough to alter the rank order of zones by several places, then it is important that the results are treated simply as estimates and with a certain degree of caution. Given the standard errors for the mean zonal distance to the nearest post office (Table 6-10) the maximum change in rank order for each zone assuming all other estimated zonal averages to be accurate is calculated as shown in Table 6-11. Again, taking a significant change in rank order to be over seven places Table 6-11 reveals that whilst no zones alter in rank significantly, zones one, seven, thirteen, seventeen and nineteen change rank by five or more places. Also due to the form of the frequency distribution of zones according to the mean average distance to the nearest post office (Figure 6-20), the same percentage standard

ZONES	THE POTENTIAL CHANGE IN RANK ORDER DUE TO THE PERCENTAGE ERROR IN ESTIMATING THE MEAN DISTANCE TO THE NEAREST POST OFFICE	
	POSSIBLE INCREASE	POSSIBLE DECREASE
1	+ 5	- 5
2	+ 3	- 1
3	+ 4	- 3
4	+ 1	- 1
5	+ 1	- 0
6	+ 3	- 4
7	+ 2	- 5
8	+ 0	- 2
9	+ 4	- 3
10	+ 4	- 2
11	+ 0	- 0
12	+ 0	- 0
13	+ 1	- 6
14	+ 2	- 0
15	+ 4	- 3
16	+ 1	- 1
17	+ 5	- 1
18	+ 1	- 1
19	+ 5	- 3
20	+ 0	- 2
21	+ 2	- 0
22	+ 2	- 4
23	+ 3	- 2

TABLE 6-11 Potential Changes in Rank Order Due to the Percentage Error in Estimating the Mean Distance to the Nearest Post Office for Each Zone

RANK ORDER COMPARISONS BETWEEN COLUMNS:	SPEARMAN'S RANK CORRELATION COEFFICIENT (r_s)	SIGNIFICANCE LEVEL (%)
a - c	0.476	95.0
b - d	0.370	90.0

TABLE 6-12 Spearman's Rank Correlation Coefficients for Comparisons Between Rank Orders Based on Post Office and Grocer Accessibility Measures

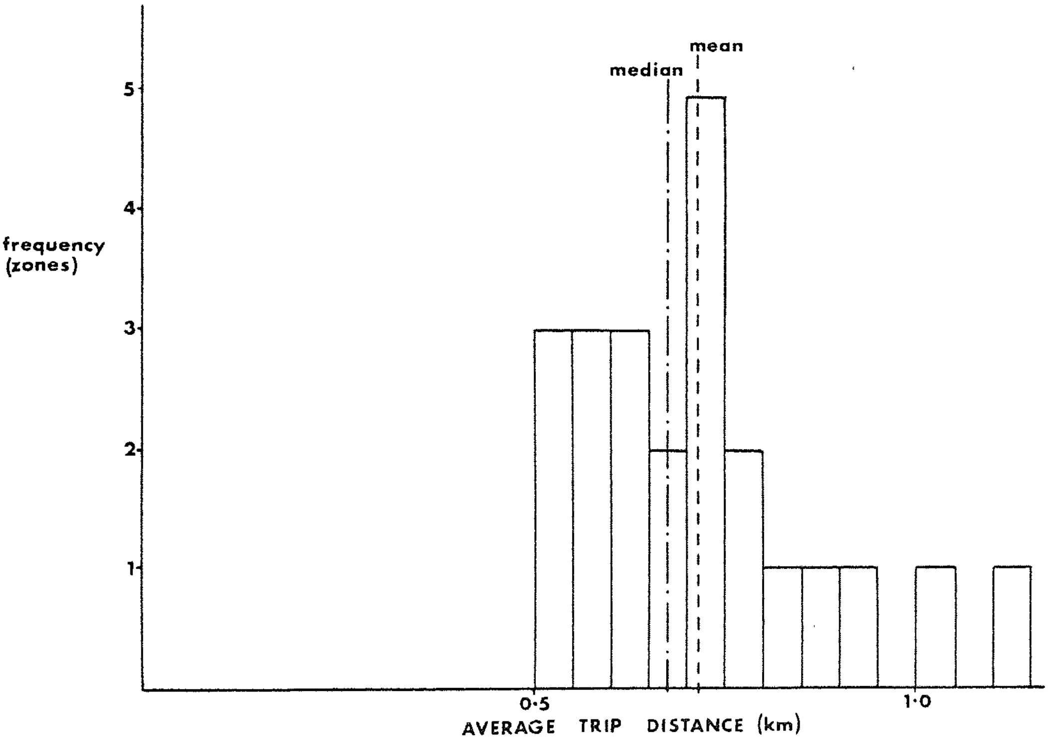


FIGURE 6-20 The Frequency Distribution of Zones According to the Average (Mean) Distance to the Nearest Post Office

error gives rise to a greater potential change in rank order for a zone with a mean of between 700m and 750m than for other zones. For example, zones nine and fourteen are both shown to have a percentage standard error of 7.9% but as indicated by Table 6-11, zone nine (mean average distance = 737m) is liable to change by up to 4 places whilst zone fourteen (mean average distance = 534m) is liable to change by only 2 places. A comparison between Tables 6-10 and 6-11 reveals that the extent to which a zone changes in rank order is a function of both the skewness and percentage variance from the mean and its position in the rank order. In this situation, therefore, the estimation of the mean average network distance to the nearest post office and, hence, those zones with the highest and lowest average accessibility can be calculated with greater accuracy than can the precise rank order of those zones with average accessibility. Clearly, from a practical point of view and in the terms of reference of this research it is more important to identify those zones to either extreme of the rank order (see later).

ii. Origin Locations

Individual's home locations may be aggregated to derive a zonal centroid as utilised in larger scale and more aggregate accessibility studies. However, with reference to this research, given the large size of zone relative to the trip lengths (as revealed in a study of travel patterns - see later), this form of analysis is considered inappropriate.

In many cases the most accessible facilities require the individual to make intra, rather than inter-zonal trips and, hence, any averaging of this nature would give rise to totally inaccurate accessibility levels.

iii. Destination Locations and Trip-Purpose

In measuring accessibility to more than one facility type and by defining their precise spatial location it is possible to investigate the extent to which post office and grocer locations correlate. It is suggested that in taking a more aggregate classification of trip-purpose grocers and post offices may both be included in a shopping and personal business category and their average location subsequently defined as a shopping centroid. A comparison between the rank order of zones based on the mean average distance to one and five facilities for post offices and grocers (see Table 6-1p.214) reveals several marked differences. The Spearman rank correlation coefficient indicates that the correlation between the two rank orders (for both one and five facilities) is positively significant (statistically) at the 95% and 90% levels respectively (Table 6-12) which is noticeably lower than for the preceeding rank order comparisons for different types and levels of values. For rank orders based on the average distance to the nearest post office and grocer, zones six, seven, ten, twelve, nineteen, twenty-two and twenty-three (see Figure 6-21) all show differences of at least nine places in rank order. Similar levels of

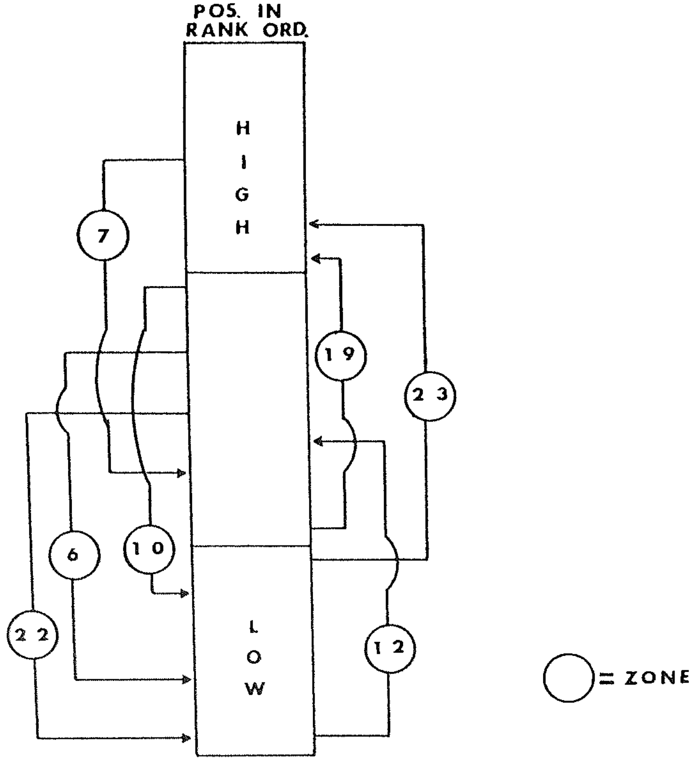


FIGURE 6-21

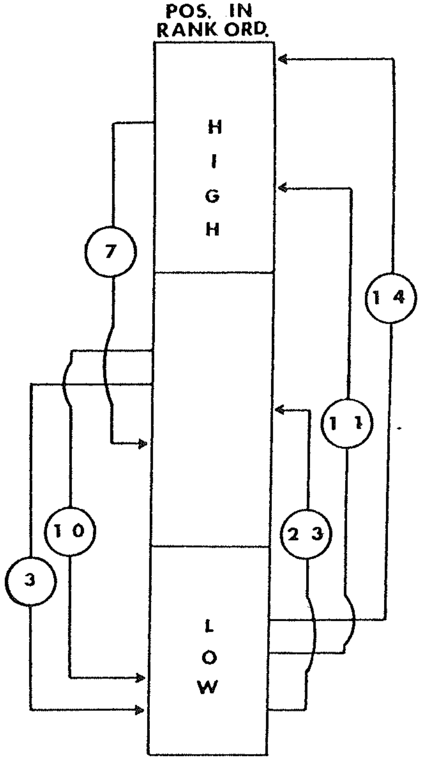


FIGURE 6-22

RANK ORDER COMPARISONS BETWEEN:

The mean distance to the nearest P.O./the mean distance to the nearest grocers.

The mean distance to the fifth nearest P.O./the mean distance to the fifth nearest grocers.

FIGURES 6-21 and 6-22 Significant Changes in the Rank Order of Zones for Comparisons Between Post Office and Grocers Accessibility Levels variance are revealed in comparing rank orders based on the average distance to the fifth nearest facilities, however, in this instance, zones three, seven, ten, eleven, fourteen, and twenty-three show differences of at least nine places (see Figure 6-22).

As with valuation, the hypothesis that rank orders vary significantly according to the types and levels of aggregation is not supported but instead there is statistical evidence to support the inverse of the hypothesis. Despite this it is still important to comprehend the margin of error associated with deriving aggregate single unit measures of accessibility. As stated previously, accessibility is a function of the characteristics of the individual and, therefore, any attempt to aggregate these characteristics based on partial information (sample) will involve some form of estimation and averaging. The above results do show that a considerable amount of information, not least the distribution of individual accessibilities, can be hidden by relying on aggregated measures of accessibility. Comparative accessibility profiles are one way of overcoming or at least representing the distributions within aggregated and, hence, potentially distorted, indices. For example, the zonal profiles in Appendix G identify those individuals with relatively poor accessibility as well as providing the zonal average accessibility. In zones one and nineteen for instance, the relatively low accessibility incident to a minority of the sample population from the zone would otherwise be concealed by more aggregate accessibility measures. As with valuation, the practical implications of the sensitivity of accessibility to aggregation is discussed later in this chapter.

6.6.2. The Sensitivity of Accessibility to Trip Structure - Testing Hypothesis Two (H.2.)

The sensitivity of accessibility levels to the trip structure (that is, a linked trip or two single purpose trips) is also investigated using the zonal accessibility profile information displayed in Appendix G. The results of the profile formulation shows that accessibility levels for the elderly to post offices and grocers by linking trips compared to single-purpose trips for the London Borough of Hammersmith and Fulham are improved by approximately 30%. In identifying areas and individuals with poor accessibility it is, however, more important to determine the extent to which the potential travel savings from linking trips vary between zones and individuals within the Borough.

By adopting different standards (values) as utilised in testing the sensitivity of accessibility to valuation the extent to which accessibility levels derived from potential post office and grocer linked trip data very from accessibility levels derived from potential single-purpose trip data (as shown in Appendix G) is examined for each zone by comparing rank orders. From the single-purpose and linked trip profiles rank orders are derived based on:

- The mean average distance to the nearest and fifth nearest combinations of post offices and grocers.

- The percentage of the population having access to at least one and five combinations of post offices and grocers in 1000m - representing the approximate average network distance to the nearest post office and grocer by single-purpose trips for the Borough and the approximate average network distance to the fifth nearest combinations of post office and grocer by linked trips.
- The median average distance to the nearest and fifth nearest combination of post office and grocer.

Table 6-13 shows the rank order of zones for each of the above accessibility measures.

The degree of positive correlation between the rank orders based on single-purpose and linked trip data for each accessibility measure is shown to be high with the Spearman rank correlation coefficient indicating a statistically significant positive correlation at the 99.9% level in all cases (see Table 6-14). As with hypothesis H.1. the same limitations of the Spearman rank correlation coefficient apply and, hence, a significant difference in rank order is again thought to be more appropriately interpreted as being a change of over seven places.

Firstly, for accessibility levels based on the mean average network distance to the nearest combination of facilities the greatest change in rank order is only six places (zone six), (see Figure 6-23). For the mean average network distance measure to the fifth nearest combination of facilities only zone

ZONES	MEAN DISTANCE TO NEAREST FACILITIES		MEAN DISTANCE TO FIVE NEAREST FACILITIES		% OF THE POPULATION HAVING ACCESS TO ONE COMBINATION OF FACILITIES IN 1000m		% OF THE POPULATION HAVING ACCESS TO FIVE FACILITIES IN 1000m		MEDIAN DISTANCE TO NEAREST FACILITIES		MEDIAN DISTANCE TO FIVE NEAREST FACILITIES	
	SINGLE PURPOSE TRIP (l)	LINKED TRIP (m)	SINGLE PURPOSE TRIP (n)	LINKED TRIP (o)	SINGLE PURPOSE TRIP (p)	LINKED TRIP (q)	SINGLE PURPOSE TRIP (t)	LINKED TRIP (u)	SINGLE PURPOSE TRIP (w)	LINKED TRIP (x)	SINGLE PURPOSE TRIP (y)	LINKED TRIP (z)
1	16th	12th	16th	16th	13th	15th=	15th=	15th	13th	10th	9th	14th
2	20th	17th	19th	11th	18th=	18th	13th	10th=	19th	16th	15th=	11th
3	5th	6th	20th	21st	10th	9th	18th	20th=	7th	8th	17th	22nd
4	4th	2nd	2nd	2nd	2nd	5th	2nd	2nd	5th	2nd	2nd	2nd
5	18th	20th	15th	15th	20th	20th	8th	17th	20th	19th=	20th	17th
6	15th	9th	17th	20th	17th	10th	21st	22nd	18th	13th	18th	18th
7	8th	5th	7th	13th	6th	6th=	12th	13th=	6th	3rd	13th	15th
8	6th	7th	5th	5th	7th	3rd	5th=	5th	3rd	7th	5th	6th
9	14th	19th	10th	14th	11th	15th=	9th=	9th	11th	18th	6th	9th
10	11th	11th	14th	18th=	12th	8th	22nd=	20th=	12th	15th	15th=	16th
11	22nd	22nd	18th	18th=	22nd	22nd	9th=	19th	22nd	22nd	21st	19th=
12	23rd	23rd	23rd	22nd	23rd	23rd	20th	18th	23rd	23rd	23rd	21st
13	10th	13th	13th	8th	5th	11th	5th=	7th=	8th	12th	14th	5th
14	1st	1st	1st	1st	2nd	4th	1st	1st	1st	1st	1st	1st
15	9th	10th	8th	7th	8th	13th	15th	7th=	9th	5th	8th	8th
16	21st	21st	22nd	23rd	21st	21st	22nd=	23rd	21st	21st	22nd	23rd
17	7th	8th	6th	10th	9th	6th=	14th=	6th	10th	11th	7th	7th
18	3rd	4th	4th	4th	3rd	1st	4th	3rd	4th	6th	4th	4th
19	12th	16th	9th	6th	15th	19th	5th=	10th=	15th	17th	11th	10th
20	2nd	3rd	3rd	3rd	1st	2nd	3rd	4th	2nd	4th	3rd	3rd
21	17th	18th	12th	12th	18th=	12th	19th	13th=	17th	19th=	10th	13th
22	18th	14th	21st	17th	14th	17th	15th=	16th	14th	9th	19th	19th=
23	13th	15th	11th	9th	16th	14th	11th	12th	16th	14th	12th	12th

TABLE 6-13 Rank Order Positions for Single-Purpose and Linked Trip Accessibility Measures

RANK ORDER COMPARISONS BETWEEN COLUMNS:	SPEARMAN'S RANK CORRELATION COEFFICIENT (r_s)	SIGNIFICANCE LEVEL (%)
l - m	0.919	99.9
n - o	0.894	99.9
p - q	0.874	99.9
t - u	0.894	99.9
w - x	0.906	99.9
y - z	0.801	99.9

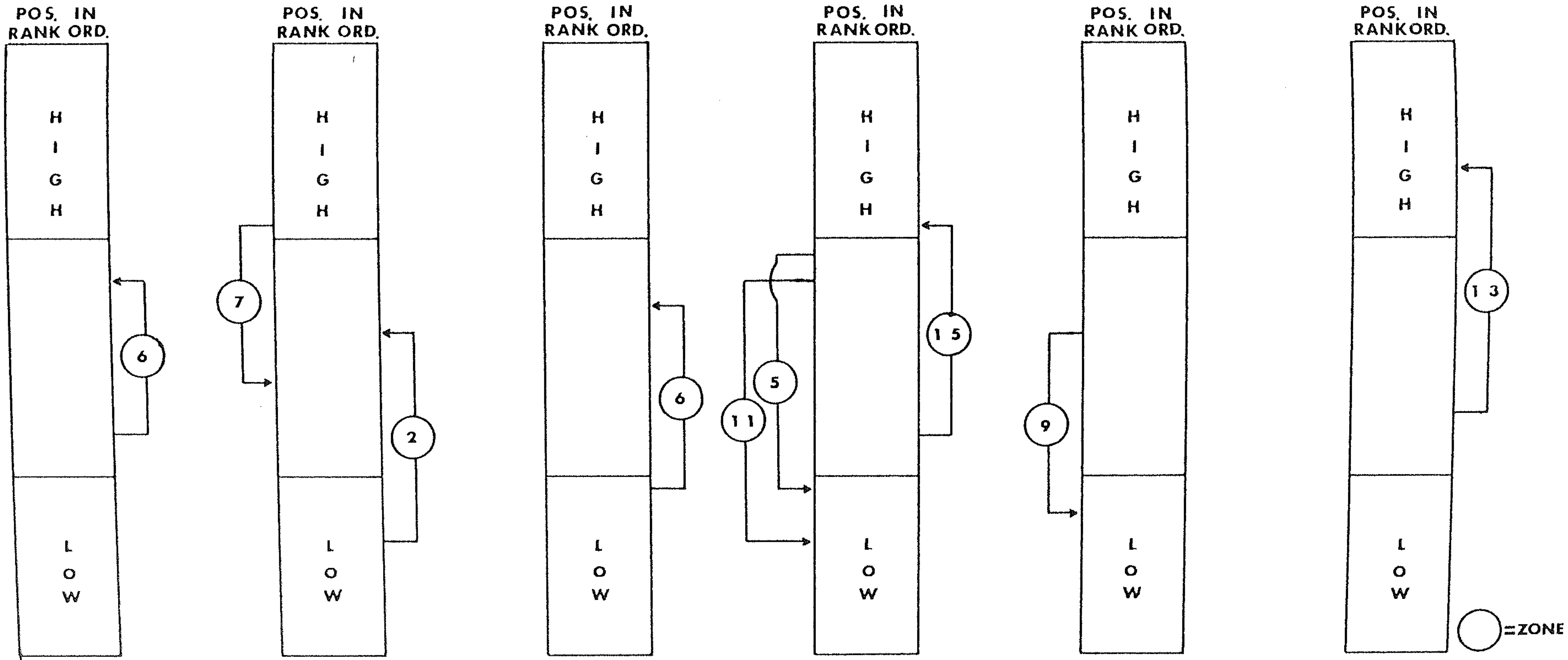
TABLE 6-14 Spearman's Rank Correlation Coefficients for Comparisons Between Rank Orders Based on Single-Purpose and Linked Trip Accessibility Measures

two shows a significant change in rank order (eight places) with zone seven changing by six places (see Figure 6-24).

Secondly, for the percentage of the population having access to at least one combination of facilities in 1000m the greatest change in rank order is experienced by zone six (seven places) (see Figure 6-25). Slightly greater variation in rank order occurs when accessibility is interpreted as the percentage of the population having access to at least five combinations of post offices and grocers in 1000m with zones five, eleven and fifteen changing significantly (see Figure 6-26).

Thirdly, the rank orders based on the median average network distance to the nearest combination of facilities reveal that only zone nine changes rank significantly (see Figure 6-27). Similarly, for rank orders based on the median average network distance to the fifth nearest combination of facilities only zone thirteen experiences a significant change in rank order (see Figure 6-28).

Those zones that do change significantly in rank order reflect either a relatively high or relatively low average travel savings from linking trips. For instance, as indicated by the zonal profiles in Appendix G, the average reduction in travel distance from linking trips to the nearest combination of facilities is approximately 37% for zone six compared with 30% for the Borough as a whole, whilst for zone nine the corresponding reduction is only 25%. Also, the greater variation in rank order



RANK ORDER COMPARISONS BETWEEN SINGLE-PURPOSE AND LINKED TRIP ACCESSIBILITY MEASURES:

FIGURE 6-23
Mean distance to nearest facilities

FIGURE 6-24
Mean distance to five nearest facilities

FIGURE 6-25
% of pop. having access to one combination of facilities in 1000m

FIGURE 6-26
% of pop. having access to five combinations of facilities in 1000m

FIGURE 6-27
Median of distance to nearest facilities

FIGURE 6-28
Median distance to five nearest facilities

FIGURES 6-23 to 6-28 Significant Changes in the Rank Order of Zones for Comparisons Between Single-Purpose and Linked Trip Accessibility Levels.

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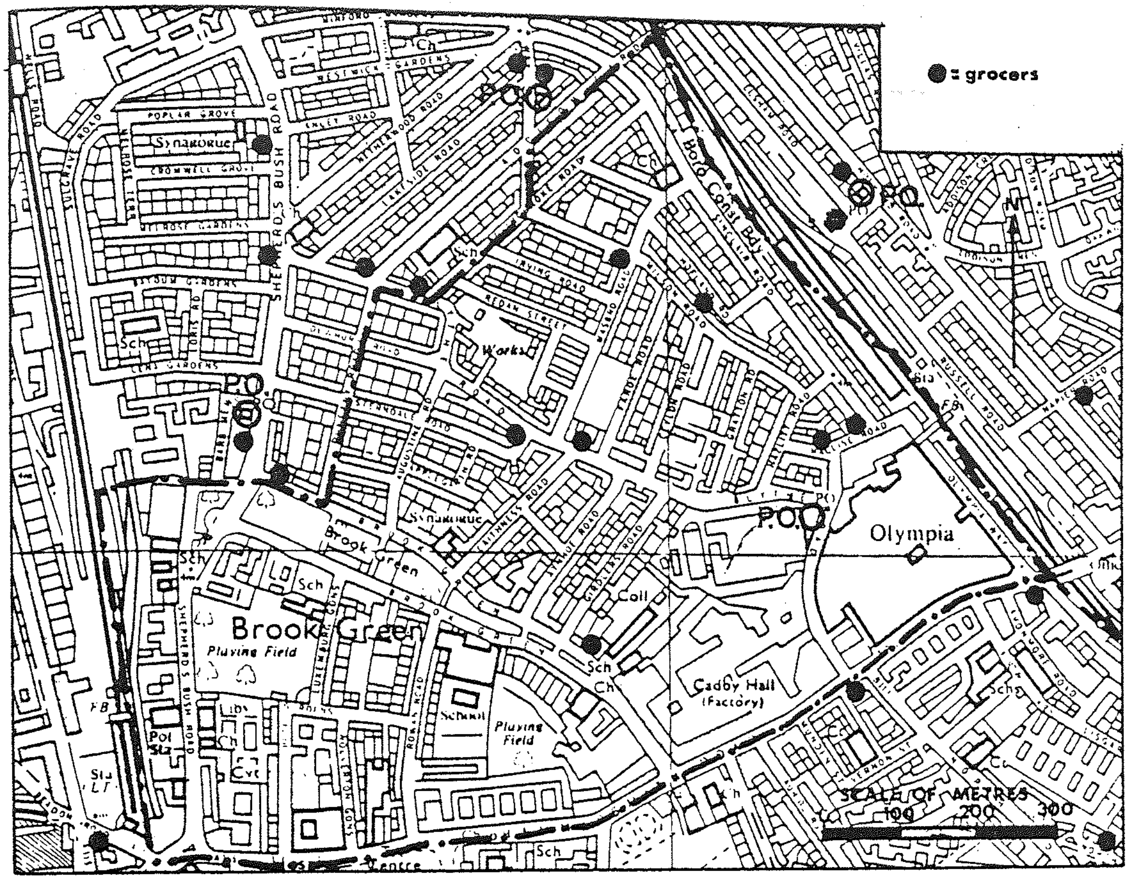
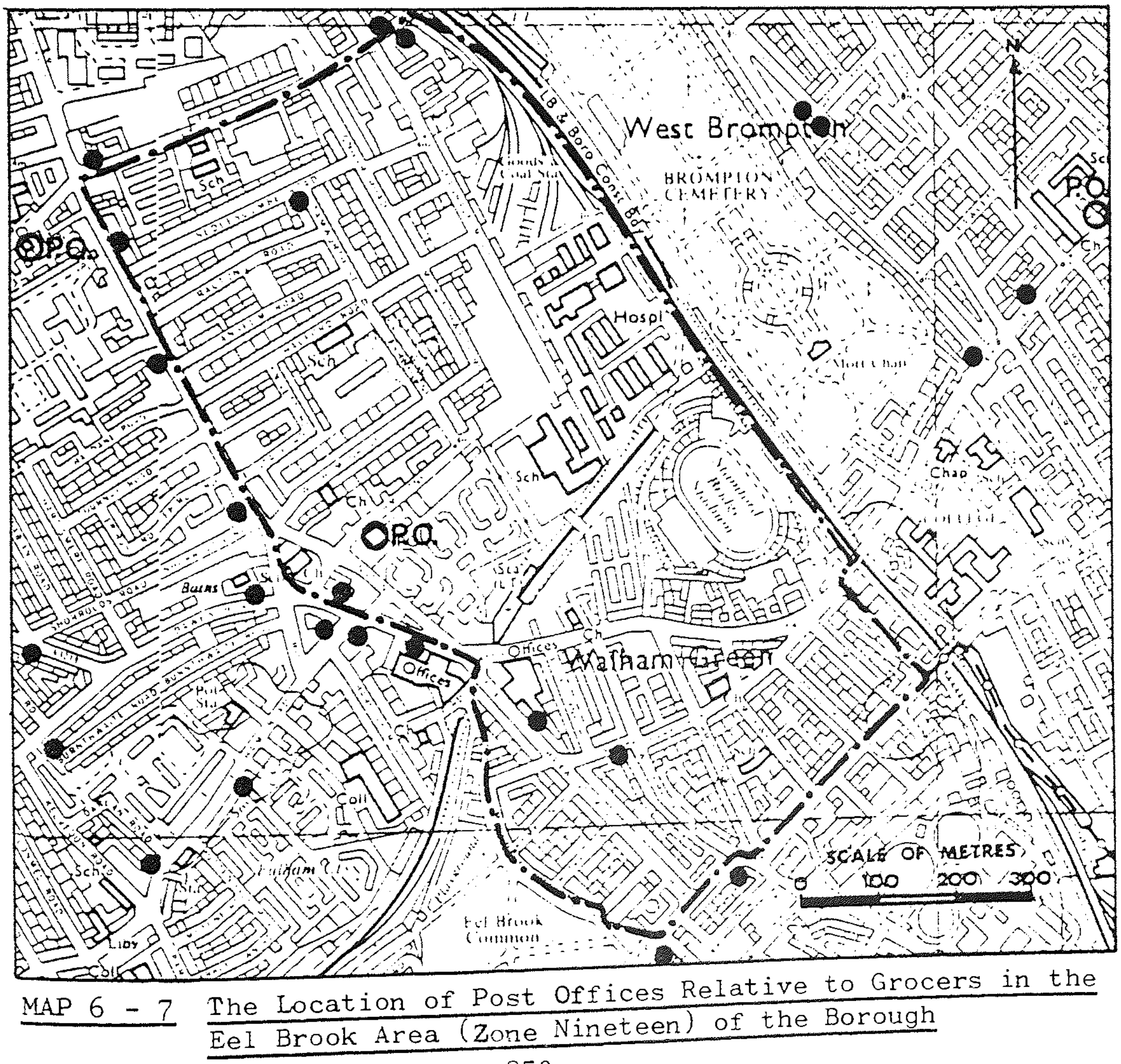
for measures based on accessibility to the fifth nearest combination of facilities reflects the greater potential to reduce total travel distance from visiting facilities other than the nearest to the individual's residential location. As indicated by the separation/opportunity profiles (Appendix G) and more specifically, by the steeper gradient of the linked trip profile, the average travel detour associated with linking a trip to the post office with a trip to the grocers of vice-versa decreases for more distant facility combinations.

The potential to improve accessibility by linking trips depends on the spatial location of post offices and grocers relative to one another as well as in relation to the individual's residential location. For example, in zones nine and nineteen the local grocers and post offices for the majority of the sample population are not located in the same proximity or on the same route (see Maps 6-6 and 6-7) even though, in the case of both zones the average accessibility to the grocers is not low relative to other areas of the Borough. Alternatively, for zones six and twenty-two the location of the local facilities offers greater potential for trip linking (see Maps 6-8 and 6-9).

The accessibility profiles indicate the potential reduction in travel distance and, hence, the potential improvement in the accessibility to post offices and grocers available to the elderly resident in the London Borough of Hammersmith and Fulham from undertaking linked trips as opposed to single-purpose trips. The variation in this potential improvement between individuals

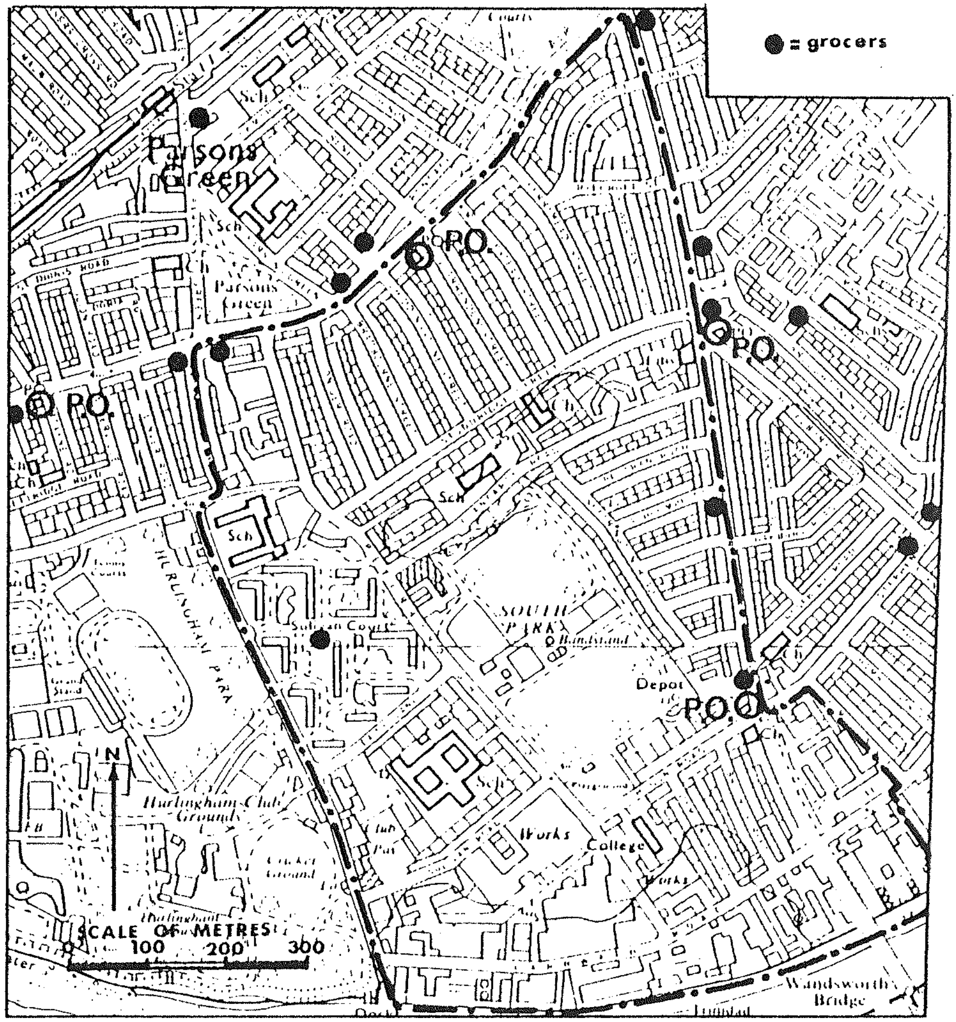


MAP 6 - 6 The Location of Post Offices Relative to Grocers in the Brook Green Area (Zone Nine) of the Borough



MAP 6 - 7 The Location of Post Offices Relative to Grocers in the Eel Brook Area (Zone Nineteen) of the Borough

MAP 6-8 The Location of Post Offices Relative to Grocers in the Ravenscourt Area (Zone Six) of the Borough



MAP 6-9 The Location of Post Offices Relative to Grocers in the Sulivan Area (Zone Twenty-Two) of the Borough

and zones is also revealed by the accessibility profile information. On the basis of this information the role of linked tripmaking in accessibility analysis can be explored further. With reference to the experimental design (Chapter Five) further analysis of journey structures is undertaken (in Chapter Seven) by investigating the proportion of trips that are linked (hypothesis H.3.), the difference in the incidence of linked trips between accessibility groups (hypothesis H.4.) and the influence of potential distance saving on journey structures. However, firstly, it is necessary to consider the implications of the results of the rank order comparisons for determining the accessibility of the elderly.

6.7. THE PRACTICAL AND POLICY IMPLICATIONS OF THE RESULTS

On the basis of the above investigations it is possible to assess the geographic distribution of accessibility to post offices between different areas (zones) of the London Borough of Hammersmith and Fulham. Whilst no single measure can be taken to be the correct interpretation of accessibility to post offices (unless certain value judgements are made), it is a safe assumption that those zones with consistently low positions in the rank orders can be taken as having relatively poor accessibility. Similarly, those zones with consistently high positions in the rank orders may be deemed to have a relatively high level of accessibility.

The analysis described in the preceeding text indicates that the larger variances in rank order can be explained by the degree of skewness and/or deviation from the curve showing the distribution of individual accessibilities for the Borough as a whole which, in turn, indicates the necessity to identify the distribution of individual accessibilities within the zone. However, changes in rank order may also be attributed to the position in rank, hence, either minor changes in the measurement may result in large rank changes or, alternatively, large changes in the measurement may result in small rank order changes.

A comparison between all the different rank orders shows there to be a greater stability in a zone's position for the low and high orders and, hence, the main variance occurs in the middle portion of the rank order due to the frequency distribution of zones according to their accessibility levels. The frequency with which zones change rank order by seven or more places for all rank order comparisons is shown in Figure 6-29. A change of seven or more places in rank orders occurs in under 12% of zone comparisons whilst zones two, three and twenty-one show variances of this magnitude in rank order in approximately 25% of rank order comparisons. It is noted that zones two and twenty-one fluctuate between low and average accessibility relative to the Borough as a whole whilst zone three fluctuates from above average to below average accessibility.

With reference to the rank order comparisons zones four, fourteen, eighteen and twenty are consistently found in the first five places of the rank orders whilst zones eleven, twelve and sixteen are consistently in the lowest five places. In addition zones one, five, nine, twenty-two and twenty-three are consistently below the average accessibility level for the area as a whole. It is noted also that even by taking into account the potential to link trips and, hence, improve the level of accessibility, these zones still have low levels of accessibility relative to other zones.

The actual density of post offices within those zones with low accessibility is not significantly different to the area as a whole. Instead, the major cause of these low accessibility levels is the constraints and limitations of the pedestrian network. It is noted that with reference to Map 6-10 those zones identified as having relatively poor accessibility are bound by land-uses that constrain movement (that is, the Thames to the

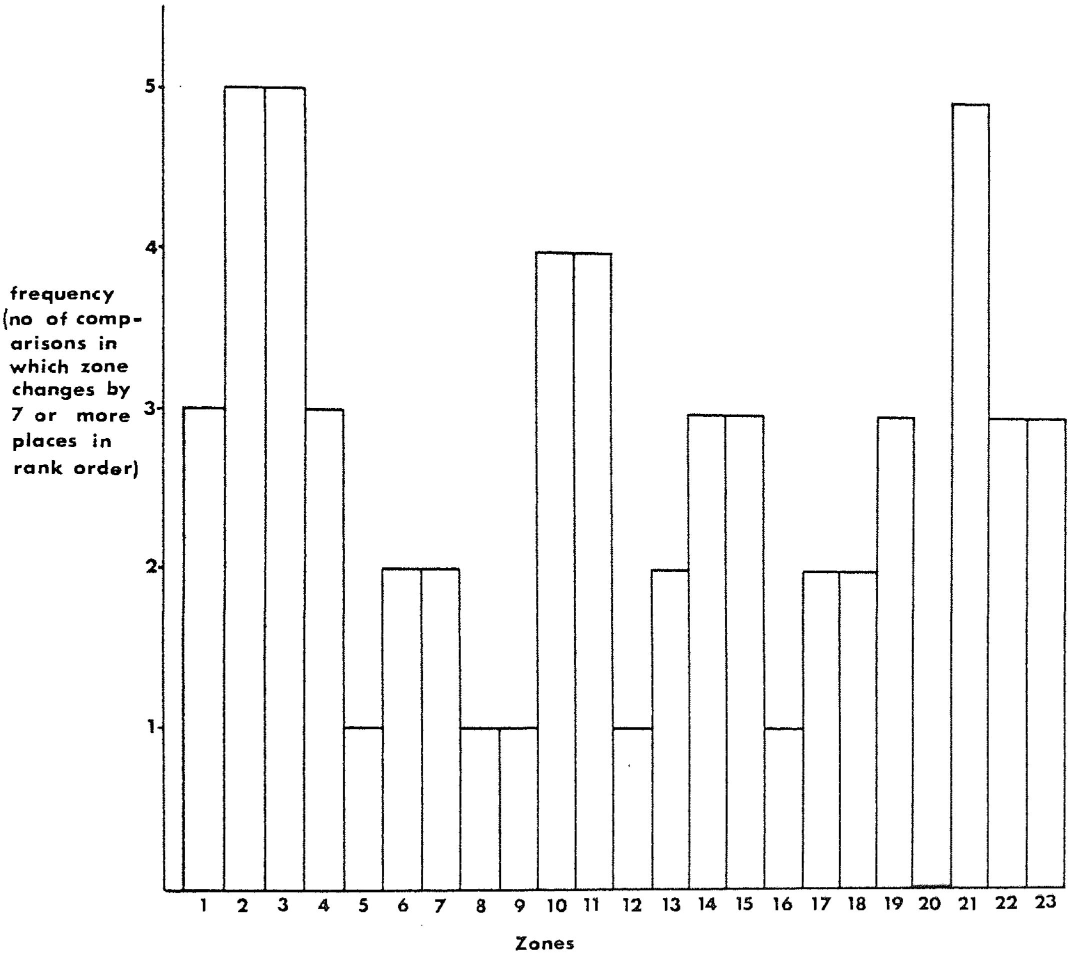
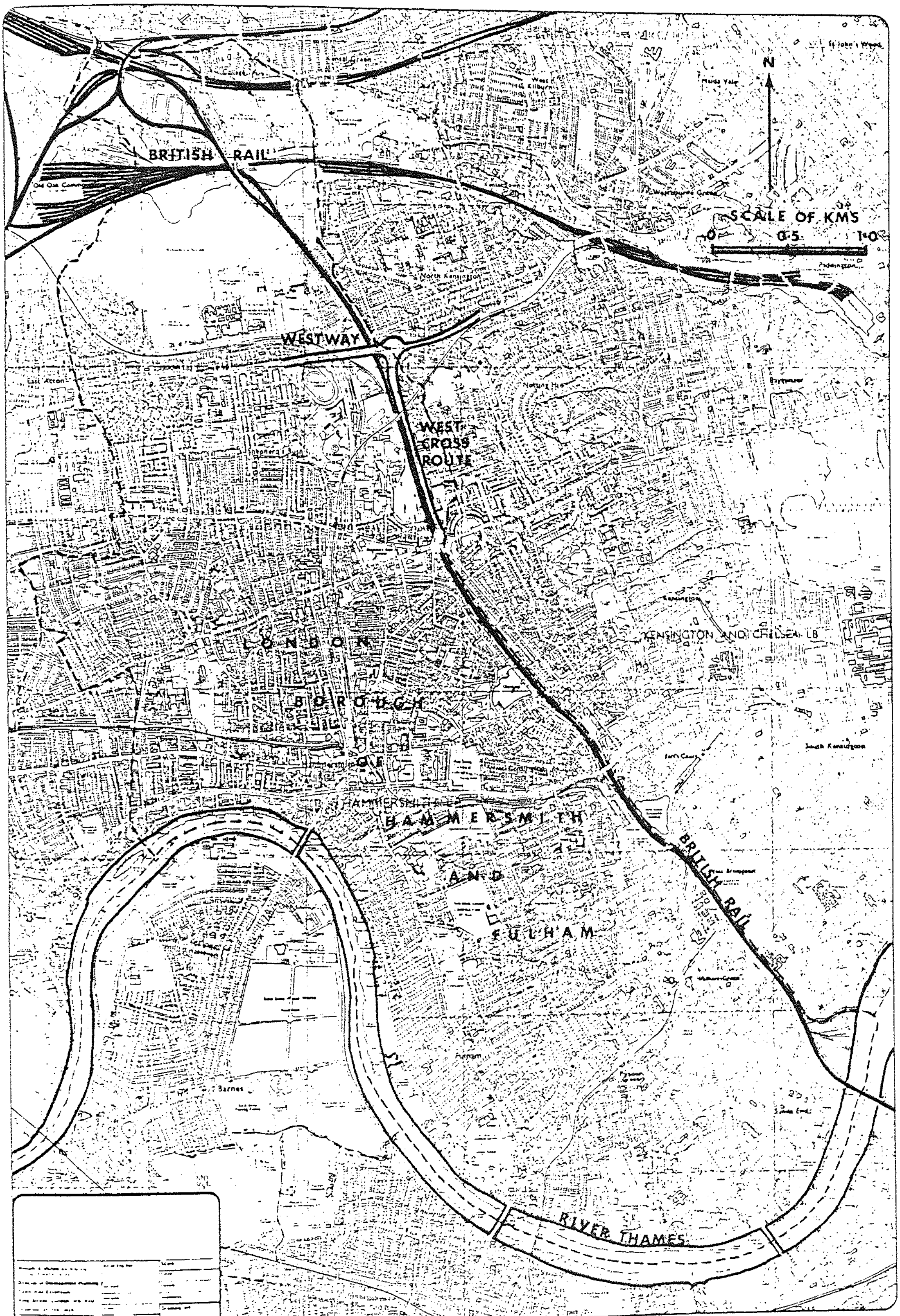


FIGURE 6-29 A Histogram Showing the Number of Rank Order Comparisons in Which Zones Change by Seven or More Places

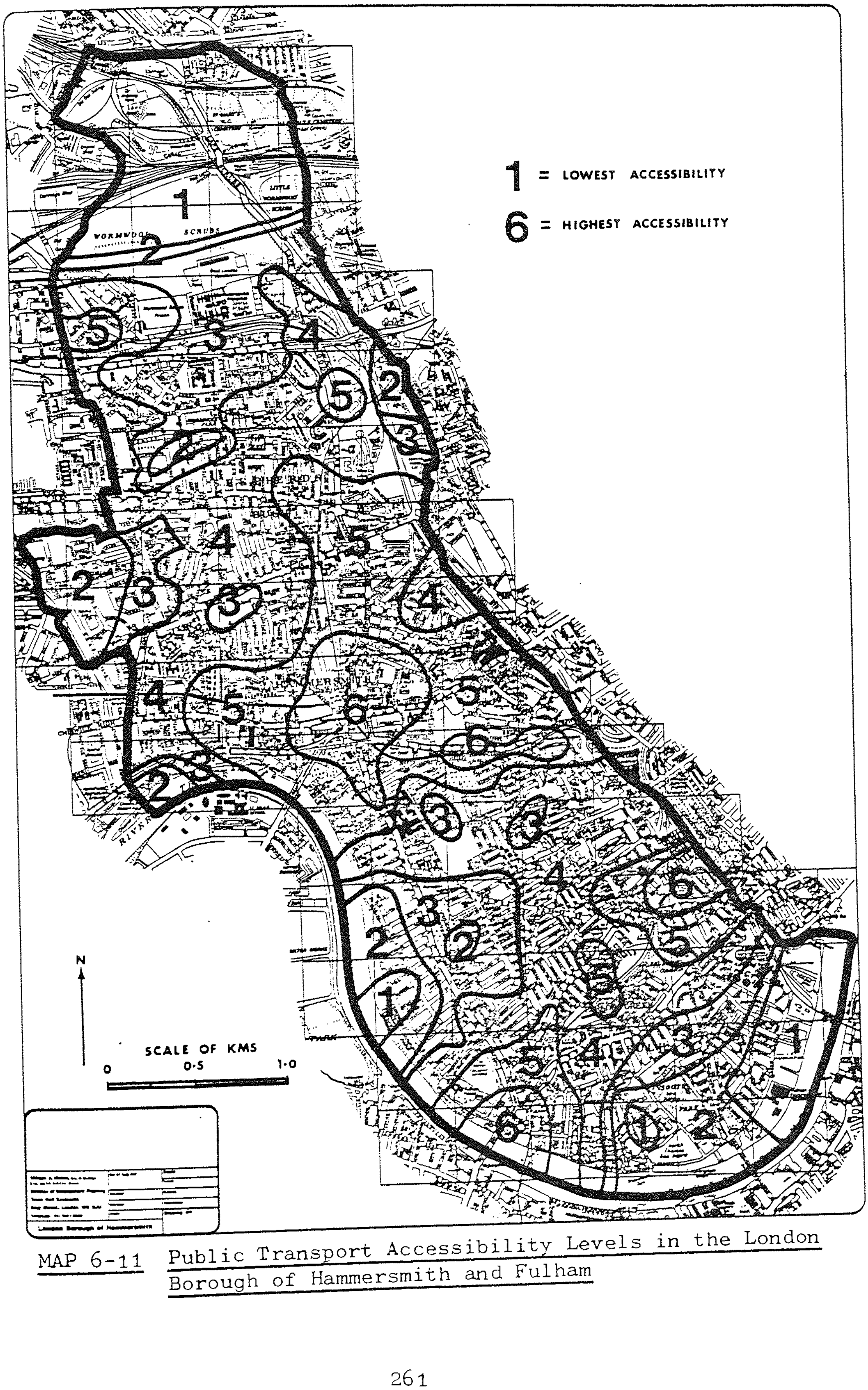


MAP 6-10 Major Land-Use Constraints on the Pedestrian Network in the London Borough of Hammersmith and Fulham

south of the Borough and the railway to the north and east of the Borough). Moreover, these results for accessibility of the elderly to post offices tend to be consistent with the results of a recent study undertaken by the London Borough of Hammersmith and Fulham (Dallal, 1980) showing the availability of public transport by area (Map 6-11). In both studies the Sands End, College Park, Old Oak and Crabtree areas of the Borough are seen to be relatively accessibility disadvantaged.

Although certain parts of the Borough are identified as having low accessibility to post offices relative to other parts of the Borough it is likely that these accessibility levels are considerably higher than the national average and probably compare well against other urban areas. However, relative to other zones in the London Borough of Hammersmith and Fulham, these zones have low accessibility. Also, given that any change in transport and land-use designed to improve the accessibility levels of the elderly in these zones is likely to involve the redistribution of resources within the Borough then the accessibility of zones relative to other zones within the local authority area is felt to be the most appropriate form of comparison and basis on which to assess 'poor' accessibility.

The improvement of accessibility to post offices in these areas may be derived through transport or land-use policies. With reference to the functions of the London Boroughs as outlined



MAP 6-11 Public Transport Accessibility Levels in the London Borough of Hammersmith and Fulham

in Chapter Five (pp 162-3) it is evident that the London Borough of Hammersmith and Fulham has limited control over the provision of transport services. The Borough's public transport accessibility study (Dallal, 1980) indicates that there is scope for increased public transport provision in the low accessibility areas. However, given that 95% of the study population have access to at least one post office within 650m (one-way distance) then the reliance on public transport for this trip-purpose even by the elderly is likely to be small. It is suggested then that alternative transport policies at a local level may be more effectively pursued.

Firstly, in view of the fact that physical land-use constraints to movement appear to be a major influence on the accessibility levels (as measured in this research), then the reduction in the ratio between straight-line distance and pedestrian network distance through a variety of pedestrian management measures may be a cost effective as well as a policy responsive option for improving accessibility. For instance, pedestrian access is severely constrained by the British Rail lines to the north and east of the Borough and by the West Cross Route (see Map 6-10). Secondly, the Local Authority may encourage, sponsor and co-ordinate voluntary and community transport schemes that are able to operate at a more local level and that are able to provide assistance for those elderly persons with relatively poor accessibility to the post office (and other local facilities) and/or mobility problems.

As regards land-use planning the Borough may exercise a certain degree of influence over the location of local facilities including post offices and grocers through the design and implementation of local plans and, in a restrictive sense, through development control procedures (particularly as regards the change of use of premises). Whilst the provision of additional post offices within the low accessibility areas would obviously improve the accessibility levels of the elderly, it is not essentially a policy responsive option under the control of the Land Authority. Alternatively, the elderly's need for post office facilities may be reduced considerably if the distribution of pensions by alternative means proves to be a feasible option open to the General Post Office.

Although the inclusion of the potential to link post office trips (with grocer trips) in accessibility measurement has been shown to have little influence on the rankings of zones by accessibility level, its potential utility as a means of improving accessibility cannot necessarily be rejected. The profiles formulated in this study show that linked trip accessibility levels for post offices and grocers are approximately 30% higher than the corresponding single-purpose trip accessibility levels and for zones six and twenty-two the percentage improvement in accessibility from linking trips is 37% and 42% respectively.

In order to establish the extent to which accessibility levels can be increased by trip linking it is necessary to determine the incidence, nature and distribution of linked trips amongst individuals with different levels of accessibility (see Chapter

Seven). Further investigation and understanding of linked trip-making may reveal that accessibility levels to post offices can be improved by locating facilities in relation to other facilities (for instance, grocers) or by planning public transport with regard to multi-purpose rather than single-purpose trip structures.

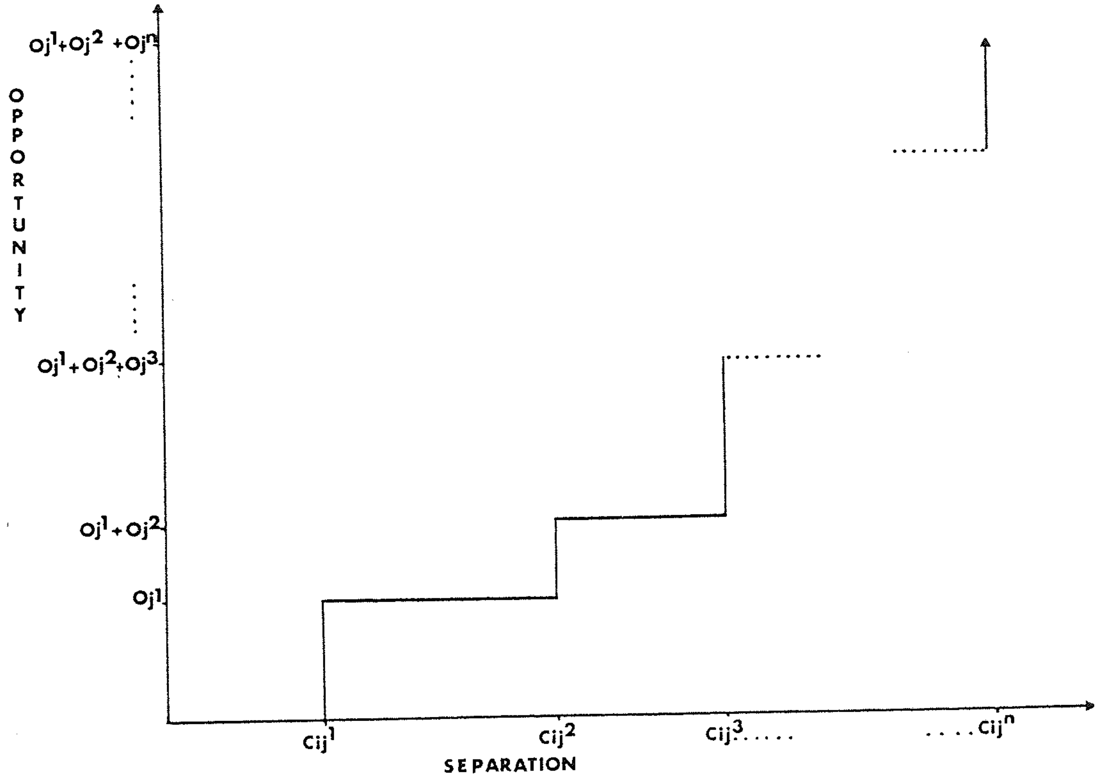
6.8. THE IMPLICATIONS OF THE RESULTS FOR ACCESSIBILITY MEASUREMENT

The above analysis, in examining the sensitivity of accessibility levels to valuation, aggregation and trip structure can be interpreted as having a number of implications for accessibility measurement in general as well as, in a practical context, for the accessibility of the elderly resident in the London Borough of Hammersmith and Fulham to local facilities. Clearly, the importance of the valuation, aggregation and interpretation of the accessibility information is dependent on its intended application and must, therefore, be assessed within this context (for example, in the context of this research changes in the rank order of zones are appropriate indicators). However, a broad indication as to the importance of valuation and aggregation procedures and the inclusion of linked trip data for accessibility measurement in general can be derived from the above analysis.

It is indicated that, on the basis of the accessibility profile information, the valuation stage in terms of deciding which cross-section of the profile is most relevant is an important determinant of the final accessibility level. The comparative approach to accessibility, as has been shown by the preceeding analysis, enables different sections of the profiles to be utilised in obtaining single accessibility scores for each zone. However, accessibility measures that assume only one point of the profile to be relevant either by establishing separation, opportunity and/ or population cut-offs beyond which point the availability of opportunity assumes zero value or by setting a standard valued as being the critical point of the profile, are heavily dependent on the validity of these, often arbitrary, valuation assumptions. The sensitivity of accessibility levels to these valuation assumptions is dependent on the shape of the profiles relative to the shape of the profiles for other zones. This form of valuation is, perhaps, justifiable only where a cut-off point or standard exists in statutory or policy terms (for example, the requirement of local authorities to provide school transport for children living further than 3 miles (2 miles for children under eight) from the nearest school).

The valuation and aggregation procedures investigated above are also integral to the formulation of composite indices of accessibility, however, unlike the comparative profiles, additional valuation and aggregation assumptions are implicit within these composite measures. In the majority of composite indices, including gravity based models, the location of opportunities (trip attractions) and the population (trip generations) is taken as an average for the zone. In this situation the availability of opportunity from each zone and the separation measures between the zones may be represented in a profile form but simply at a more aggregate level. For example, the accessibility for zone i may be plotted as shown in Figure 6-30.

Composite measures of accessibility such as the Hansen-type index are derived from combining the separation and opportunity dimensions of accessibility, thus, necessitating the relative



Where: Cij^n = the travel disutility between zones i and j^n; and

Oj^n = the opportunity available at zone j^n

FIGURE 6-30 The Potential Availability of Opportunity from Zone i Expressed in a Profile Form valuation of each component. The use of decay functions enables the utility of increasing opportunity with distance to be valued. Referring to the accessibility profiles this implies that separation (or opportunity) is expressed on a non-linear scale and, thus, distorts the shape of the curve. Given that the results of the rank order comparisons indicate that accessibility is sensitive to the decision (value judgement) as to which part of the profile is most relevant, then it is inferred that accessibility is also sensitive to the value judgement as to relative weightings attached to the measurement scales of separation and opportunity.

The combination of the profile dimensions as in the Hansen index involves, for each zone, multiplying the opportunity available in each of the other zones by the average separation. With regard to the accessibility profiles this implies that for different points of the profiles the separation and opportunity units (that is, distances from the origin on the vertical and horizontal axes) are multiplied and summed to give a final accessibility score. Clearly, the accessibility score is dependent on the shape of the curve and, hence, the relative importance (value) of the utility of increasing opportunity with distance. Alternatively, the intervening opportunities approach to accessibility is based on the assumption that the probability that a trip is of a certain travel disutility is dependent on the availability of opportunity within this travel disutility. Therefore, by valuing the opportunity and separation dimensions to the profile by expressing them on a non-linear scale the probability that a trip is of a certain level of travel disutility can be calculated. It is evident, then, that whilst different types of indices are compiled using different methods, the basic information is essentially comparable and can be presented in modified profile form. Irrespective of the additional assumptions made in deriving composite indices the same types of valuation decisions as utilised in interpreting the accessibility profile information earlier in this chapter are encountered in one form or another.

As regards aggregation procedures, the above analysis shows that the use of zones in accessibility analysis either as a means of averaging individual accessibilities or averaging locations and, hence, the measure of accessibility may distort and conceal the accessibility levels of individuals within the zone. For instance, for the London Borough of Hammersmith and Fulham the variance in the accessibility of the elderly to local facilities within zones is almost as large as the variance in the average accessibility levels between zones. It is inferred, therefore, that accessibility is potentially sensitive to aggregation and that the larger the averaging assumptions (for example, the zone size) the greater the margin of error. Any form of accessibility study that involves averaging or aggregating to a zonal level is liable to distort information, the extent of which depends on the zone size relative to the level of separation, and the extent of the non-uniform spatial distribution of individuals within the zone. The zone size influences the skewness and variance of the distribution of individual accessibilities within the zone which, in turn, increases the sensitivity of accessibility levels to both valuation and aggregation. Moreover, in all types of accessibility index it is important to take cognisance of the margin of error (and its implications for the accessibility study) involved in estimating the average accessibility for a zone from a sample of the population or, as in the case of more aggregated and large scale studies, in averaging the location of trip origins and destinations.

Despite there being little significant difference in rank order, the comparison of accessibility levels for linked trip and single-purpose trip structures reveals that, on the evidence of this study, substantial improvements in accessibility can potentially be gained by linking trips. The failure of other indices to take account of this potential either by not disaggregating trip-purposes or by making assumptions about trip origins and destinations has important implications for accessibility measurement as a whole. These implications are discussed in relation to further investigations into trip structures in Chapter Seven.

6.9. SUMMARY AND CONCLUSIONS

i) Accessibility profiles comprising network distances, the number of facilities and the proportion of the sampled zonal population having access to a specified number of facilities were formulated showing the availability of opportunity from linked trip as well as home-based trip measurements. The data presented in these profiles provides the basic accessibility information for each zone and forms the basis on which to investigate the sensitivity of accessibility to valuation, aggregation and trip-structure.

ii) Numerous different interpretations of profiles exist, varying by the types and levels of aggregation used. The choice of the most appropriate interpretation depends on the intended application of the results and a degree of subjective assessment or political input. Guidelines, however, can be used in determining this interpretation and by presenting accessibility information in a comparative, disaggregated form, the sensitivity of different interpretations can be made explicit by expressing values in terms of standards and by plotting the distribution of individual accessibilities within the zone.

iii) Within the practical context of the research, the hypothesis that accessibility levels vary with the use of different values and levels of aggregation is felt to be most appropriately tested by comparing the rank order of zones. The statistical significance of changes in rank order is measured in terms of the Spearman rank correlation coefficient and reveals a positive correlation between all relevant rank order comparisons, statistically significant at least at the 95% level. However, this statistical measure of correlation is sensitive to the number of pairs of rankings and, whilst providing, a broad indication of the extent of the correlation between the rank orders as a whole is limited in its ability to identify a large change in rank order for particular zones. Further analysis relevant to the practical and policy context of the research is, therefore, undertaken by identifying those zones that change by more than seven places (one third of the rank order) representing a change between the three fundamental categories of below average, average and above average accessibility.

iv) Alternative separation, opportunity and population standards representing value judgements as to the most relevant cross-section of the accessibility profiles enable the information contained in the profiles to be expressed as a single accessibility score. It is apparent that the margin of change in rank order for comparisons between different levels of the same type of standard and between standards is dependent on the extent to which the point of the profile at which accessibility information is derived is representative of the curve as a whole. Greater variation in rank order arises from varying the level of separation standard as opposed to opportunity and population standards whilst fewer significant changes in rank order occur in comparing different types of standard. It is concluded, therefore, that in measuring accessibility it is more important to determine the relevant cross-section of the profile rather than the units in which accessibility is expressed.

v) The analysis of the aggregation process inherent in deriving accessibility indices indicates the danger of placing too great a reliance on single unit accessibility levels and shows the extent to which measures based on samples are only estimates of the true level of accessibility. The margin of error (within a 95% probability) associated with estimating the distance to the nearest post office is over 10% either side of the mean for four zones leading to potential changes in rank order of at least five places.

vi) The aggregation of data to produce zonal measures conceals the distribution of individual accessibilities within the zone. Depending on the level of skewness of this distribution and the variance from the mean the relatively low accessibility incident to a minority of the population in certain zones is overlooked. Also, in producing zonal measures of the average accessibility to local facilities the zone size is such that the variance of individual accessibilities within the zone is almost equal to the variance between the zones.

Clearly, whilst aggregation is often a necessary step in accessibility measurement, irrespective of the type of index, it is important to realise the limitations and inaccuracies involved and, more significantly, their bearing on the utility of the accessibility results.

vii) The hypothesis that rank orders vary between single-purpose and linked trip accessibility measurements is not supported using the Spearman rank correlation coefficient on the evidence provided by the accessibility profiles. Again, there is a statistically significant positive correlation between the rank orders. Certain zones do, however, change markedly in rank order due either to a relatively high or low potential to link trips. For the Borough as a whole, as indicated by the accessibility profiles, linked trip accessibility levels are potentially on average 30% higher than for single-purpose trip accessibility levels. The extent to which this potential increase in accessibility is realised by individuals can be analysed only by undertaking further investigation of travel patterns and trip structures.

viii) By adopting a range of interpretations of the accessibility profiles, those zones that are ranked consistently high or low can be identified as representing areas of high and low accessibility relative to other areas of the Borough. The Sands End, Crabtree and Avonmore areas are subsequently shown to have 'poor' accessibility for the elderly to post offices and may warrant particular attention in determining future transport and land-use policies for the Borough.

ix) On the evidence of the information presented in this chapter, it is suggested that accessibility levels in those areas shown to have poor accessibility may be improved by making changes to the provision of post office facilities, the availability of services provided by post offices, the provision of public transport and, perhaps, more usefully, the pedestrian network. In addition and, perhaps, most significantly, accessibility levels may also be improved by increasing the potential travel savings arising from trip linking.

x) The results of the analysis of the rank order comparisons have implications for accessibility measurement in general. The basic accessibility information utilised in formulating composite as well as comparative accessibility indices can be expressed in a profile form but is open to different interpretations through various valuation and aggregation procedures. The valuation of the profile information is dependent on determining the measurement scales of the profile dimensions and the most relevant cross-section(s) of the profile. The rank order analysis earlier in this chapter suggests that for certain zones the final accessibility score is sensitive to these value judgements.

xi) The extent to which individuals can improve their potential accessibility levels by linking trips can only be determined by investigating the travel behaviour of individuals with different accessibility characteristics. The results of a behavioural travel survey of selected individuals form the basis of the proceeding chapter and, in the light of this further investigation, a better understanding of the role of linked trips in accessibility measurement can be acquired.

CHAPTER SEVEN

INVESTIGATING LINKED TRIP-MAKING

7.1. INTRODUCTION

The interpretation of the above accessibility profiles and, more specifically, the accessibility level afforded by trip linking is dependent on understanding the nature and incidence of linked trip-making.

As indicated in Chapter Six, the inclusion of the potential to link trips in the measurement of the accessibility of the elderly to post offices does not change the rank order of zones significantly. However, this may be true only of the data analysed in this research and it is conceivable that trip linking in other areas and for other trip purposes may show more significant changes in accessibility levels. Moreover, the actual appropriateness of the measurement of accessibility from non-home origins may take various forms depending, for instance, on the journey structures of individuals, the constraints on potential opportunities, the incidence and reasons for linking trips and their distribution between individuals with different levels of accessibility.

In order to clarify the importance of linked trip-making in accessibility measurement and to suggest ways in which comparative profiles may be adapted to encompass potential opportunity from non-home based origins, not only for post offices and grocers trips but for other trip purposes, a survey of travel behaviour was undertaken. Three hypotheses were developed, as outlined in Chapter Five, with the purpose of answering three questions about travel behaviour:-

i. What proportion of trips are linked?

ii. Who links trips?

iii. Why do people link trips?

The hypotheses, therefore, address these questions by investigating:-

i. The incidence of linked trip-making. Hypothesis (H.3.) - a significant proportion of trips are multi-purpose and, hence, are linked with trips to other facilities.

ii. The distribution of linked trips between individuals with different levels of accessibility. Hypothesis (H.4.) - persons with low accessibility are more likely to link trips than persons with high accessibility.

iii. The rationale for linked trip-making. Hypothesis (H.5.) - persons with high potential distance savings from linking trips are more likely to link trips than persons with low potential distance savings.

7.2. METHODS OF INVESTIGATION

In order to test hypotheses H.3., H.4. and H.5. information on the elderly's travel patterns is required. In relation to the practical context of the research the following methods of investigation are pursued (as outlined in the experimental design, Chapter Five).

H.3. The incidence of linked trip-making is tested by calculating, for a sample of the elderly population, the proportion of trips to post offices that are linked with other activities.

H.4. The distribution of linked trips between individuals with different levels of accessibility is investigated by calculating the difference in the incidence of linked trip-making between a sample of elderly persons with low accessibility to the nearest post office and a sample of elderly persons with high accessibility to the nearest post office. A null hypothesis stating that there is no difference in the incidence of linked trip-making between the two samples is tested using Chi-squared analysis (as described in Appendix D). The results reveal the percentage probability that the inverse of the null hypothesis is correct within specified confidence limits. Accessibility to post offices is measured from the same data utilised in developing the zonal accessibility profiles in Chapter Six and is defined as the network distance to the nearest facility on the assumption that choice is not an important criterion in selecting which post office to visit. The validity of this assumption is supported by the survey results (see later text).

H.5. The rationale for linked trip-making is investigated by calculating the difference in the incidence of linked trips between a sample of elderly persons with a low potential distance saving from linking trips and a sample of elderly persons with a high potential distance saving from linking trips. Similarly, the null hypothesis stating that there is no difference in the incidence of linked trips between the two samples is tested using Chi-squared analysis. Potential distance saving from linking trips is defined initially as the difference between the shortest linked trip to a post office and grocers and the sum of the shortest two separate single-purpose trips to a post office and grocer.

7.3. SURVEY DESIGN

With reference to the experimental design outlined in Chapter Five and given the methods of testing hypotheses H.3., H.4. and H.5. a sampling frame, the sample size and the data requirements were determined.

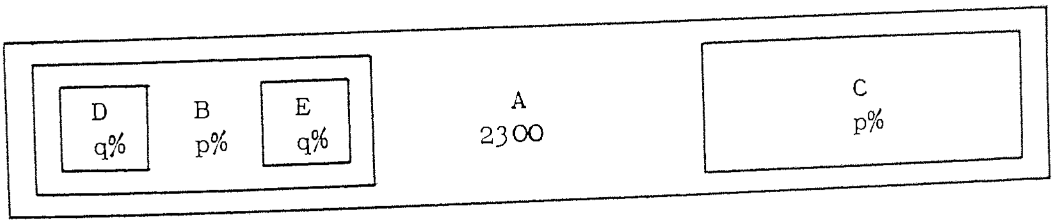
7.3.1. Sampling Frame

A sub-sample from the 2300 individuals identified in formulating the accessibility profiles is required for testing each of the three hypotheses (H.3., H.4. and H.5.). By identifying the degree of possible overlap between the samples required for testing each hypothesis, the total sample size required was reduced to a minimum. Hypothesis H.3. requires a sample of elderly persons representative of the Borough as a whole. Hypothesis H.4. requires a sample of elderly persons identified as having low accessibility to the post office and a sample of elderly persons identified as having high accessibility to the post office. Alternatively, hypothesis H.5. requires a sample of elderly persons identified as having low potential distance saving from linking trips and a sample of elderly persons identified as having a high potential distance savings from linking trips.

Given the definitions of accessibility and potential distance saving then it is recognised that, by way of these definitions, those individuals with high accessibility do not have high potential distance savings (in that the maximum potential distance saving is equal to the return trip distance to the post office). Moreover, in testing the relationship between potential distance saving and linked trip-making it is necessary, assuming there to be some evidence to support hypothesis H.4., to control for the influence of accessibility on linked trips. The two samples of high and low potential distance saving groups were, therefore, drawn from within the sample of the low accessibility group.

The low and high accessibility groups were defined as the extreme p percentiles of the original sample of 2300 individuals and, in turn, low and high potential distance savings groups were defined as the lowest and highest q percentiles of the low accessibility group. The calculation of p and q was determined with reference to the distributions of accessibility levels and potential distance savings (see Appendix I).

The sampling frame can be represented diagrammatically as shown in Figure 7 - 1.



Where: A = the total sample used in formulating the accessibility profiles;
B = individuals defined as having low accessibility to post offices;
C = individuals defined as having high accessibility to post offices;
D = individuals defined as having a low potential distance saving;
E = individuals defined as having a high potential distance saving.

FIGURE 7 - 1 The Sampling Frame for Testing Hypotheses on the Incidence and Nature of Linked Trip-Making.

The hypotheses are tested using random samples from the following sets as specified in the sampling frame (Figure 7 - 1).

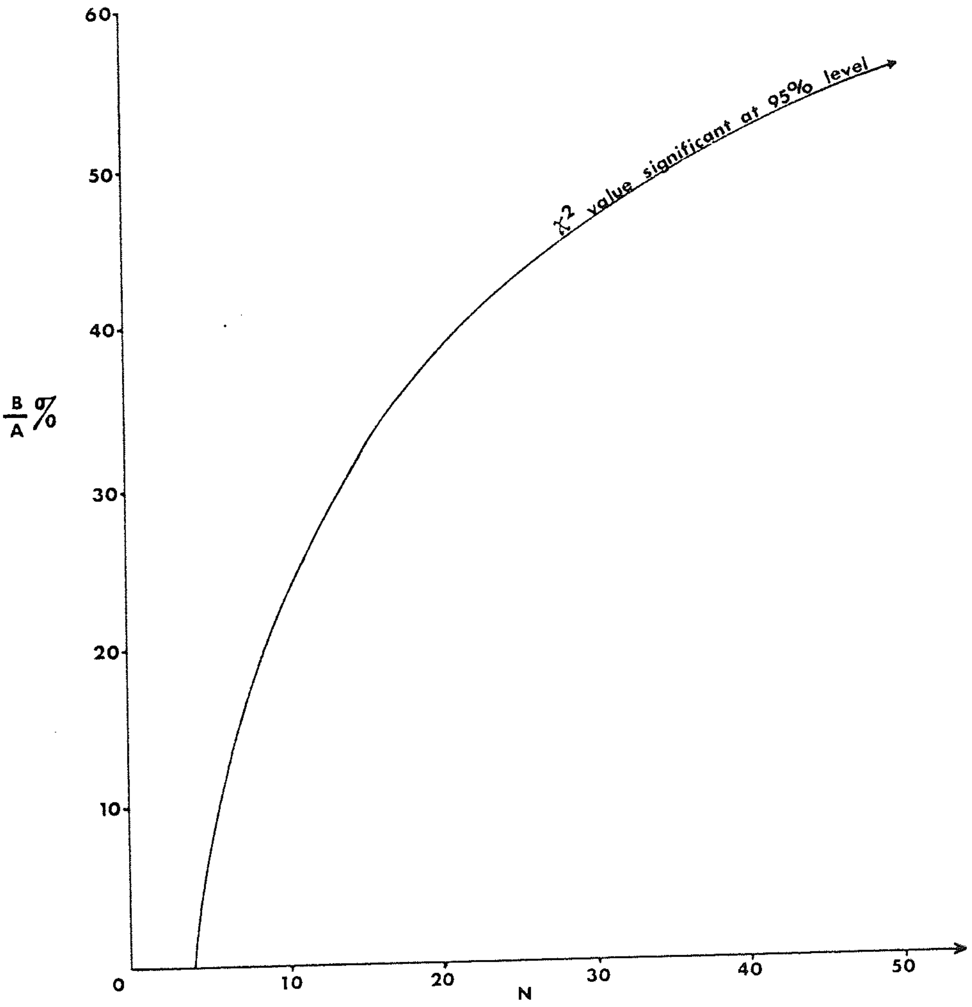
Hypothesis One - C,D,E
Hypothesis Two - D,E compared with C
Hypothesis Three - D, compared with E

7.3.2. Sample Size

With reference to the sample frame it is evident that information on the elderly's travel patterns is required for three groups of individuals:

- persons with high accessibility to post offices (C);
- persons with low accessibility and low potential distance savings (D); and
- persons with low accessibility and high potential distance savings (E).

The sample size for each group was determined according to the statistical analysis (Chi-squared) and the practical limitations. The Chi-squared value for hypotheses H.4. and H.5. is dependent on the difference in trip structure between the two samples and the sample size. Figure 7 - 2 shows that by increasing the sample size the percentage difference between the incident of linked trips in the two samples (assuming the two samples to be equal) necessary to maintain χ^2 at a significance level of 95% is reduced. For a small sample a marginal increase in the sample size leads to a relatively large fall in the percentage difference between the two samples necessary to maintain χ^2 at the same significance level. For a larger sample the marginal increase in the sample



Where: N = Sample size

$\frac{B}{A}$ % = the incidence of linked trips in sample group B as a % of the incidence of linked trips in sample group A; and assuming 50% of trips to be linked:

A+B = $\frac{N}{2}$

FIGURE 7 - 2 The Influence of Sample Size on χ^2

leads to a relatively small percentage difference in the incidence of linked trips between the two samples necessary to hold X^2 at a constant value. As the sample size increases, therefore, an insignificant X^2 value is more likely to be due to the proportions of the independent variable (that is linked trips) between the two samples rather than the sample size. Given the limited resources available for data collection and in order to avoid collecting more data than is necessary for testing the null hypothesis that there is no difference in the incidence of linked trip-making between two sample groups, the sample size was taken as the point at which the marginal decrease in the percentage difference in the frequency of linked trips between the two samples that retains X^2 at the 95% significance level is less than the marginal increase in the sample size. On this basis the sample size was taken as approximately 25 individuals for each hypothesis (see Figure 7 - 2).

However, in testing hypotheses H.4. and H.5. it is necessary to control for factors that may influence the independent variable (linked trips) other than accessibility and potential distance saving and adjust the sample size accordingly. The following factors were considered to have a possible bearing on travel patterns and trip structures.

a) <u>Disability</u>

This was considered to be significant where individuals are totally housebound or where they have to forego participating in certain activities due to their physical disability or ill-health. A recent study on the mobility of old people shows that approximately 11% of old people are immobile (Hopkin et. al., 1978b) and Moseley (1979) indicates that approximately 25% of the elderly have serious difficulty in physically moving. It was felt, however, that the percentage of disabled elderly persons in the survey sample could be assumed to be lower, in that the sample includes only those persons living alone or with other elderly persons. Disabled persons requiring health-care are more likely to be living either with families or in institutions. Therefore, on the educated assumption that the proportion of disabled elderly persons was likely to be small, they were controlled out of the statistical analysis and the sample size adjusted accordingly. Hence, hypotheses H.3., H.4. and H.5. are tested for elderly persons able to undertake trips to the post office and other facilities.

b) Household Structure

This was considered to be important where some trips are undertaken by other members of the household for the elderly person in question. In this instance, the incidence of linked trip-making may be reduced by the ability of old people to delegate trips and activities to other household members which effectively reduces their out-of-home activity requirements. Household structure was controlled out of the sample to some extent in that only elderly persons living alone or with other elderly persons are included in the sample. Household structure was considered, therefore, unlikely to have a significant bearing on linked trip-making. On the basis that the distribution of sampled individuals between these two categories was approximately equal and by assuming that they were distributed equally between the high and low accessibility groups then the need to control any further for household structure was largely eliminated. The validity of this assumption is supported by the results of the survey of travel patterns (see section 7.3.2.).

c) Car Availability

It was considered likely that car availability has a significant influence on the incidence of linked trip-making. In order to test this it was necessary to stratify the sample and test the hypothesis with two levels of car availability (that is, car available and no car available). However, given that car-ownership for the elderly is between 10% and 20% (Hopkin et. al., 1978a and Hillman et. al., 1976), then the relationship between accessibility and linked trip-making can be tested principally for persons (the large majority) in the no car available category. The sample size required was, therefore, increased by 20% to take account of car availability.

d) Income

It was assumed that, whilst income may have an influence on the mobility of individuals and the ability to participate in certain discretionary activities, there was no need to control for it separately as its influence on the incidence of linked post office trips is reflected in car availability.

e) Age

The importance of age in terms of linked trip-making was assumed to be reflected in mobility which is already accounted for by the variables disability and car availability.

f) Occupation

It is likely that a small proportion of the elderly population are still employed either on a part-time or full-time basis. This is likely to influence their activity patterns in that time is a more scarce resource than it is for retired persons and, hence, imposes greater constraints on their activity patterns. The Hammersmith Sample Census (London Borough of Hammersmith and Fulham, 1977) indicates that approximately 16% of persons over retirement age are in employment and, in view of this fact, economically active elderly persons were excluded from the statistical analysis and again the sample size adjusted accordingly.

In order to exclude disabled and employed persons and to control for car availability the sample size required for testing each hypothesis based on the estimated proportion of the sample that are housebound, employed or car owners was increased to 30 individuals. It is noted that it is not necessary for the sample size to be equal for the two categories of accessibility or the two categories of potential distance saving provided that there are at least the minimum (15 respondents) in each category. Therefore, given the overlap between the low accessibility sample and the potential distance saving samples (as outlined in section 7.3.1.) the total number of respondents required was estimated to be at least 45 distributed as follows:

Hypothesis H.3.	Hypothesis H.4.	Hypothesis H.5.
(45)	Low accessibility (30) High accessibility (15)	Low potential distance saving (15) High potential distance saving (15)

Due to the form of the sampling frame the low accessibility category is double the sample size of the high accessibility category.

Working on the basis of a 50% average response rate for in-home interviews and allowing for the fact that this response rate may be lower for any of the three sub-samples, 34 individuals were selected using random numbers from each of the three population sets specified in the sampling frame (that is a total of 102 persons). From this sample 70 persons were contacted and are distributed between the sets as follows:

Hypothesis H.3.	Hypothesis H.4.	Hypothesis H.5.
(70)	Low accessibility (48) High accessibility (22)	Low potential distance saving (20) High potential distance saving (28)

After eliminating those persons who did not visit the post office in the month previous to the interview for whatever reason and those persons in full or part-time employment, the sample for testing each of the three hypotheses was reduced to:

Hypothesis H.3.	Hypothesis H.4.	Hypothesis H.5.
(59)	Low accessibility (39) High accessibility (20)	Low potential distance saving (16) High potential distance saving (23)

7.3.3. Data Collection

In order to test the three hypotheses, household interviews were undertaken providing information on the travel and activity behaviour of elderly persons selected in the random sample. The highest possible response rate was ensured by circulating letters, a few days prior to the interviews being conducted, informing the respondents of the purpose of the study.

Whilst a travel diary technique was considered capable of providing more detailed and accurate information on journey structures, it was felt that a questionnaire asking individuals to recollect their most recent journey to the post office and grocer and to describe their usual travel behaviour when visiting these facilities would be more cost effective given the time and resources available for conducting the interviews and the precise use of the data in analysing linked trip behaviour. The questionnaire approach can also be justified on the basis that the facilities of interest tend to be visited frequently and, hence, regular journey patterns are normally established (as supported by the survey results).

A small pilot study of 6 interviews was conducted in order to determine the precise form of the questionnaire. Five sections to the questionnaire were subsequently compiled providing information on:

- Part A Activity Requirements and Constraints - identifies non-trip makers who are either disabled or who have someone who makes the trip(s) on their behalf.
- Part B Personal and Household Characteristics - identifies those persons in employment and categorises the sample by car availability and household structure.
- Part C Usual Travel Patterns - Post Offices - provides information on trip frequency, location of facility, mode of transport and journey structure.
- Part D Usual Travel Patterns - Grocers - provides information on trip frequency, location of facility and mode of transport.
- Part E Journey Structure - Most Recent Post Office Trip - provides information on location of facility, mode of transport and specific details of journey structure.

The full questionnaire and the letter circulated prior to the interviews being undertaken are contained in Appendix J.

7.4. SURVEY RESULTS AND ANALYSIS

The interview survey of the elderlys' travel patterns and trip structures provides the data necessary for testing the three hypotheses (H.3., H.4. and H.5.). Before analysing (testing) these hypotheses the composition of the sample in terms of the personal and household characteristics of the respondents are summarised and the validity of the assumptions about travel behaviour implicit in formulating the hypotheses are examined.

7.4.1. Composition of the Sample

A total of 70 elderly persons were contacted in the survey of which 9 did not visit the post office in the month prior to the interview. Out of these only one person actually stated disability or ill-health as the reason for this and all nine indicated that a friend or relation made the trip for them. A further six persons stated that they did not normally participate in doing the main food shopping for the household and in these cases home-helps or the husband/wife made the trip instead.

The distribution of respondents between the two categories of household structure (that is, single person households and family households) is approximately equal as is the distribution for the total sample used in formulating the accessibility profiles. Of the 15 respondents not making trips to the post office or grocers, six lived in single person households whilst, of the remaining nine respondents, eight stated that their husband or wife undertook the trip purpose on their behalf.

Out of the total number of respondents who were recorded as making post office trips (61), 59 were retired and 2 were engaged in full-time or part-time work. This percentage is lower than the 16.6% given for elderly persons by the Hammersmith Sample Census (1977). However, this is likely to be due to the fact that the sample is drawn from only those elderly persons living alone or with other elderly persons and, hence, those persons who have recently reached retirement age but are still in employment and living in a family household are excluded from the survey.

7.4.2. The Validity of the Assumptions about Travel Behaviour Implicit in Formulating the Hypotheses.

In formulating the hypotheses about linked trip-making (as specified above) it is recognised that a number of assumptions are made regarding the travel behaviour of the elderly. Before discussing the results of the hypothesis tests it is necessary to examine the extent to which the questionnaire data supports or refutes the assumptions that:

- the elderly undertake frequent and regular trips to the post office and grocers and that every post office trip has the potential to be linked with a trip to the grocers;
- only 10 to 20% of the sample population have regular access to a car; and
- the majority of the trips undertaken by the elderly to the post office and grocers are made on foot.

a) Trip Frequencies

Tables 7 - 1 and 7 - 2 show the frequency with which the respondents normally visited the post office and grocer respectively. 68% visit the post office once a week whilst 80% do their main food shopping at least twice a week. It is likely that the post office trip frequencies coincide with the issue of state pensions. Whilst elderly persons are able to collect their pensions less frequently over 80%, according to the G.P.O., collect them on a weekly basis.

A comparison between post office and grocer trip frequencies (see Table 7 - 3) shows that 98% of the respondents do their main food shopping at least as frequently as they visit the post office. This supports the assumption implicit in formulating the third hypothesis that every trip to the post office can potentially be linked to visiting the grocers. It is also noted that, because of the differential trip frequencies, the reverse does not apply.

b) Car Availability

Table 7 - 4 reveals that approximately 20% of the respondents had regular use of a car during the day either as a driver or a passenger. In comparison with the figures given by Hopkin et. al. (1978a) and used in estimating the sample size necessary for testing hypotheses H.4. and H.5., this is slightly higher than expected. This is probably attributable to a small percentage of the respondents having the regular use of a friend's or neighbour's car (as a passenger) but not being car owners themselves. The figure indicates that, with the present sample size, the second

FREQUENCY	RESPONDENTS	
	No.	%
More than once a week	7	12
Once a week	41	68
Once a fortnight	10	17
Less than once a fortnight	2	3
	61	100

TABLE 7-1 Trip Frequency - Post Offices

FREQUENCY	RESPONDENTS	
	No.	%
More than twice a week	24	44
Twice a week	20	36
Once a week	11	20
Less than once a week	0	0
	55	100

TABLE 7-2 Trip Frequency - Main Food Shopping

FREQUENCY	RESPONDENTS	
	No.	%
Food Shopping > Post Office	45	82
Food Shopping = Post Office	9	16
Food Shopping < Post Office	1	2
	55	100

TABLE 7-3 A Comparison of Food Shopping and Post Office Trip Frequencies

	RESPONDENTS No.	 %
Car Available	12	20
Car not Available	49	80
	61	100

TABLE 7-4 Car Availability

TRIP TYPE	MODE NO. and % of RESPONDENTS WALK No.	 %	 CAR No.	 %	 BUS No.	 %	 CYCLE No.	 %	 TOTAL No.	 %
Post Office	51	83	6	10	4	7	0	0	61	100
Food Shopping	31	56	8	15	15	27	1	2	55	100

TABLE 7-5 Travel Mode

	P.O. TRIP STRUCTURE (NO. and % of RESPONDENTS) USUAL No.	 %	 MOST RECENT No.	 %
Linked Trip	34	58	34	58
Single-Purpose Trip	25	42	25	42
	59	100	59	100

TABLE 7-6 Post Office Trip Structure

LINKED TRIP TYPE	RESPONDENTS No.	 %
Shopping Trip (Non-grocer)	14	41
Grocer Trip	17	50
Other Trip	3	9
TOTAL	34	100

TABLE 7-7 Linked Trip Types

and third hypotheses can be statistically analysed when controlling for car availability within the non-car availability category. Further consideration is given to this later in the text.

c) Mode of Travel

The use of network distance as the measure of separation is justified on the evidence from past studies that a substantial majority of trips by elderly persons are made on foot. Table 7 - 5, whilst supporting this, shows that 83% of post office trips were made on foot compared with only 56% for food shopping trips. A significantly higher proportion of respondents travelled by bus to the grocers (27%) as compared with the post office (7%).

By cross-tabulating Table 7 - 4 with Table 7 - 5 it is shown that 50% of those persons having regular access to a car used it for post office trips whilst 67% used it for food shopping. The full implications of these results are discussed in relation to the testing of hypotheses H.4. and H.5. (see later).

7.4.3. The Incidence of Linked Trip-Making - Testing Hypothesis H.3.

Table 7 - 6 shows that, out of a total sample of 59 persons, 58% usually linked post office trips with other trip purposes and the same percentage (58%) linked their most recent trip. Further to this, Table 7 - 7 shows that out of those persons linking trips 91% usually linked post office trips to other

shopping facilities and 50% linked trips to the grocers.

In comparison with the limited results from previous research the proportion of linked trips indicated in this study is greater. For instance, Morris and Wigan (1979) show that, across all trip purposes, approximately 45% of trips are linked. However, this is thought to be attributable to the fact that, previous to this research, all shopping trips have been encompassed in the same trip-purpose category.

It is evident that from the results of this survey the incidence of trip-linking is a significant and, in fact, major proportion of post office trips. Whilst no data has been collected for other trip purposes it is apparent that, for at least certain types of trip, the assumption that all journeys are single purpose and, hence, home-based is false.

7.4.4. The Distribution of Linked Trip-Making Between Accessibility Groups - Testing Hypothesis H.4.

Table 7 - 8 shows the number of persons who usually linked trips to post offices grouped according to low or high accessibility to post offices. Table 7 - 9 shows the equivalent for the respondents' most recent post office trip. The difference in the distributions is minor and, therefore, it is assumed that the recollection of information by the respondent for usual travel behaviour is relatively reliable.

	ACCESSIBILITY		
	LOW	HIGH	TOTAL (No. of Respondents)
Linked Trip	26	8	34
Single Purpose Trip	13	12	25
TOTAL	39	20	59

$\chi^2 = 3.85$

Significance Level = 95%

TABLE 7-8 Usual Trip Structures by Accessibility Group

	ACCESSIBILITY		
	LOW	HIGH	TOTAL (No. of Respondents)
Linked Trip	25	9	34
Single Purpose Trip	14	11	25
	39	20	59

TABLE 7-9 Most Recent Trip Structure by Accessibility Group

Chi-squared analysis is applied to the information displayed in Tables 7 - 8 and, on the evidence of this (χ^2 = 3.85) it would appear that there is a significant difference in the incidence of trip linking between persons with low and high accessibility at the 95% level. It is necessary, however, to investigate the distribution of trip linking in relation to factors likely to influence journey structures other than accessibility. It will be recalled (section 7.3.2.) that the sample size is structured in order to investigate the incidence of trip linking between accessibility groups whilst controlling for the influence of car availability. Due to the low percentage of the population having regular access to a car the sample size is estimated with regard to the number of respondents required in order to investigate the relationship within only the non-car availability category. Hence, by elaborating the matrix according to car availability it is shown that, within the no car available category (Table 7 - 10), the χ^2 value is lower than for the aggregated matrix (Table 7 - 8) but the proportional difference between the categories is similar. The lower χ^2 value is due largely, therefore, to the reduction in the sample size. It is also worth noting that for the car availability category, whilst the incidence of linked trip-making appears to be biased in favour of the low accessibility group (Table 7 - 11), the χ^2 value is, as expected, lower, and insignificant due principally to the small sample size.

In order to investigate whether linked trip-making is significantly different between categories of car availability

	ACCESSIBILITY			
	LOW	HIGH	TOTAL (No. of Respondents)	
Linked Trip	19	7	26	
Single Purpose Trip	12	11	23	
TOTAL	31	18	49	$\chi^2 = 2.30$

TABLE 7-10 Usual Trip Structures by Accessibility Group for Elderly Persons Without Regular Access to a Car

	ACCESSIBILITY			
	LOW	HIGH	TOTAL (No. of Respondents)	
Linked Trip	7	1	8	
Single Purpose Trip	1	1	2	
TOTAL	8	2	10	$\chi^2 = 1.42$

TABLE 7-11 Usual Trip Structures by Accessibility Group for Elderly Persons with Regular Access to a Car

	CAR AVAILABILITY			
	YES	NO	TOTAL (No. of Respondents)	
Linked Trip	7	19	26	
Single Purpose Trip	1	12	13	
TOTAL	8	31	39	$\chi^2 = 1.96$

TABLE 7-12 Usual Trip Structures by Car Availability Group for Elderly Persons with Low Accessibility to Post Offices

	CAR AVAILABILITY			
	YES	NO	TOTAL (No. of Respondents)	
Linked Trip	1	7	8	
Single Purpose Trip	1	11	12	
	2	18	20	$\chi^2 = 0.09$

TABLE 7-13 Usual Trip Structures by Car Availability Group for Elderly Persons with High Accessibility to Post Offices

as well as accessibility, a further Chi-squared test was undertaken. Table 7-12 shows that, within the low accessibility category, car owners are more likely to undertake linked trips than non-car owners at only an 80% significance level ($\chi^2 = 1.96$). The χ^2 value for the same relationship within the high accessibility category (Table 7 - 13) is insignificant due principally to the lower sample size.

In summary then, it is evident that elderly persons with low accessibility to post offices are more likely to link trips to the post office with other activities. Before discussing the implications of these results, the hypothesis that linked trips are undertaken in order to reduce total travel disutility is investigated.

7.4.5. The Rationale for Linked Trip Making - Testing Hypothesis H.5.

As stated previously, the hypothesis that persons with high potential distance saving are more likely to make linked trips than persons with low potential distance saving is examined for the travel patterns to post offices and grocers within the sample of elderly persons identified as having low accessibility. The hypothesis is tested for alternative definitions of potential distance saving so that the travel choice decisions and the constraints on the travel patterns of the elderly are taken into account in identifying the true potential to reduce travel disutility by linking trips and, hence, in determining the correct relationship between potential distance saving and trip structure.

a) Testing Hypothesis H.5. with the Initial Definition of Potential Distance Saving (p.d.s^1)

Potential distance saving is defined initially for each individual (as outlined in the preceeding text) as the difference in network distance between the shortest linked trip to a post office and grocers and the sum of the two shortest single-purpose trips to the post office and grocers. Given that 67% of the sample population with low accessibility link trips, Table 7 - 14 shows how these are distributed according to whether the individual has a low or high potential distance saving. It is immediately obvious that the results do not provide any evidence to support the hypothesis and, in fact, the incidence of linked trips is biased in favour of those individuals with low potential distance savings! Controlling for car availability (Tables 7 - 15 and 7 - 16) fails to alter significantly the proportions of linked trips in each category.

In the light of these results, a re-examination of the hypothesis suggests that the above definition of potential distance saving is incorrect. Given that, from the results derived in testing hypothesis H.4., individuals with low accessibility to the nearest post office are more likely to link trips than individuals with high accessibility to the nearest post office then it is rational to assume that the reason for the bias in linked trip-making towards the low

	POTENTIAL DISTANCE SAVING (p.d.s^1) LOW	HIGH	TOTAL (No of Respondents)
Linked P.O. and Grocer Trip	9	7	16
Other P.O. Trip	7	16	23
TOTAL	16	23	39

TABLE 7-14 Trip Structures by Potential Distance Saving Group as Initially Defined (p.d.s1)

	POTENTIAL DISTANCE SAVING (p.d.s^1) LOW	HIGH	TOTAL (No. of Respondents)
Linked P.O. and Grocer Trip	1	2	3
Other P.O. Trip	1	4	5
TOTAL	2	6	8

TABLE 7-15 Trip Structures by Potential Distance Saving Group as Initially Defined (p.d.s1) for Elderly Persons with Regular Access to a Car

	POTENTIAL DISTANCE SAVING (p.d.s^1) LOW	HIGH	TOTAL (No. of Respondents)
Linked P.O. and Grocer Trip	8	5	13
Other P.O. Trip	6	12	18
TOTAL	14	17	31

TABLE 7-16 Trip Structures by Potential Distance Saving Group as Initially Defined (p.d.s1) for Elderly Persons Without Regular Access to a Car

accessibility group stems from the ability to reduce total network distance. Moreover, the definition of accessibility to post offices (that is, the distance to the nearest) is shown to be appropriate on the evidence of the travel survey in that the majority of respondents visit the nearest post office. The above potential distance saving measure is hypothesised, therefore, as being deficient due to the invalid assumption that individuals visit the nearest grocer (according to linked or single-purpose trips). The information contained in the completed questionnaires supports this by showing that individuals tend to visit grocers at more distant locations and in particular major shopping centres. Assuming the potential distance saving definition to be incorrect, the Chi-squared test is re-applied using alternative definitions.

b) Testing Hypothesis H.5. with Potential Distance Saving Constrained by the Actual Grocer Visited (p.d.s.^{2})

Potential distance saving is re-defined as the difference in network distance between the sum of the single-purpose trips to the nearest post office to the home and the grocer actually visited and the shortest linked trip involving any post office and any grocer actually visited. In this instance, the potential distance savings are relatively large due mainly to the fact that elderly persons travel further to the grocers than implied by the original definition of potential distance saving. Taking low potential distance to be 700m or less, and high potential distance saving to be 1200m or more, a marked difference in the distribution of linked trip-making biased towards the high category is revealed with the χ^2 value being significant at the 98.0% level (see Tables 7 - 17). By controlling for car availability the χ^2 value increases slightly (see Table 7 - 18).

It is suggested, then, on the evidence of this analysis, that the potential distance saving from linking trips is an important determinant of the trip structure. As noted before, however, the questionnaire answers reveal that the large majority of elderly persons visit the nearest post office to their residential location and, hence, do not necessarily take advantage of the full potential distance saving as re-defined above. In more precise terms individuals, whilst linking trips, are not necessarily undertaking the shortest linked trip involving the grocer actually visited and, thus, a further definition of the distance saving is derived.

c) Testing Hypothesis H.5. with Potential Distance Saving Constrained by the Actual Grocer Visited and the Nearest Post Office (p.d.s.^{3})

Potential distance saving is re-defined for a second time as the difference between the sum of the single-purpose trips to the nearest post office (to the residential location) and the grocer actually visited and the linked trip to the same grocer and post office, thus, holding the locations constant and simply varying the trip structure. Again, taking low potential distance saving to be 700m or less and high potential

	POTENTIAL DISTANCE SAVING (p.d.s^2)		
	LOW	HIGH	TOTAL (No. of Respondents)
Linked P.O. and Grocer Trip	0	17	17
Other P.O. Trip	5	12	17
All types of P.O. Trip	5	29	34

χ^2 = 5.86 Significance Level = 98.0%

TABLE 7-17 Trip Structures by Potential Distance Saving Group (Constrained by the Actual Grocer Visited)(p.d.s^2)

	POTENTIAL DISTANCE SAVING (p.d.s^2)		
	LOW	HIGH	TOTAL (No. of Respondents)
Linked P.O. and Grocer Trip	0	13	13
Other P.O. Trip	5	8	13
All types of P.O. Trip	5	21	26

χ^2 = 6.19 Significance Level = 98.0%

TABLE 7-18 Trip Structures by Potential Distance Saving Group (Constrained by Actual Grocer Visited)(p.d.s^2) for Elderly Persons Without Regular Access to a Car

	POTENTIAL DISTANCE SAVING (p.d.s^3)		
	LOW	HIGH	TOTAL (No. of Respondents)
Linked P.O. and Grocer Trip	3	14	17
Other P.O. Trip	14	6	20
All types of P.O. Trip	17	20	37

χ^2 = 10.14 Significance Level = 99.5%

TABLE 7-19 Trip Structures by Potential Distance Saving Group (Constrained by the Actual Grocer Visited and the Nearest P.O.) (p.d.s^3)

	POTENTIAL DISTANCE SAVING (p.d.s^3)		
	LOW	HIGH	TOTAL (No. of Respondents)
Linked P.O. and Grocer Trip	1	11	12
Other P.O. Trip	12	3	15
All types of P.O. Trip	13	14	27

χ^2 = 8.58 Significance Level = 99.5%

TABLE 7-20 Trip Structures by Potential Distance Saving Group (Constrained by the Actual Grocer Visited and the Nearest P.O.)(p.d.s^3) for Elderly Persons Without Regular Access to a Car distance saving to be 1200m or more an even greater difference in the distribution of linked trips between the two groups is observed (see Table 7 - 19). In this case the χ^2 value is significant at the 99.5% level due partly to the more even balance between the number of cases in the potential distance saving categories. By controlling for car availability the χ^2 value is lower (see Table 7 - 20) due principally to the lower sample size. Given that not all the sample population visit the nearest post office,a fourth definition of potential distance saving is utilised in testing hypothesis H.5.

d) Testing Hypothesis H.5. with Potential Distance Saving Constrained by the Actual Grocer and Post Office Visited (p.d.s.^{4})

Further analysis is undertaken by replacing the measure of potential distance saving with a measure of actual distance saving, that is, the difference in the network distance between the sum of the single-purpose trips to the grocer and the post office actually visited and the linked trip to the same grocer and post office. Given that, from the survey results, the majority of the sample population visit the nearest post office to their residential location then a difference between the actual distance saving and the preceeding potential distance saving measure arises for only a small proportion of the sample population. A similarly significant χ^2 value is (in this instance, at the 99.9% level) therefore, derived (see Table 7 - 21). Moreover, when controlling for car availability (Table 7 - 22) the χ^2 value increases with the difference in

	POTENTIAL DISTANCE SAVING (p.d.s^4)		
	LOW	HIGH	TOTAL (No. of Respondents)
Linked P.O. and Grocer Trip	2	15	17
Other P.O. Trip	14	6	20
All types of P.O. Trip	16	21	37

$\chi^2 = 12.72$

Significance Level = 99.9%

TABLE 7-21 Trip Structures by Potential Distance Saving Group (Constrained by the Actual Grocers and Post Office Visited)(p.d.s^4)

	POTENTIAL DISTANCE SAVING (p.d.s^4)		
	LOW	HIGH	TOTAL (No. of Respondents)
Linked P.O. and Grocer Trip	0	12	12
Other P.O. Trip	12	3	15
All types of P.O. Trip	12	15	27

$\chi^2 = 17.26$

Significance Level = 99.9%

TABLE 7-22 Trip Structures by Potential Distance Saving Group (Constrained by the Actual Grocers and Post Office Visited) (p.d.s^4) for Elderly Persons Without Regular Access to a Car the samples and is also significant at the 99.9% level.

It is concluded, then, that distance saving is an important determinant of trip structure. However, full potential distance savings are not taken advantage of due to either choice, the constraints on trip structures and/or the constraints on the facilities that can be visited. Clearly, these results and their interpretation have important bearing on the measurement of accessibility and, more specifically, the interpretation of the accessibility profiles developed in Chapter Six. The following text, therefore, considers the meaning of the results of the hypothesis tests and the related analysis and also discusses the implications for accessibility measurement in general.

7.5. INTERPRETATION OF RESULTS

The survey results indicate that, whilst over 50% of trips to the post office are linked, the significance of trip linking in determining the accessibility levels of the elderly to post offices is unclear. In testing hypothesis H.4. it is evident that elderly persons with low accessibility to the post office are more likely to link trips than elderly persons with high accessibility to the post office. As shown by testing hypothesis H.5., the maximum potential distance saving attributed to linking trips to the post office with trips to the grocers (as indicated by the accessibility profiles formulated in Chapter Six) is not taken full advantage of by the elderly in that those facilities offering the greatest reduction in total travel distance are not visited. In this light, it is apparent that distance saving from linking trips is not influential in determining the individual's choice of facility location. However, by assuming the activity locations to be fixed, distance saving is an important determinant of journey structure (as indicated by the difference in the incidence of linked trips between elderly persons with low actual distance saving and high actual distance saving). On the evidence of the survey analysis a number of possible reasons for this are suggested which, as discussed in section 7.6., have a number of implications for the definition, measurement and valuation stages of accessibility index formulation both in the context of this research and in general.

i. Criteria for Choosing Activity Locations

The individual's choices as to which post office and grocer to visit are made independently of one another. The main criterion in selecting which post office to visit appears to be single-purpose travel disutility with 82% of the survey population visiting the nearest post office to their home. By contrast travel disutility appears to be a less dominant criterion in selecting which grocer to visit and it is suggested that the range, price and quality of goods available and, perhaps, the ability to link food shopping with different activities other than visiting post offices are also significant factors (only 21% visit the nearest grocer).

ii. Constraints on the Choice of Activity Locations

In addition to the differences in the criteria for selecting which post office and which food shopping facility to visit, it is also suggested that the elderly's choice of post office is constrained. Retiring persons have to specify a post office from which they can collect their pension, normally on a weekly basis, and unless special arrangements are made, are unable to obtain their pension from alternative post offices. Whilst the elderly undoubtedly undertake other activities at the post office, pension collection is likely to be a dominant influence on their choice of location. The initial decision as to which facility to visit is taken with regard to single-purpose travel disutility (as suggested above) and, hence, future post office trips are constrained by this decision.

Other constraints on the individual's travel behaviour such as the extra travel effort incurred in carrying shopping, may reduce the elderly's ability to link trips between post offices and grocers as the total travel disutility incurred in undertaking two single-purpose trips, as opposed to a linked trip, may be greater in terms of distance but less in terms of effort.

iii. Trip Frequencies

The ability to link trips to different activities (grocers and post offices) is dependent on the demand for these activities being of a similar level (in terms of trip frequency) and at similar times of the day (common temporal availability). Whilst for grocers and post offices the latter condition is satisfied it is apparent that, as indicated by the survey results, there is a differential trip frequency for the two activity types. The data (Table 7 - 3) shows that 98% of the survey population visit the grocer at least as frequently as the post office. Hence, because of this difference in trip frequency all post office trips can potentially be linked to grocer trips but all grocer trips cannot be combined with visits to the post office. On this evidence, it is considered legitimate in measuring linked trip accessibility to take grocer locations as a potential non-home trip origin for post office trips but not vice versa.

iv. Mode of Transport

The survey results reveal that for post office trips the dominant travel mode is walking (83%) whilst for food shopping only 56% walk, with a higher proportion travelling by bus or car. Given this change of mode, it is noted that appropriate measures of separation differ for the two activity types not only in terms of cost and travel time becoming more significant (for food shopping trips) at the expense of distance but also in the fact that the shortest route changes due to differences between and the configuration of the pedestrian and public transport networks.

In a number of specific examples extracted from the survey data a linked trip is undertaken by an individual who visits the post office and travels by bus to the grocers having boarded the bus at a bus stop within the same vicinity of the post office. In this situation the post office is on route to the grocers but is not necessarily reflected by the pedestrian network. Also, the bus journey effectively makes redundant the post office opportunities on the in-transit route to the grocers. These points are, perhaps, more adequately illustrated by the following example.

Figure 7 - 3 shows that for the individual residing at location Oi the nearest post office (P.O.1.) is at location j and the most accessible grocer (G.1) at k. In terms of the pedestrian network, the potential distance saving from linking trips is relatively small when visiting P.O.1 and G.1 and the combined distance is less when P.O.n and G.1 are visited through linking trips. However, in taking account of the public transport network the individual may walk to bus stop Sx and travel by bus to grocers G.1. In this instance, the potential distance saving from linking trips to P.O.1. and G.1 is greater than shown on the pedestrian network. Moreover, the accessibility of P.O.n is effectively reduced in that between Sx and Sy the individual is in-transit and does not, therefore, have access to opportunities on route without changing buses or mode of transport at P.O.n.

It is evident then that the potential to link trips and the distance saving arising from trip linking varies according to the travel mode. It is apparent that where public transport is used as the mode of travel, the network distance saving, as measured on the pedestrian network, is redundant to some extent in that the individual travels on a different network and the incurred travel disutility is not adequately reflected in terms of distance. In this context the public transport network effectively distorts spatial separation from a linear to a non-linear scale and, hence, makes those facilities located in the proximity of public transport boarding points more accessible.

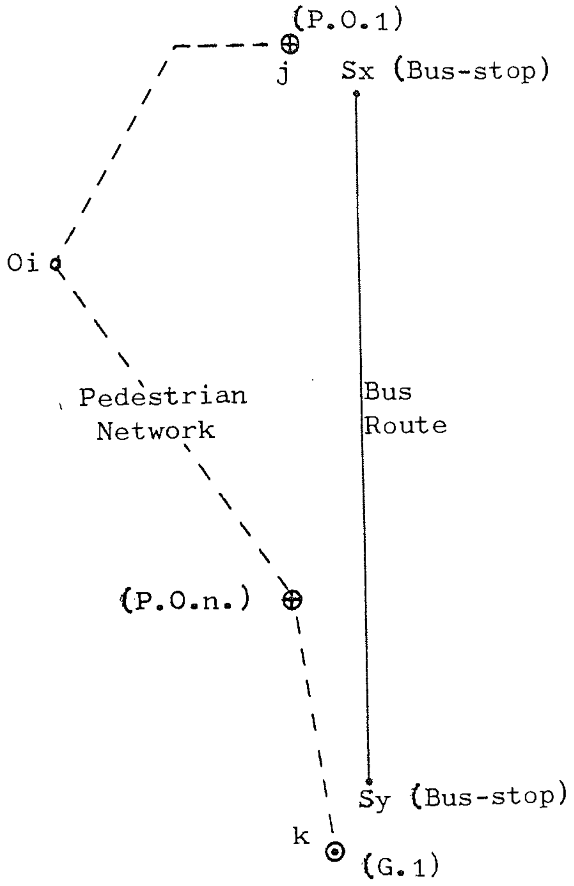


FIGURE 7-3 The Effect of Transport Mode on Linked Trip Potential

	POTENTIAL DISTANCE SAVING (p.d.s.^{4})		
	LOW	HIGH	TOTAL (No. of Respondents)
Linked P.O. and Grocer Trip	0	10	10
Other P.O. Trip	10	2	12
All types of P.O. Trip	10	12	22

$\chi^2 = 15.3$

Significance Level = 99.9%

TABLE 7-23 Trip Structures by Potential Distance Saving Group (Constrained by the Actual Grocers and Post Office Visited)(p.d.s^{4}) for Elderly Persons Undertaking the Trip(s) on Foot

The measures of potential distance savings utilised in testing hypothesis H.5. are, therefore, innaccurate for a minority of the sample population in that not all the respondents undertake the post office and grocer trips on foot. By excluding those persons travelling by modes other than walking from the potential distance saving groups (as finally defined, that is, p.d.s.[4]), the χ^2 value is re-calculated for only those persons making trips to the post office and grocers on foot. Table 7-23 shows that the difference in the trip structures between the two groups is pronounced as in Table 7 - 22 (p.309) and, despite the reduction in the sample size, the χ^2 value is significant at the 99.9% level ($\chi^2 = 15.3$).

On the basis of this interpretation of the survey results, suggestions may be made as to the most appropriate method of incorporating linked trips into accessibility measurement.

7.6. IMPLICATIONS FOR ACCESSIBILITY MEASUREMENT

On the basis of the above interpretations of the elderly's travel behaviour and journey structures as revealed by the survey it is possible to explore how accessibility measurement and, more specifically, comparative profiles can be adapted to accommodate linked trip opportunities. The survey results and analysis have implications not only for the measurement of the accessibility of the elderly to post offices and grocers but, in a wider context, the measurement of accessibility in general.

7.6.1. Measuring the Accessibility of the Elderly to Post Offices

The profiles shown in Appendix G indicate the potential availability of combinations of post offices and grocers by undertaking two single-purpose trips or a linked trip. However, as accessibility to grocers and post offices is represented as a combined measure, then, separate measures to either activity from non-home trip origins are indeterminable. The ability to distinguish between accessibility to different activity types is necessary on the grounds that both the frequency with which the activities are undertaken and the utility derived from undertaking them is likely to differ. In accepting grocers as an alternative origin location for post office trips, it is apparent that accessibility to post offices can be measured from grocers or from the individual's home location.

The survey results and their subsequent interpretation provide the basis on which to measure the accessibility of the elderly to post offices taking into account the potential to link trips. The formulation of accessibility profiles showing how the potential availability of post offices increases with distance is considered before introducing the fact that, on the basis of the survey data, the cross-section of the profile showing the availability of the nearest post office is the most relevant. It is indicated that grocer and post office activity locations are selected independently and, hence, in measuring accessibility to post offices the alternative trip origin (that is, the grocers) can be taken as being spatially fixed. The potential accessibility to post offices from grocers may, therefore, be represented by the additional travel disutility attributable to visiting a post office via the grocer. This will be represented by the linked trip distance minus the single-purpose trip distance to the grocer.

Relating this to the profiles formulated in Chapter Six, it is evident that changes in the definition, measurement and valuation of the accessibility components may be required to reflect more accurately the potential availability of post offices in a profile form. Provided that it is possible to specify the non-home origin location by redefining the opportunity component utilised in measuring the accessibility of grocers so as to take account of the price, range and quality of opportunity at each facility location, then, the post office accessibility profile may comprise a combination of the potential availability of post offices from the individual's home location and the potential availability of post offices from the non-home activity location. Figure 7-4 indicates the general form that this profile might take. As with the profiles displayed in Appendix G, this profile shows how the potential availability of post offices increases with separation. In interpreting the relevant cross-section of the profile, the survey results suggest that individuals are constrained or at least choose to visit the nearest post office (as measured from the home) and, thus, this may not be the 'first' facility measured from the non-home trip origin.

In introducing a second curve on the profile (that is, the availability of post offices from the non-home trip origin), it is apparent that additional information may be displayed on the profile showing either the availability of post offices from other potential non-home trip origins of the same activity type (that is, in this case grocers) or from other potential non-home trip origins of different activity types (provided that it has been established that the potential to link post office trips to these activities exist). Figure 7-5 indicates the general form that this profile might take. Whilst this additional information offers the advantage of representing the true potential opportunity and does not restrict the non-home activity location it is subject to difficulties on three accounts:

i. The complexity of the profiles increases with the inclusion of additional non-home trip origin locations and, in practice, the profiles are likely to be incapable of accommodating all potential non-home trip origins.

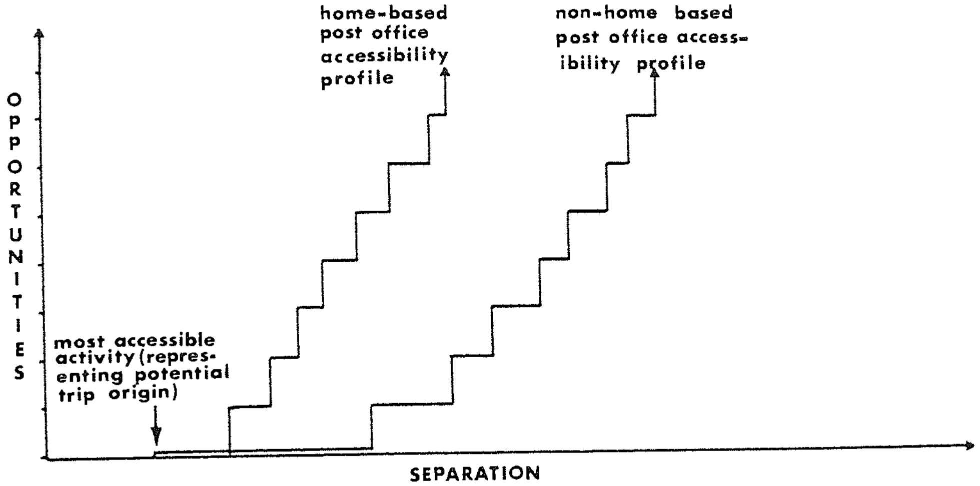


FIGURE 7-4 Accessibility Profile Showing the Increasing Availability of Post Offices with Separation from a Non-Home as well as Home Trip Origin

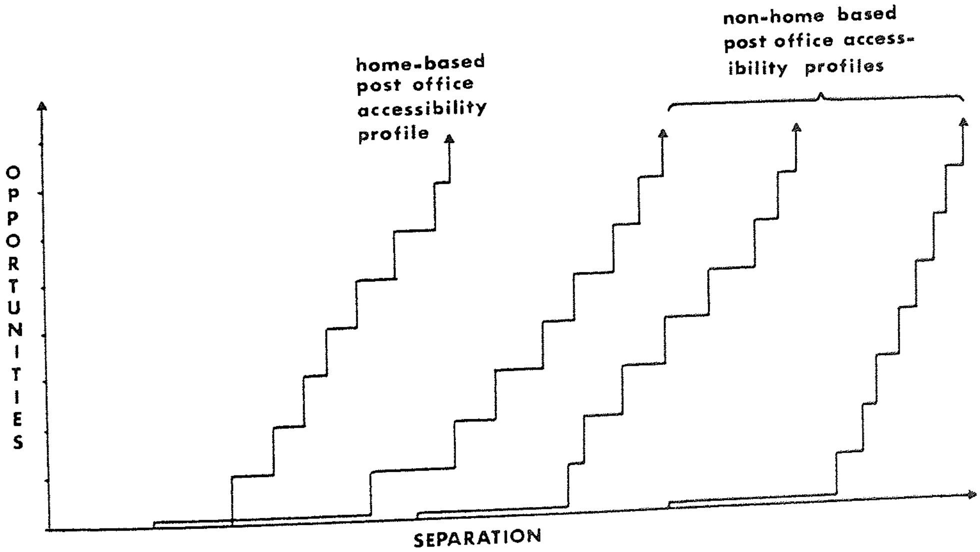


FIGURE 7-5 Accessibility Profile Showing the Increasing Availability of Post Offices with Separation from more than One Non-Home Trip Origin

ii. The measurement and valuation of the separation component reflecting the travel disutility incurred by the elderly in travelling to both the post offices and the non-home trip origins must be expressed on a common scale. For example, in the context of the accessibility profiles developed in this study, the separation incurred in accessing non-home trip origins as well as post offices must be expressed in terms of pedestrian network distance.

iii. The interpretation of the profile is more complicated due to the problems of determining not only the relevant cross-section of one curve but also which curve(s) are the most relevant to assessing the accessibility of the elderly to post offices.

It is evident from the above discussion that, in taking account of the complex nature of journey structures, the measurement of the full potential opportunity to post offices increases the amount of accessibility information displayed in the profiles and, hence, increases the range of possible interpretations of the accessibility profile data. Depending on the policy context of the accessibility study, the profiles may be confined to certain shopping facilities for which there is a regular and frequent need (for instance, grocers) and, on a more aggregate level, shopping centres.

7.6.2. Measuring Accessibility in General

The above investigations reveal that non-home based trips comprise a major proportion of all post office trips undertaken by the elderly. It is suggested that multi-purpose trips form a significant proportion of trips undertaken for other purposes (as noted in more recent accessibility studies, for instance, Morris and Wigan, 1979, and Pirie, 1979) and the complexity of journey structures is under-represented in many previous transportation studies due either to the difficulty of accommodating them in the analysis or through the process of aggregation. Accessibility measurement based solely on trips originating from the individual's place of residence may, therefore, be deficient. Thus, accessibility profiles showing the potential opportunity available from non-home as well as home locations are regarded as being more comprehensive and, hence, more accurate than conventional home-based profiles or indices.

However, the analysis of post office and grocer accessibility data, whilst providing an insight into the complexity of travel behaviour and linked trip-making, does not provide any conclusive evidence to support any particular method of representing linked trips in accessibility measures in general. It is felt that a number of concepts can be defined that provide a basis on which to extend the present confines of accessibility measurement to incorporate linked trips.

i. The Specification of Non-Home Origins

The full range of potential non-home trip origins from which accessibility to a particular facility can be measured is dependent on the travel characteristics associated with particular types of activity. The validity of the assumption that certain activity locations are potential trip origins is dependent on that activity being undertaken at least as frequently as the activity in question and at similar times of the day. It is evident then that the accessibility profiles developed in this research (Appendix G) only take into account a proportion of non-home trip origins (grocers) in measuring accessibility to post offices. For accessibility measurement in general it may be useful to establish an hierarchy of non-home activities based on the frequency with which activities are participated in. For a specified activity all those activities higher in the hierarchy may be taken as potential non-home trip origins provided there is a common temporal availability.

ii. The Measurement of the Level of Accessibility to a Specified Activity

Having defined the non-home potential trip origins, it is necessary to be able to distinguish between the proportion of separation attributable to visiting the non-home origin in order to participate in an associated activity and the proportion attributable to participating in the activity to which accessibility is being measured. In undertaking a linked trip to two activities the separation levels of all three stages of the journey may be influenced by either the location of the associated activity (that is, the non-home trip origin), the location of the activity to which accessibility is being measured or, in some cases, the locations of both activities. It is suggested, then, that the proportion of travel incurred in visiting different activities at different non-home locations varies according to the types of activity in question:

- Where for each individual the non-home based trip origin(s) is known, constrained to one location and is selected independently of the location of the activity to which accessibility is being measured.
- Where for each individual the non-home based trip origin is unknown and is dependent on the location of the activity to which accessibility is being measured.

In the former situation the non-home based trip origin(s) can be assumed to be fixed and, hence, the potential opportunity available for participating in a specified activity is represented by calculating, in addition to the single-purpose trip travel disutility, the additional travel disutility associated with visiting this activity via the fixed non-home trip origin. Accessibility profiles of similar form to those showing the linked trip accessibility levels for post offices via grocers may be formulated.

In the latter case, the level of accessibility to one particular activity type is more difficult to determine in that the most accessible facility by single-purpose trip may not necessarily be the most accessible facility by linked trip. The determination of the most accessible non-home origin location requires that the level of opportunity as well as the level of separation is expressed on a common scale. Moreover, the measurement of the accessibility to a particular activity type from these non-home locations, as well as home locations, necessitates representing the opportunity as well as the separation components in the same terms as the opportunity and separation components of the activity to which accessibility is being measured. The extent of the problems inherent in measuring opportunity, as indicated in the case study undertaken in this research, depend on the degree to which the level of opportunity varies between activity locations and the extent to which the choice of activity location is influenced by opportunity as opposed to separation.

Assuming that, depending on the availability of data, the most accessible location can be defined in the most appropriate terms for the activity in question, then the travel disutility incurred in participating in a specific activity through linking trips may be represented as the travel disutility over and above that to the most accessible non-home location. Accessibility profiles can, thus, be plotted comprising the availability of the activity to which accessibility is being measured from home-based trips (as shown for post offices in the profiles contained in Appendix G) and from linked trips (also as shown in the profiles contained in Appendix G) but with the travel disutility of the most accessible non-home origin location subtracted.

iii. The Identification of Constraints on Trip Linking

Having formulated accessibility profiles showing the potential opportunity from linked as well as home-based trips, it is necessary to interpret these profiles not only by making value judgements but also by taking into account any constraints on the availability of different combinations of facilities. It has already been shown that for post offices and grocers the elderly may be constrained by their own initial decision to visit the nearest post office to their homes. Whilst these types of constraints are partly taken into account in determining whether the location of different activity types are dependent or independent of one another, it is suggested that other constraints associated with particular activity combinations may reduce the potential opportunity available from trip linking.

A distinction can be drawn between those constraints attributable to the location (and, hence, the travel disutility) of activities and, alternatively, those attributable to the types of activity (sequencing constraints). The travel disutility between two or more out-of-home activities may constrain the availability of opportunities and/or prevent certain activities from being undertaken. With reference to the space-time graphs in Chapter Four, the time taken to undertake a linked trip may be greater than the time slots available to an individual for participating in these activities but each activity may be accommodated in separate time slots and, hence, can be undertaken through home-based trips. Sequencing constraints exist where certain activities have to be undertaken in a particular order (for example, the survey indicates that the elderly tend to visit the grocer after the post office possibly due to the problems of carrying shopping or, perhaps, the necessity to collect their pension before visiting the grocers).

Whilst the above concepts have proved useful in explaining the journey structure characteristics and, hence, the accessibility levels of individuals, they are essentially areas in which further research on accessibility measurement should be concentrated. Clearly, the results of the interview survey provide only guidelines as to the inclusion of linked trips in comparative accessibility profiles and there is no evidence to show that these properties are common to other trip purposes or other areas. Their identification, however, provides a framework in which further investigations can focus on the inclusion of the potential to link trips in accessibility measurement (either on the basis of the profiles described above or through composite indices), the linking of trips by different population groups for various trip purposes and the structure of trips in different geographic areas.

7.7. SUMMARY AND CONCLUSIONS

i. A survey of travel behaviour was undertaken in order to investigate the incidence and nature of linked trips and, on this evidence, determine the most appropriate means of adapting and interpreting comparative accessibility profiles to encompass the potential to link trips. The survey reveals that:

- The majority of trips to the post office by elderly persons in the London Borough of Hammersmith and Fulham are linked with a high proportion of these being linked to food shopping activities.
- Elderly persons identified as having low accessibility to post offices are more likely to link trips to post offices than those persons identified as having high accessibility.
- Individuals link trips between post offices and grocers to reduce overall travel disutility and, hence, a trip is more likely to be linked where there is a large distance saving. However, it appears that individuals do not base their choice of facility on potential distance savings and any benefit accruing from a linked trip appears to be subsequent to the choice of facility locations.

ii. Other characteristics associated with the journey structures of the elderly and that assist in identifying the most appropriate method of encompassing linked trips in accessibility measurement are derived from analysing and interpreting the survey results:

- In almost all cases grocers are visited at least as frequently as post offices and, hence, can be taken as alternative origin locations from which to measure accessibility to post offices.
- It is indicated that car availability has a significant influence on the incidence of linked trips, in that elderly persons with regular access to a car are more likely to link trips to the post office than are elderly persons (the large majority) without regular access to a car.
- The choice as to which post office and grocer to visit are made independently of one another. Network distance is shown to be a more dominant factor in influencing the individual's decision as to which post office to visit (as compared with grocers).
- The majority of trips by the elderly to the post office are undertaken on foot whilst bus trips are more significant for food shopping purposes. The potential reduction in travel disutility from linking post office trips with food shopping trips is, therefore, also dependent on the availability of public transport as well as the configuration of the pedestrian network and the relative locations of each activity.

iii. On the basis of the survey results and their subsequent interpretation, the most appropriate method of measuring accessibility levels from non-home origins (that is, taking account of trip linking) and, more specifically, the most appropriate method of representing accessibility information in comparative profiles is determined. It is concluded that the full potential opportunity available from linking trips (as shown in the profiles in Chapter Six) is constrained by the requirement that the elderly collect their pensions from a specified post office and that the choice of grocer is taken independently of the post office location. In this instance, the most appropriate cross-section of the profile is, therefore, the availability of the nearest facility. However, given that the nearest facility for a single-purpose trip is not in all cases the nearest from a linked trip, then the true availability of post offices may be expressed by a set of curves each representing the increasing availability of post offices with travel disutility from alternative trip origins (as shown in Figure 7-5, section 7.6.1.). The interpretation of this profile in terms of deciding upon the most relevant cross-section may then take account of the constraints imposing on the choice of activity locations and the potential to link trips.

Alternatively, as regards accessibility measurement in general it is concluded that where the choice of non-home trip origins and the activity locations are dependent on one another the full potential opportunity from linking trips (for example, as shown in the profiles contained in Appendix G) becomes relevant. In this instance, the potential accessibility to the activity may be represented by a profile showing the increasing opportunity with travel disutility incurred in undertaking a linked trip less the travel disutility to the most accessible non-home trip location (as shown in Figure 7-4, section 7.6.1.).

iv. The survey results indicate that the general complexity of journey structures of which linked trips are an important element. The interpretation of these results assists in providing a foundation on which to encompass the complexity of trip linking into accessibility measurement in general. Whilst there is considerable scope for further research it is suggested, on the evidence provided by this study, that three concepts may prove useful in extending the confines of accessibility measurement:

- The specification of non-home trip origins for each activity type derived from a hierarchy of activity types based on trip frequencies and common temporal availability.
- The locational relationship between activity types making the distinction between the dependence or independence of the choice of location of an activity in relation to the location of other activities.

- The constraints on trip linking taking into account the limitations on activity choice and the sequencing of trips to different activity types.

The conclusions to be drawn from the analysis of linked trip-making and the areas in which further research would be beneficial are discussed in more detail in Chapter Eight.

CHAPTER EIGHT

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER RESEARCH

8.1. CONCLUSIONS

In drawing together the findings of the research the following major conclusions are reached. A more detailed set of conclusions has already been presented at the end of each Chapter and, for this reason, the practical and policy implications of the research are not referred to in the following text, (see, however, Chapters 6 and 7).

8.1.1. The Need for a Conceptual Framework of Accessibility

The literature on accessibility measurement frequently refers to the difficulties, ambiguities and confusion associated with defining and measuring accessibility. This, together with the execution of this research, indicates the need for a conceptual framework of accessibility as developed in Chapter Two. In a theoretical context accessibility is a measure and, hence, the formulation of accessibility indices should conform to the principles of measurement. The establishment of a conceptual framework enables the different variables and components that give rise to indices to be assessed against a set of criteria and, more specifically, with regard to the principles of definition, measurement, valuation and aggregation. This framework is seen to have universal application and serves as a 'starting block' for all accessibility analysis, irrespective of the level of complexity and intended application of the index.

8.1.2. Presenting Accessibility Information

With reference to the conclusions drawn from the development of a conceptual framework (Section 2.4.) and the review of accessibility indices (Section 3.5.) the author advocates that accessibility information should be presented in a disaggregate and largely value-free form, thus, enabling greater decision-maker involvement and making the value judgements and aggregation assumptions necessary to produce a single-unit score of accessibility more explicit.

8.1.3. Accessibility Measurement and Linked Trips

One of the key areas in which existing accessibility measures are deficient is that they do not take account of the complexity of trip structures but assume all trips to be single-purpose and originating from the individual's home. In order to encompass the sequential nature of activity patterns into accessibility indices it is concluded that the confines of accessibility measurement should be extended in line with current developments in disaggregate activity and travel modelling (this conclusion is expanded on in Section 4.6.)

8.1.4. The Findings of the Case Study

In the narrow context of the case study the following conclusions are reached:

- The rank order of zones according to accessibility levels based on different value judgements, aggregation procedures and trip structures do not vary significantly. However, some zones do change markedly in rank order due to the skewness and variance of the distribution of individual accessibilities within the zone relative to other zones. Particular attention should, therefore, be paid to the valuation and aggregation of accessibility information and the implications for the results in light of their intended application.

- The majority of trips undertaken by the elderly to the post office are linked to other facilities.
- The elderly are more likely to link trips where they have a relatively low level of accessibility and where there is a substantial distance saving to be gained from linking trips.
- The accessibility levels of the elderly can be and are improved substantially through linking trips between post offices and grocers. However, the potential to reduce total travel disutility by linking trips is shown not to be a major factor in the elderly's choice of activity locations. Also, this potential is constrained by travel mode and the non-travel criteria by which facilities are chosen.

These conclusions are expanded in Sections 6.9. and 7.7.

8.1.5. The General Applicability and Limitations of the Case Study Findings

Whilst the more theoretical conclusions drawn from this research are recognised as having a wide validity, the general applicability of the conclusions drawn from the case study are limited for two reasons:

- The nature of journey structures and the significance of linked trip-making for accessibility measurement has been revealed only in the context of the accessibility of the elderly to post offices and grocers in inner urban areas. The elderly's mobility and activity characteristics are likely to be factors influencing their journey structures as is the geographic location of the case study. Hence, the hypotheses about linked trip-making (that is, H.3., H.4. and H.5., Chapter Seven) may not be supported, at least to the same extent, if tested for other population groups, activities and/or in areas other than an inner city.
- The time and resource constraints limited the measurement accuracy of the three variables comprising the dimensions of the accessibility profiles. Firstly, the availability of data constrains the choice of zones which, in turn, influences the testing of the sensitivity of accessibility levels to different valuation and aggregation procedures (that is, hypothesis H.1.). Secondly, the choice of distance as a measure of separation ignores the other less tangible aspects of pedestrian travel disutility (for example, difficulties in crossing roads) and, perhaps, more importantly, is not a full reflection of the travel disutility incurred in accessing grocers (given that 42% of the survey population use motorised transport). Thirdly, the measurement of opportunity used does not fully reflect the relative attractiveness of grocers in terms of their quality. This complicates the measurement of accessibility to grocers and, hence, creates difficulties in the measurement of potential distance savings (as utilised in

testing hypothesis H.5.).

Given the above limitations of the case study findings, it is concluded that a full understanding of the role of linked trip-making in accessibility measurement is dependent on undertaking further research into those areas not covered by this study (see recommendations for further research). However, despite these limitations, the results of the case study and subsequent analysis do enable more general conclusions to be drawn regarding the formulation of accessibility indices that show the potential opportunity available from non-home as well as home-based trips. It is concluded that the inclusion of linked trips in accessibility measurement is dependent on identifying:

- The criteria by which facilities are chosen and whether these facilities are selected dependently or independently of one another.
- The frequency, duration and timing of trips to different activity types. An hierarchy of activities may be established according to the ability to combine different activities.
- Constraints on the sequencing of activities that limit the potential opportunity available from linking trips.
- All potential non-home trip origins.

8.2. RECOMMENDATIONS FOR FURTHER RESEARCH

The concept of accessibility is fundamental to both transportation and land-use planning in that the full effect of policies can only be realised by determining their impact on accessibility levels. It is considered essential, therefore, that further attention is given to ways of improving present measurement techniques. Whilst this study has explored ways of overcoming some of the major deficiencies of existing accessibility measures, it is recognised that there is considerable scope for further research and in the light of this, it is recommended that the following areas of study are pursued.

8.2.1. Applications of the Conceptual Framework

The conceptual framework as developed in Chapter Two may profitably be applied to classifying the different applications of accessibility analysis and to providing the basis for the production of a step-by-step guide to accessibility measurement through which both professionals and politicians can grasp a full understanding of accessibility and its role in transportation and land-use planning.

8.2.2. Implications of Data Aggregation

Particular attention should be given to the sensitivity of and potential distortions implicit within:-

- zone configurations and sizes;
- the averaging of trip origins and destinations; and
- the combination of trip purposes.

8.2.3. Measuring Opportunity

Further research is required into the measurement of opportunity so as to take account of choice, quality and price. This is seen as a key problem in determining the choice of potential non-home trip origins when measuring accessibility from linked trips (see Section 7.6.2.).

8.2.4. Accounting for Linked Trip-Making in Accessibility Measurement

Due to the limitations imposed by the adoption of a case study approach and the time and resources available for this research there are inevitably areas that this research has not addressed. The major areas relevant to the understanding of linked trip-making and its role in accessibility measurement that are not addressed in any great detail and which, therefore, require further investigation include:-

- the measurement of opportunity to take account of choice, quality and price (as above).
- the role of linked trips in total activity patterns rather than simply in combining two particular activities;
- the incidence and nature of linked trip-making in rural areas with much lower levels of accessibility relative to inner city areas;
- the role of linked trip-making as a means of improving accessibility for population groups whose activity patterns are subject to timing constraints; and
- the incidence of linked trips and the structure of journeys undertaken by modes other than walking.

8.2.5. Accessibility Measurement Within a Disaggregate Activity Based Framework

Considerable scope is seen to exist for further research that explores the sequential nature of travel and activity patterns, the constraints on the timing and duration of activity participation and the inter-dependence of certain activity types. In order to encompass these factors in accessibility measurement and to ensure that the notion of accessibility assumes greater importance in transport planning practice, future studies must be pursued along the same lines as current trends in disaggregate activity and travel modelling.

APPENDIX A

DERIVING SUBSEQUENT ORDERS OF CONNECTIVITY MATRICES THROUGH MATRIX ALGEBRA

The second and subsequent orders of the binary connectivity matrix, indicating the number of alternative ways of linking nodes, may be obtained from matrix algebra where:

$$C^2 = C^1 \times C^1 \quad , \quad C^3 = C^2 \times C^1 \quad \text{etc.}$$

With reference to Hohn (1964), if matrix A is an m x p matrix and matrix B is a p x n matrix then the second order matrix (AB) is given by the m x n matrix. The element in the ith row and jth column of matrix AB(Cij) is derived by multiplying the corresponding elements of the ith row of A and of the jth column of B and then adding the results. That is:

$$\underline{A}\begin{bmatrix} a11 & a12 & \ldots\ldots a1p \\ a21 & a22 & \ldots\ldots a2p \\ \vdots & \vdots & \vdots \\ am1 & am2 & \ldots\ldots amp \end{bmatrix} \times \underline{B}\begin{bmatrix} b11 & b12 & \ldots\ldots b1n \\ b21 & b22 & \ldots\ldots b2n \\ \vdots & \vdots & \vdots \\ bp1 & bp2 & \ldots\ldots bpn \end{bmatrix} = \underline{AB}\begin{bmatrix} c11 & c12 & \ldots\ldots c1n \\ c21 & c22 & \ldots\ldots c2n \\ \vdots & \vdots & \vdots \\ cm1 & cm2 & \ldots\ldots cmn \end{bmatrix}$$

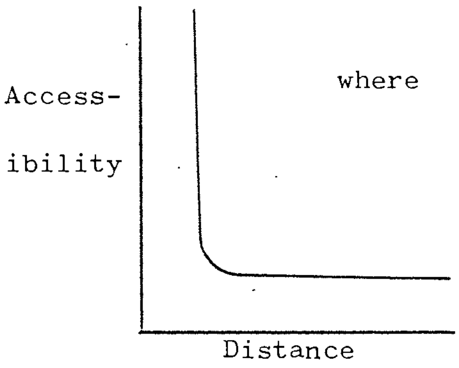
$$\text{where } Cij = ai1.b1j + ai2.b2j + \ldots\ldots\ldots\ldots\ldots\ldots \; aip.bpj = \sum_{k=1}^{p} aik.bkj$$

APPENDIX B

ALTERNATIVE FORMS OF DISTANCE DETERRENCE FUNCTIONS

Ingram (1971) identifies three different forms of function relating accessibility to distance:

i) A reciprocal function of the form:



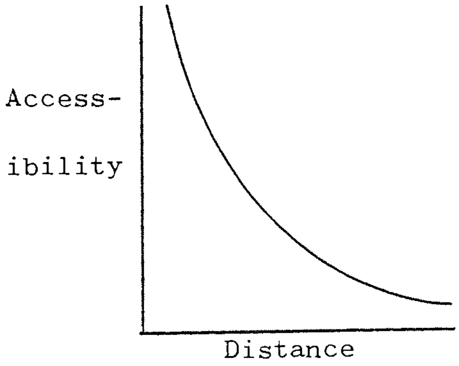
$a_{ij} = 100\ d_{ij}^{-k}$

where a_{ij} = the relative accessibility of i to j.

d_{ij} = the distance between i and j.

FIGURE B - 1 A Reciprocal Deterrence Function

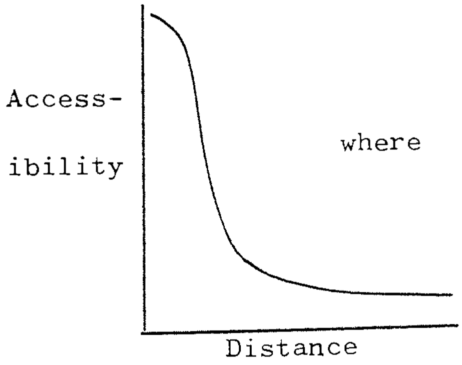
ii) An exponential function of the form:



$a_{ij} = e^{-d_{ij}}$

FIGURE B - 2 An Exponential Deterrence Function

iii) A Gaussian function of the form:



$a_{ij} = 100\ e^{(-(d_{ij}^{2}\ V^{-1}))}$

where V = a constant

FIGURE B - 3 A Gaussian Deterrence Function

Ingram argues that the modified Gaussian function is the most suitable.

APPENDIX C

THE SPEARMAN RANK CORRELATION COEFFICIENT

The Spearman rank correlation coefficient (r_s) is a relatively simple method of determining the correlation between two sets of data where the values are expressed in a rank order of magnitude rather than as absolute values. The coefficient is calculated as:

$$r_s = 1 - \frac{6 \sum d^2}{n^3 - n}$$

where n = the number of pairs of occurrences being considered; and

d = the difference in rank order between the two sets of data.

The limits of the coefficient (r_s) are +1 and -1. A coefficient of +1 indicates that a perfectly positive correlation exists with the rank orders being exactly the same for both sets of data, whilst a coefficient of -1 indicates that a perfectly negative correlation exists with the rank orders for the two sets of data being totally opposite.

The significance of the value of the coefficient can be determined with reference to a table or graph showing critical values for r_s for various degrees of freedom (see for instance, Freund, 1967), where:

the degrees of freedom = n - 2

With reference to the rank order comparisons of twenty-three zones undertaken in Chapter Six of this research it is noted that a Spearman rank correlation coefficient (r_s) of 0.503 (with 21 degrees of freedom) is significant at the 99% level whilst a coefficient of 0.549 is significant at the 99.5% level.

APPENDIX D

THE CHI-SQUARED TEST

The Chi-squared test provides a method of assessing the statistical significance of differences between sample data where the data is presented in the form of frequencies. The Chi-squared value (χ^2) indicates whether the observed frequencies of a given phenomenon differ from the frequencies that might be expected according to an assumed hypothesis.

Given two sets of variable conditions (X and Y) where the frequency distribution in each set takes a binomial form (Xo or Xi and Yo or Yi) as shown in the following matrix, then the level of the causal relationship between the two sets of variables (X and Y) can be determined. The null hypothesis that there is no difference between the frequency distribution of one variable in relation to the other is postulated.

		Variable X		
		Xo	Xi	
Variable Y	Yo	a	b	a + b
	Yi	c	d	c + d
		a+c	b+d	a+b+c+d

With reference to the above matrix, the χ^2 value is calculated as:

$$\chi^2 = \sum \frac{(O - E)^2}{E}$$

where: O = the observed values in each cell of the matrix (that is, a, b, c, d); and

E = the expected values in each cell assuming the null hypothesis to be correct. E is calculated as the product of the row and column totals divided by the total sample which is for cell Xo, Yo:

$$E = \frac{(a + b) \times (a + c)}{a + b + c + d}$$

Once the χ^2 value is obtained it is necessary to refer to the appropriate Chi-squared table or graph and read off the significance level of the value against the degrees of freedom. The degrees of freedom is derived from the number of rows and columns in the matrix where:

degrees of freedom = (row - 1) x (columns - 1)

hence, for a 2 x 2 matrix (as above) the degrees of freedom = 1.

The significance level indicates the probability that the null hypothesis is correct and, thus, also indicates the probability that the inverse of the null hypothesis is correct. For instance, a χ^2 value of 3.841 with 1 degree of freedom indicates that there is only a 5% probability that the null hypothesis is correct and, therefore, it follows that there is a 95% probability that there is a causal relationship between the two sets of variable data. The higher the χ^2value the greater the probability that the null hypothesis is incorrect.

APPENDIX E

THE CALCULATION OF SAMPLE SIZE FOR COMPILING ZONAL ACCESSIBILITY PROFILES

The sample size necessary to give accessibility levels for each zone within a specified degree of accuracy was calculated on the evidence of accessibility data collected in a pilot survey in six of the twenty-three zones in the Borough. Two simple measures of accessibility were utilised in calculating the required sample size:

a) The mean average distance to the nearest post office; and

b) the percentage of the sonal population having access to at least one post office in a given distance.

A sample comprising every fifteenth elderly person living alone or with other elderly persons (that is, the study population) was selected from zones one, four, eight, twelve, sixteen and twenty giving the following sample sizes in each zone:

Zone one - 90
Zone four - 58
Zone eight - 60
Zone twelve - 66
Zone sixteen - 61
Zone twenty - 60

a) For each zone the sample mean distance to the nearest post office $(\bar{x})$ was calculated together with the best estimate of the standard deviation ($\hat{\sigma}$)

where:

$$\bar{x} = \frac{\sum_{i=1}^{i=n} xi}{n}$$

xi = distance to the nearest post office for individual i; and

n = number of individuals in the sample.

$$\hat{\sigma} = \sqrt{\frac{\sum_{i=1}^{i=n} (xi-\bar{x})^2}{n - 1}}$$

The sample size (N) that gives the mean ($\bar{x}$) within ±5% of the true mean ($\bar{X}$) with a 95% probability was calculated where:

$$N = \left(\frac{\hat{\sigma}}{d}\right)^2$$

d = a desired value for the standard error which, in this case, is given by: $2.\ d = \frac{\bar{x}.5}{100}$, hence, $d = \frac{\bar{x}.2.5}{100}$

For each of the zones the sample size required was calculated as:

	$\bar{x}$(m)	$\hat{\sigma}$	N
Zone one	370	2.05	491
Zone four	250	1.12	321
Zone eight	320	1.04	169
Zone twelve	510	1.76	191
Zone sixteen	440	2.26	422
Zone twenty	250	0.97	241

By accepting a sample size that gives the mean within $\pm$7.5% of the true mean ($\bar{X}$) with a 95% probability the required value for N is reduced considerably:

Zone one	218
Zone four	155
Zone eight	76
Zone twelve	86
Zone sixteen	188
Zone twenty	109

It is noted that the wide fluctation in the required sample size (N) results from the variation in the best estimate of the standard deviation ($\hat{\sigma}$). In taking the best estimate of the standard deviation for the pilot sample as a whole ($\hat{\sigma} = 1.9$) and the mean average distance to the nearest post office for the total sample ($\bar{x} = 3.6$) then the sample size required to give the mean within $\pm$ 7.5% of the true mean with a 95% probability is calculated as 198. However, it is assumed that in calculating the required sample size that there is a normal distribution of individual accessibilities within the zones but as indicated by the pilot survey data, due to the spatial locations of the sample population and the nearest post offices the distribution is skewed. The calculation of the sample size for the second type of accessibility measure is, therefore, more useful.

b) The sample size (N) that gives the proportion of the sample population who have access to at least one post office within a specified distance within a certain percentage of the true proportion with a 95% probability was calculated.

If p = the proportion of the sample population who can reach at least one post office in a given distance, then the remaining proportion of the population (q) is given by: $q = 1 - p$.

With reference to Gregory (1963) the standard error in the normal distribution is expressed as $\frac{\hat{\sigma}}{\sqrt{N}}$ which in a binomial distribution can be replaced by $\sqrt{N.p.q}$. The values in a binomial distribution, however, are most readily expressed as a proportion or a percentage. Hence, to obtain this form the standard error can be multiplied by $\frac{100}{N}$ giving $\sqrt{\frac{p\%.q\%.}{N}}$ Therefore, it follows that $N = \frac{p\%.q\%}{d^2}$ where d = the desired value for the standard error.

As with the mean distance to the nearest post office, the proportion of the zonal population having access to at least one post office in a specified distance will obviously fluctuate from zone to zone. The proportion giving the greatest sample size (the 'worst case') was, therefore, assumed (that is, p = 50% and q = 50%). The sample size (N) required to give the proportion within ±5% of the true proportion with a 95% probability was calculated as:

$$N = \frac{50 \cdot 50}{d^2}$$

where 2.d = 5 and, hence, d = 2.5

Thus, $$N = \frac{2500}{6.25} = 400$$

Clearly, such a large sample (that is, 400 x 23 = 9200 for the whole Borough) is beyond the resources of this research, particularly as the sample would comprise the large majority of the whole study population. Therefore, in accepting the proportion within ± 10% of the true proportion within a 95% probability the required sample size for each zone can be reduced to:

$$N = \frac{2500}{5^2} = 100.$$

APPENDIX F

THE S.P.S.S. COMPUTER PROGRAMS

The computations described in Chapter Six were undertaken using S.P.S.S. (Statistical Package for the Social Sciences). Firstly, the S.P.S.S. programming package was used:-

i. to compute the frequency distributions of individual accessibilities for each zone and for the sample as a whole to various levels of opportunity for post offices (NPO1 - NPO5), grocers (NG1 - NG10) and to combinations of post offices and grocers by linked trip (LT1 - LT5) and single-purpose trips (SPT1 - SPT5); and to calculate the statistics associated with these frequency distributions. For example, for the sample as a whole (ZONES MERGED)the job specification file took the following form:

```
UASPSS DATA ASJOIN, TIME 400 SECS, LINES 10000
RUN NAME          ZONES MERGED CALCS
FILE NAME         ZONES MERGED
VARIABLE LIST     ZONE, PERSON, NPO1, NPO2, NPO3, NPO4, NPO5,
                  NG1, NG2, NG3, NG4, NG5, NG6, NG7, NG8, NG9,
                  NG10, SPT1, SPT2, SPT3, SPT4, SPT5, LT1, LT2,
                  LT3, LT4, LT5
INPUT MEDIUM      CARD, ASJOIN
INPUT FORMAT      FIXED (1F2.0, 1F3.0, 20F2.0, 5F4.1)
   OF CASES       2300
VAR LABELS        NPO1, 1ST NRST PO/NPO2, 2ND NRST PO/NPO3,
                  3RD NRST PO/
```

```
                    NPO4, 4TH NRST PO/NPO5,5TH NRST PO/
                    NG1, 1ST NRST GROCER/NG2, 2ND NRST
                    GROCER/NG3, 3RD NRST GROCER/ NG4, 4TH
                    NRST GROCER/NG5, 5TH NRST GROCER/NG6,
                    6TH NRST GROCER/ NG7, 7TH NRST GROCER/
                    NG8, 8TH NRST GROCER/ NG9, 9TH NRST GROCER/
                    NG10, 10TH NRST GROCER/
MARGINALS           NPO1 TO LT5
STATISTICS          ALL
READ INPUT DATA
FINISH
****
```

ii. Secondly, the S.P.S.S. programming package was used to compute the potential distance saving (DSAVED) from undertaking linked trips (LT1 - LT5) as opposed to undertaking two single-purpose trips (SPT1 - SPT5) for each individual in the sample. For example, for the sample as a whole (ZONES MERGED) the job specification file took the following form:

```
UASPSS DATA ASJOIN, TIME 400 SECS, LINES 10000
RUN NAME            ZONES MERGED CALCS
FILE NAME           ZONES MERGED
VARIABLE LIST       ZONE, PERSON, NPO1, NPO2, NPO3, NPO4, NPO5,
                    NG1, NG2, NG3, NG4, NG5, NG6, NG7, NG8,
                    NG9, NG10, SPT1, SPT2, SPT3, SPT4, SPT5,
                    LT1, LT2, LT3, LT4, LT5
```

```
INPUT MEDIUM        CARD, ASJOIN

INPUT FORMAT        FIXED (1F2.0, 1F3.0, 20F2.0, 5F4.1)

    OF CASES        2300

VAR LABELS          NPO1,1ST NRST PO/NPO2, 2ND NRST PO/NPO3,

                    3RD NRST PO/NPO4, 4TH NRST PO/NPO5, 5TH

                    NRST PO/NG1, 1ST NRST GROCER/NG2, 2ND

                    NRST GROCER/ NG3, 3RD NRST GROCER/

                    NG4, 4TH NRST GROCER/ NG5, 5TH NRST

                    GROCER/NG6, 6TH NRST GROCER/ NG7, 7TH

                    NRST GROCER/ NG8, 8TH NRST GROCER/NG9,

                    9TH NRST GROCER/NG10, 10TH NRST GROCER/

COMPUTE             DSAVED1=SPT1-LT1

COMPUTE             DSAVED2=SPT2-LT2

COMPUTE             DSAVED3=SPT3-LT3

COMPUTE             DSAVED4=SPT4-LT4

COMPUTE             DSAVED5=SPT5-LT5

WRITE CASES         (2X,1F2.0,2X,1F3.0,5/2X,1F3.1))ZONE, PERSON,

                    DSAVED1, DSAVED2, DSAVED3, DSAVED 4, DSAVED5

MARGINALS           DSAVED1 TO DSAVED 5

STATISTICS          ALL

READ INPUT DATA

FINISH

****
```

APPENDIX G

ACCESSIBILITY PROFILES OF THE ELDERLY BY ZONE IN THE LONDON BOROUGH OF HAMMERSMITH AND FULHAM

FIGURES G - 1 to G - 48

Trip Purpose

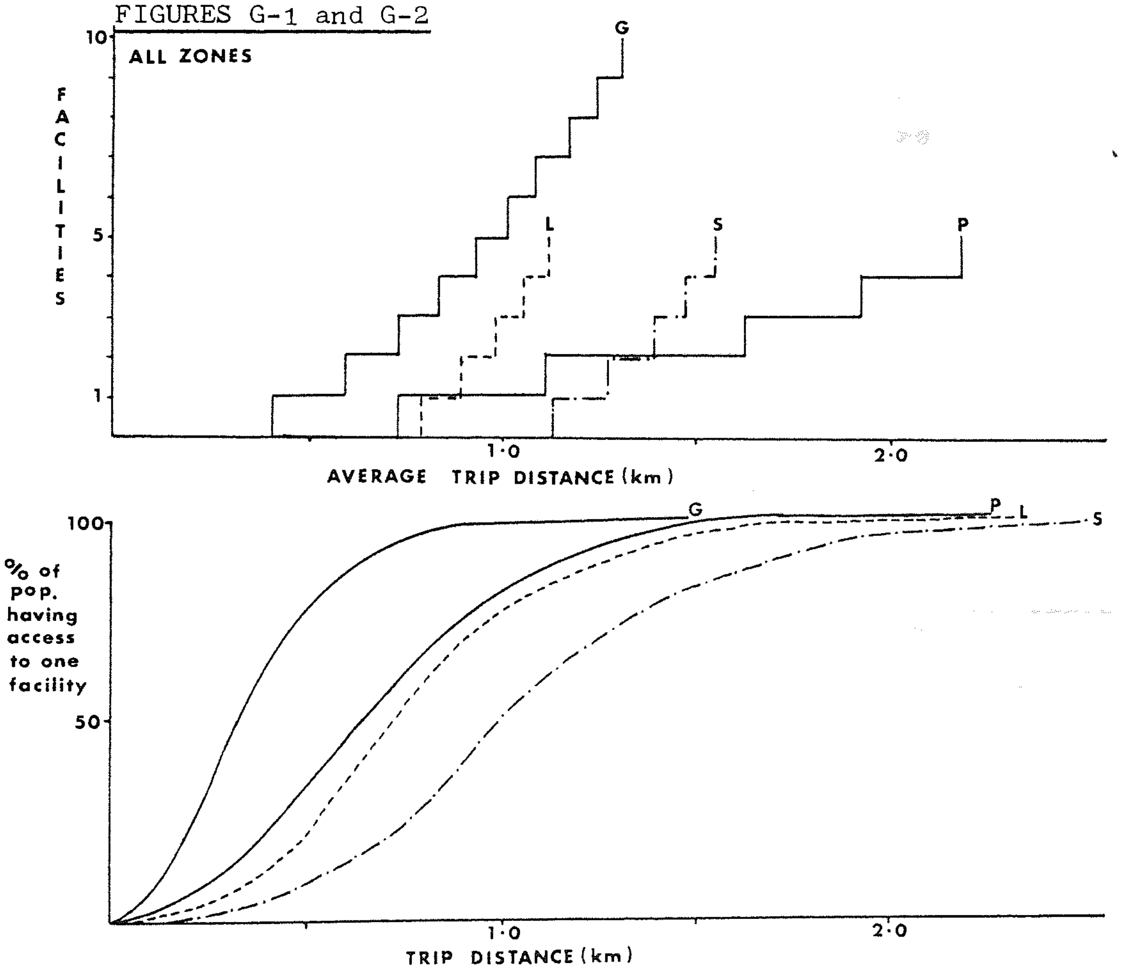
——— G = Grocers

——— P = Post Offices

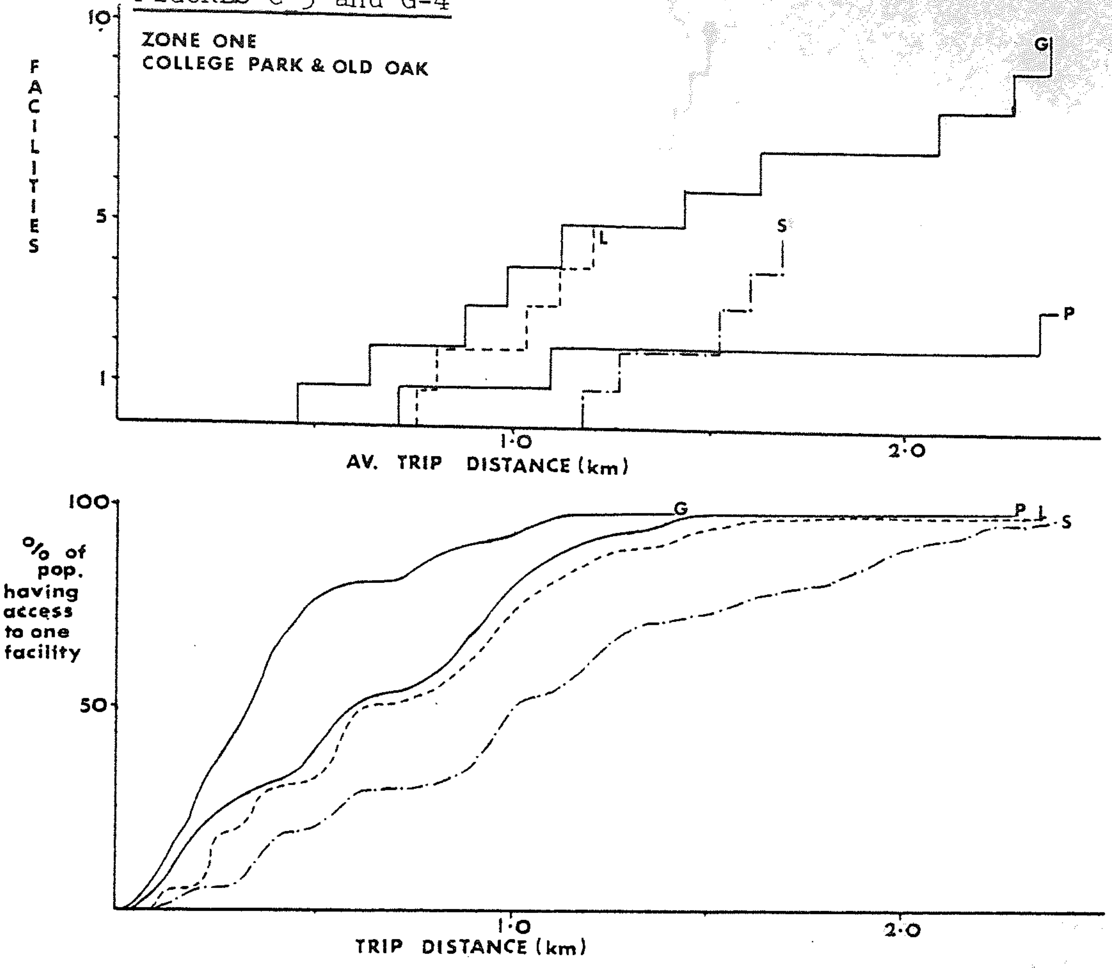
- - - - - - L = Grocers & Post Offices by Linked Trip

—·—·—S = Grocers & Post Offices by Single-purpose Trip

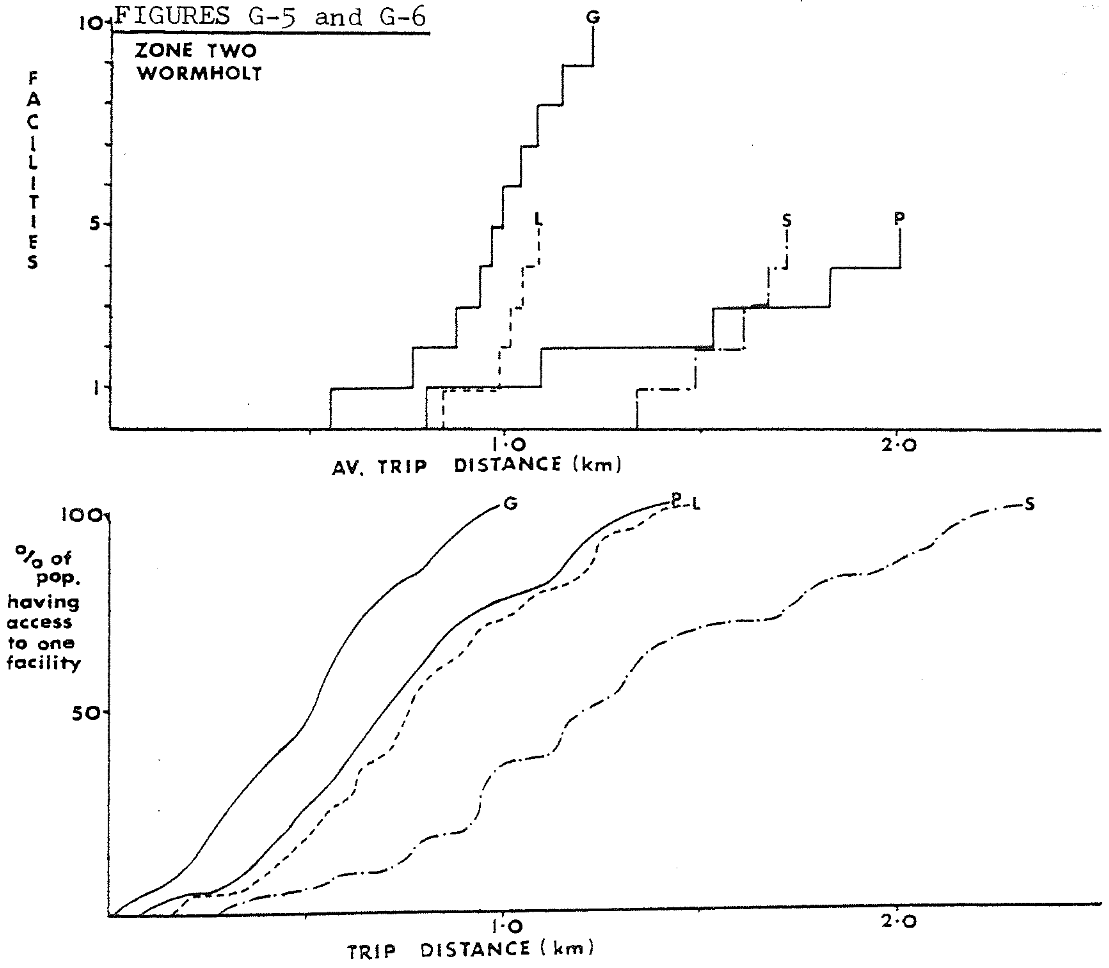
FIGURES G-1 and G-2



FIGURES G-3 and G-4

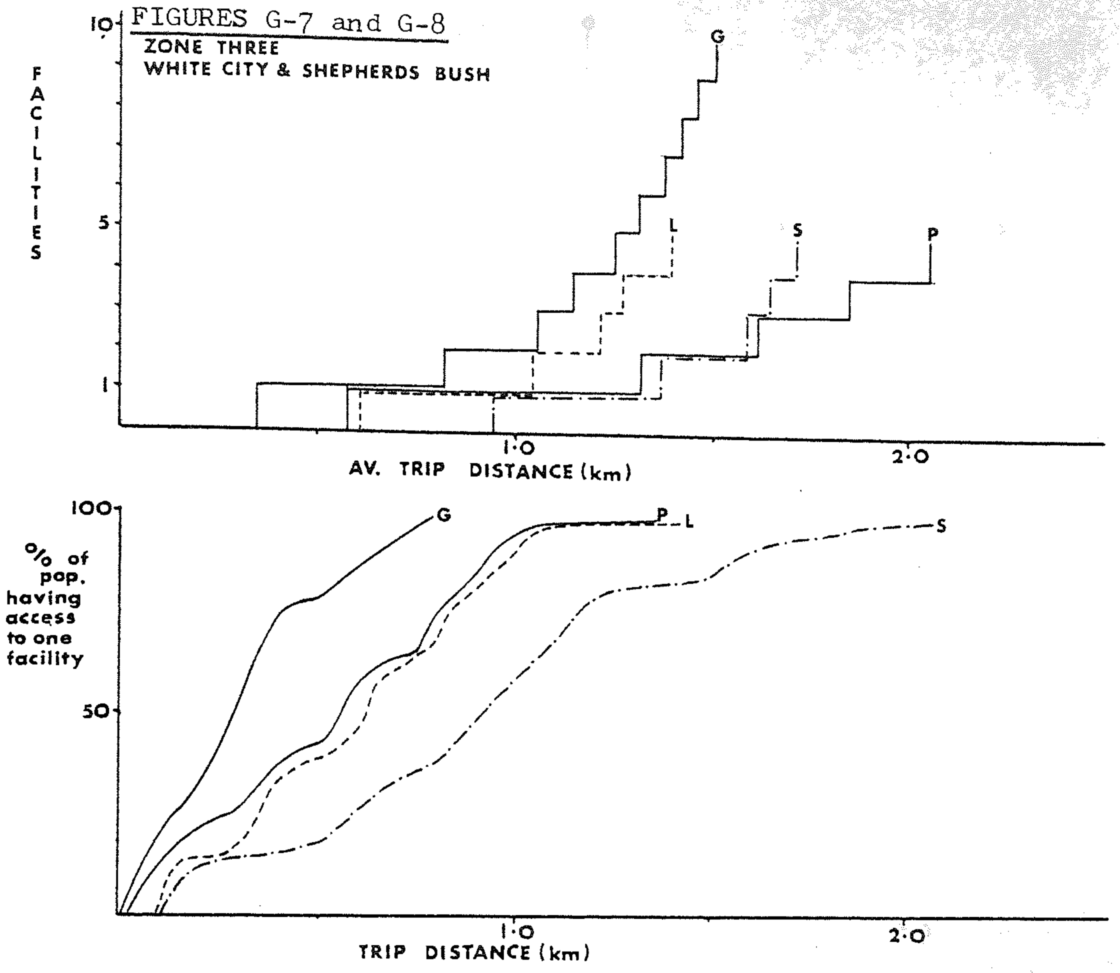


FIGURES G-5 and G-6



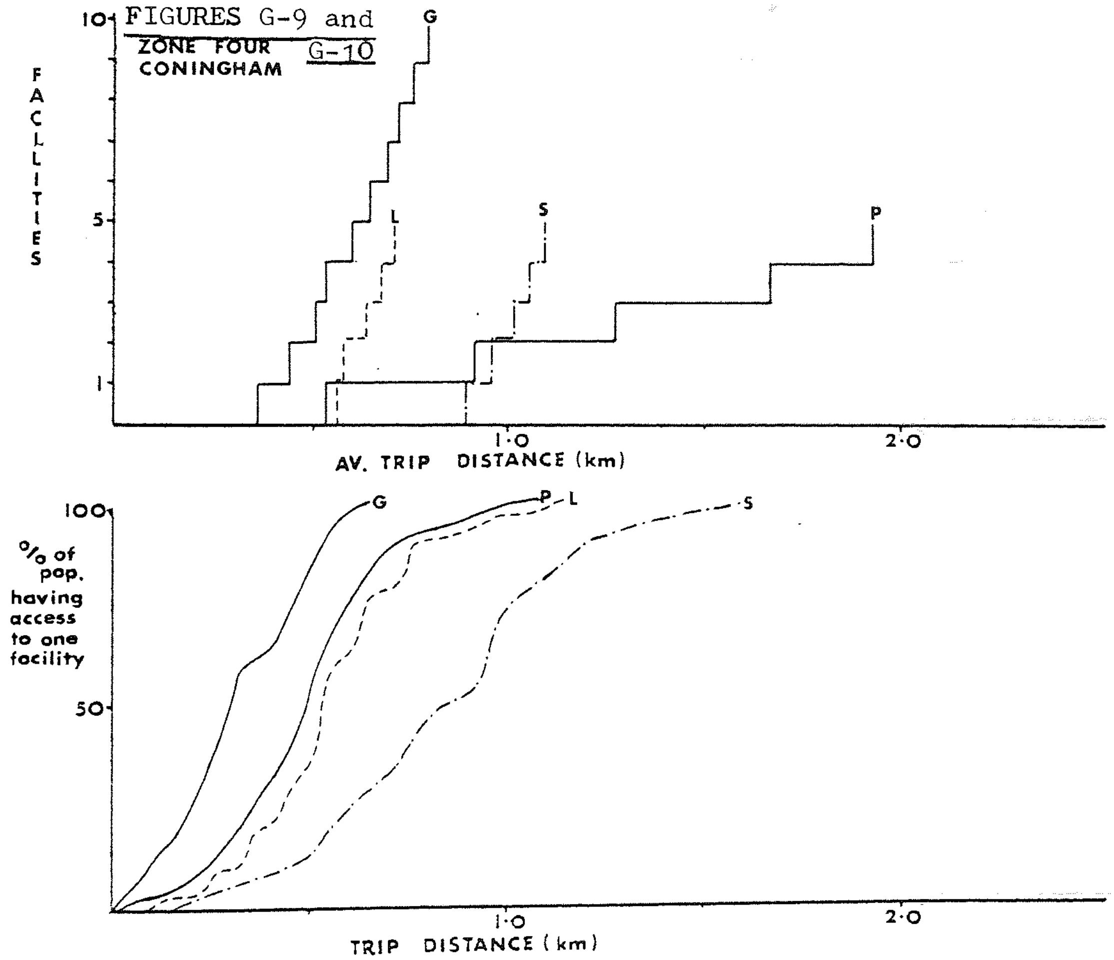
FIGURES G-7 and G-8

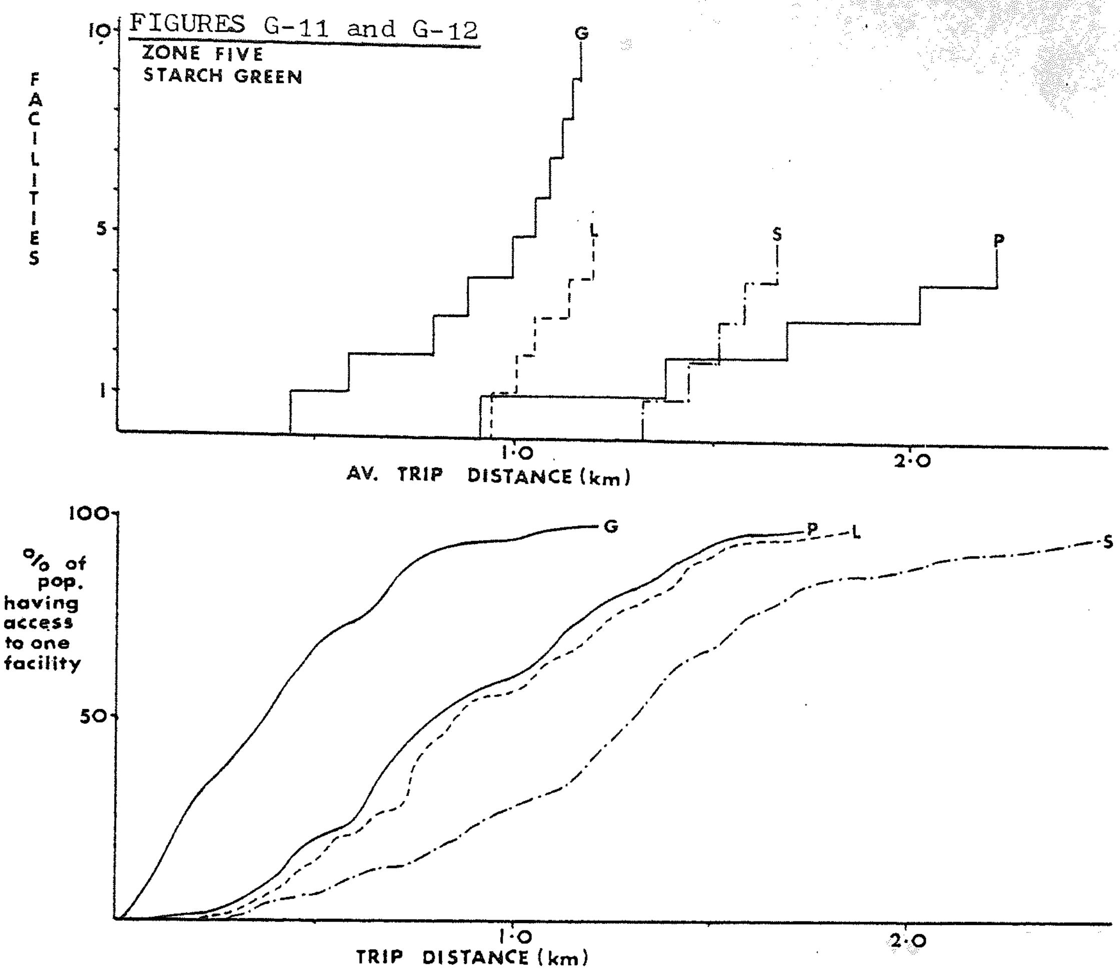
ZONE THREE
WHITE CITY & SHEPHERDS BUSH



FIGURES G-9 and G-10

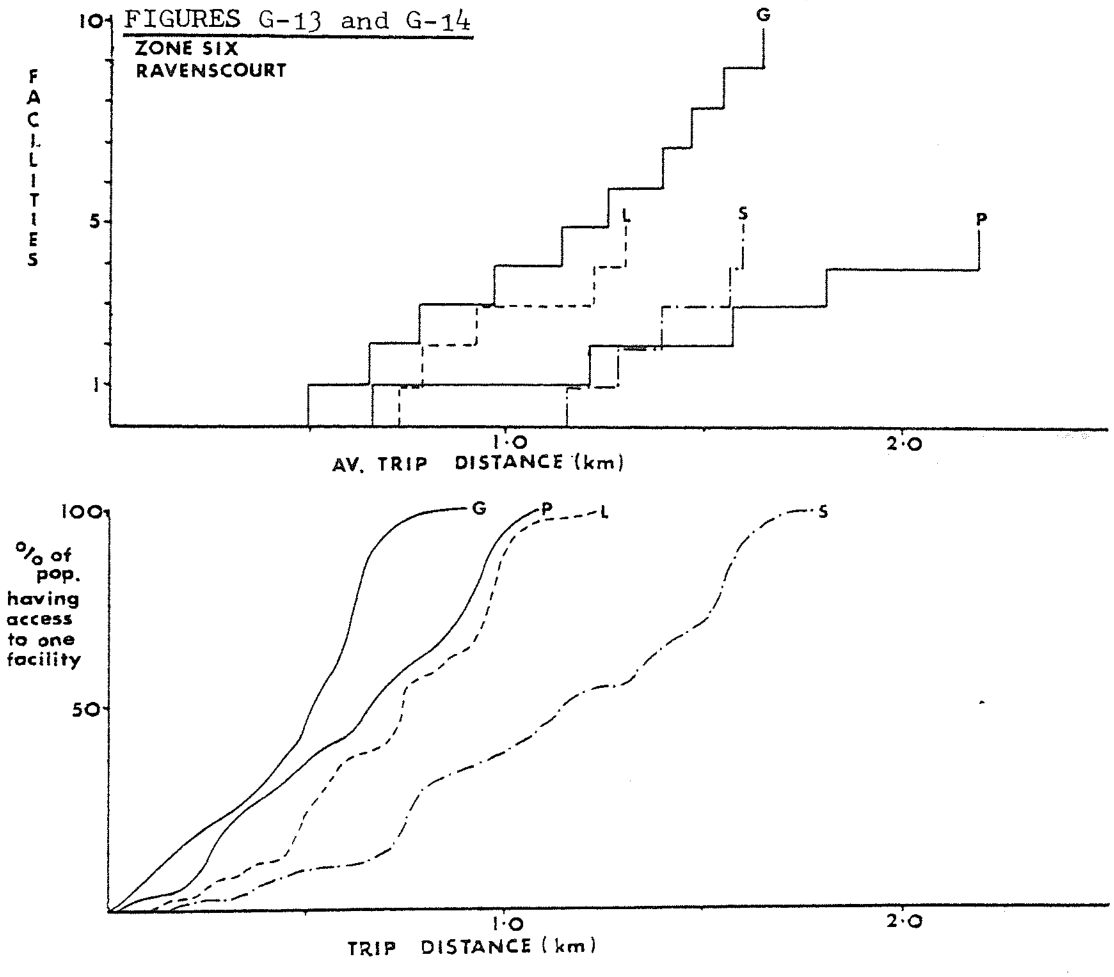
ZONE FOUR
CONINGHAM





FIGURES G-11 and G-12

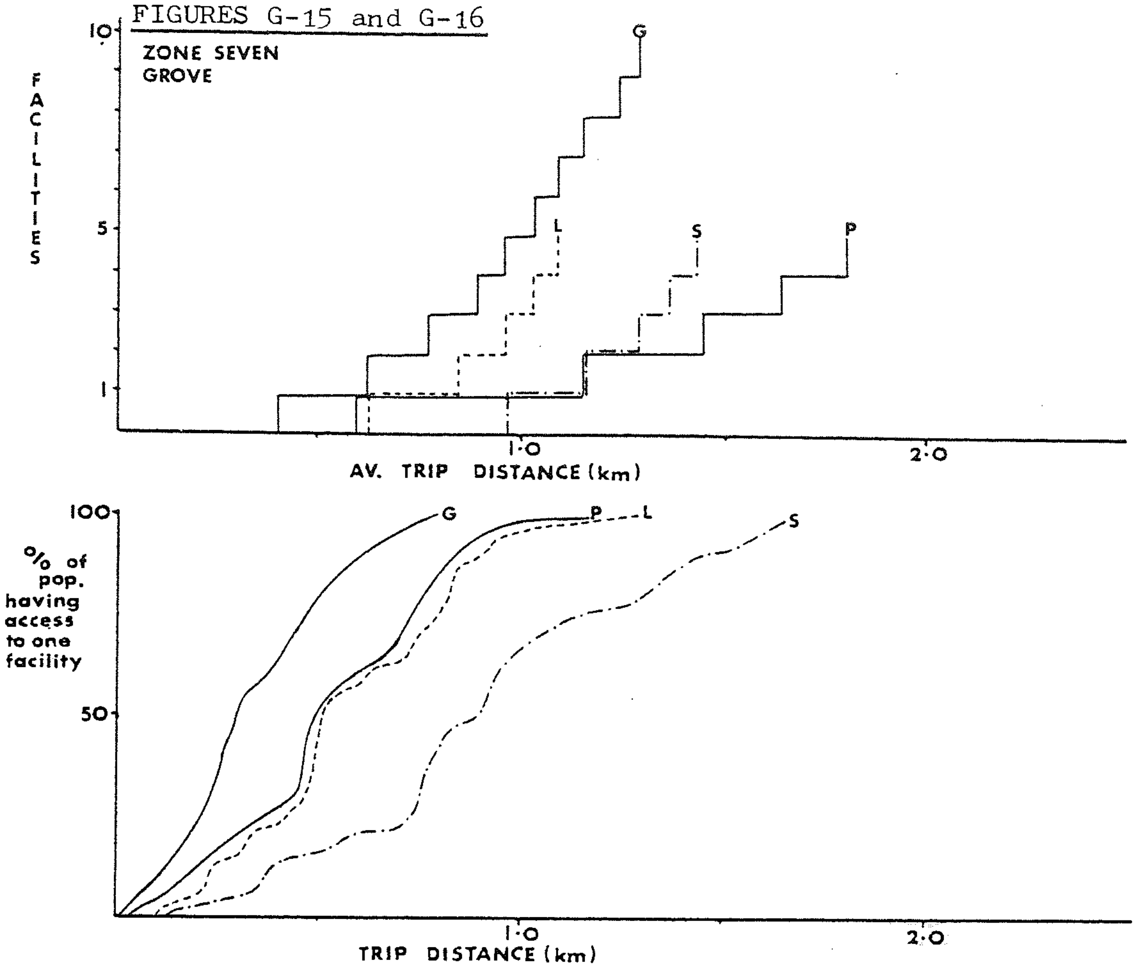
ZONE FIVE
STARCH GREEN



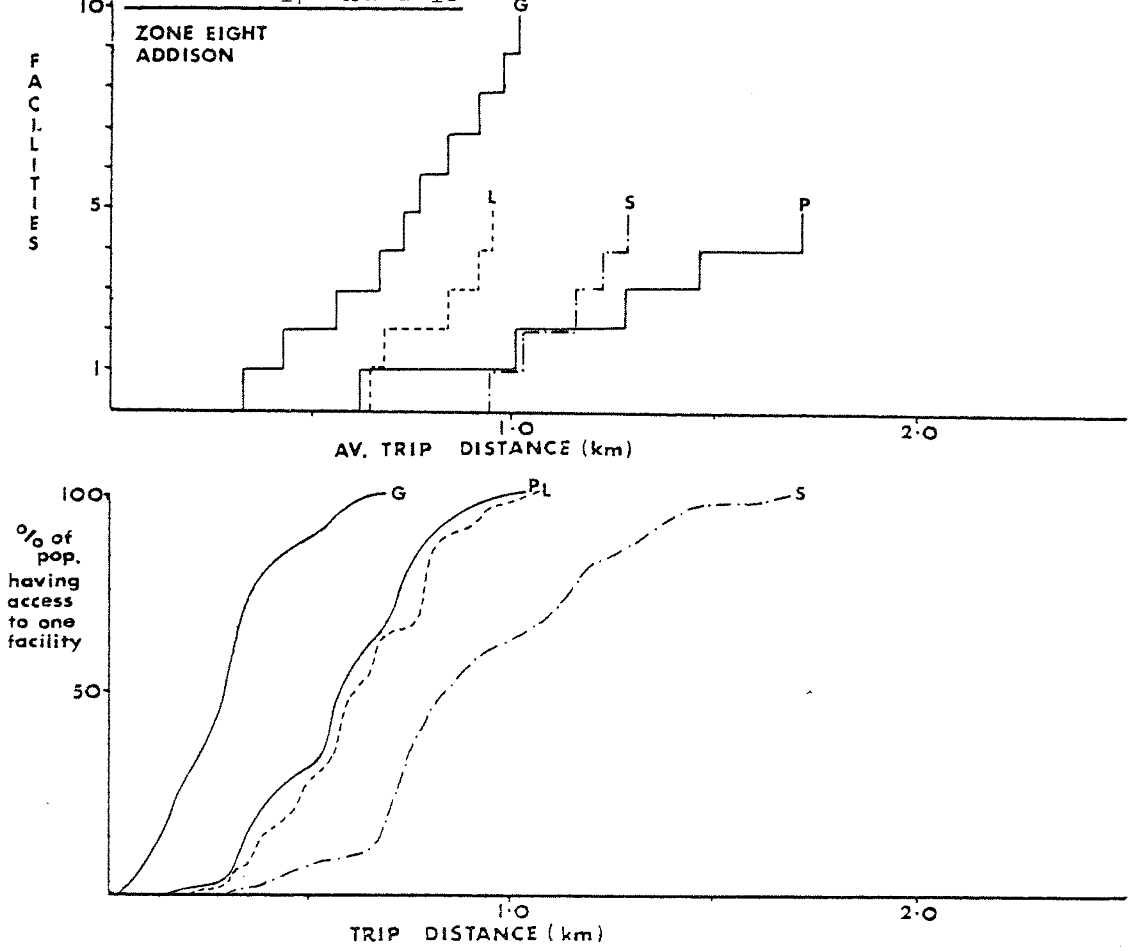
FIGURES G-13 and G-14

ZONE SIX
RAVENSCOURT

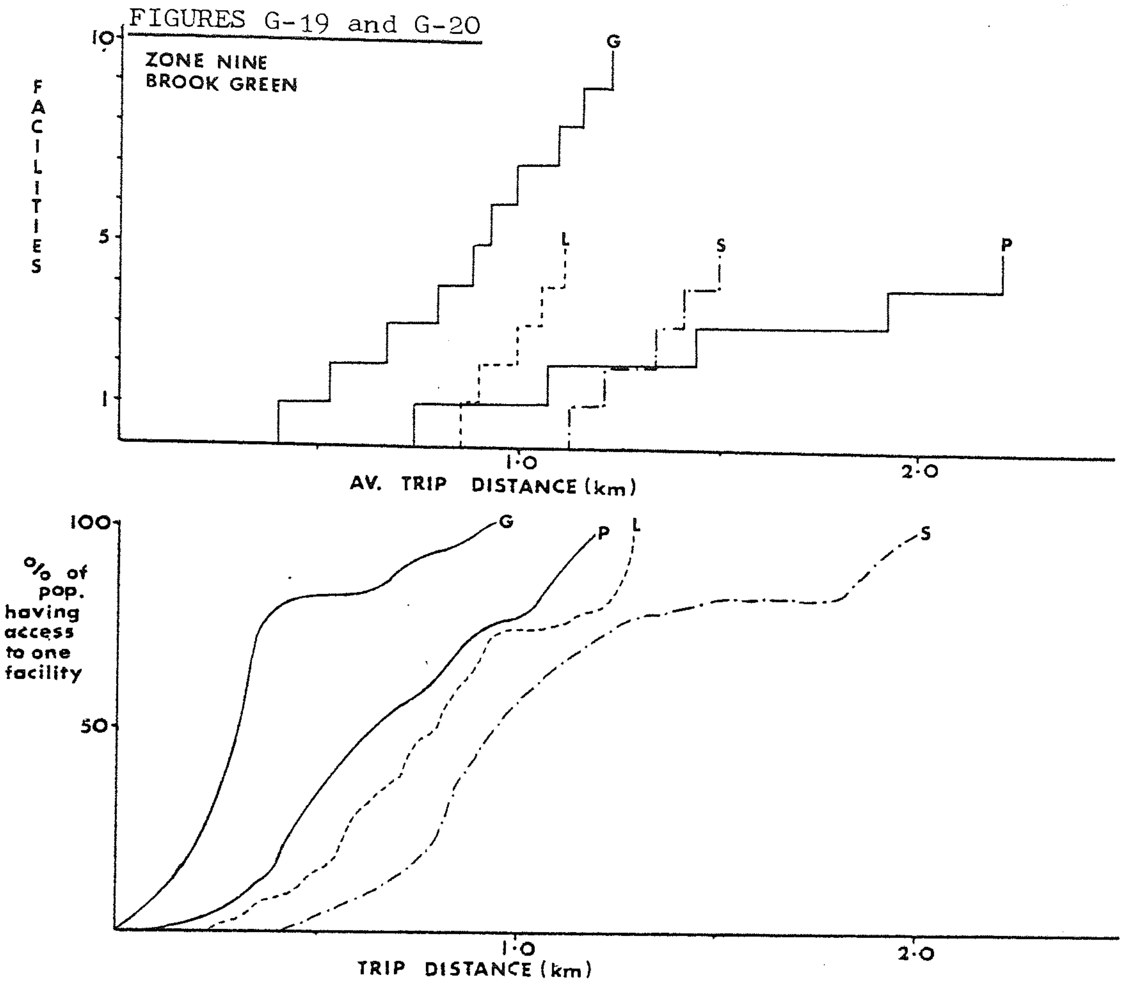
FIGURES G-15 and G-16



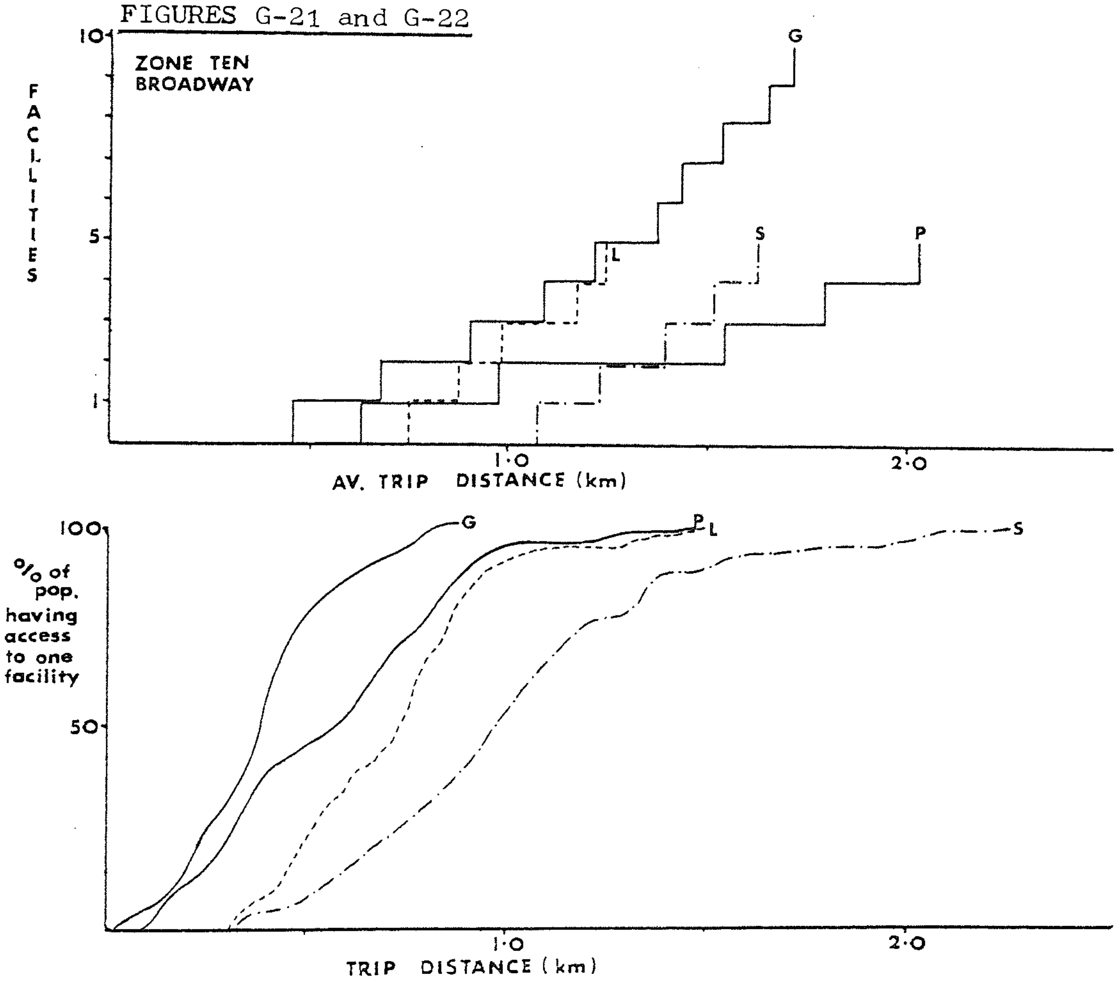
FIGURES G-17 and G-18

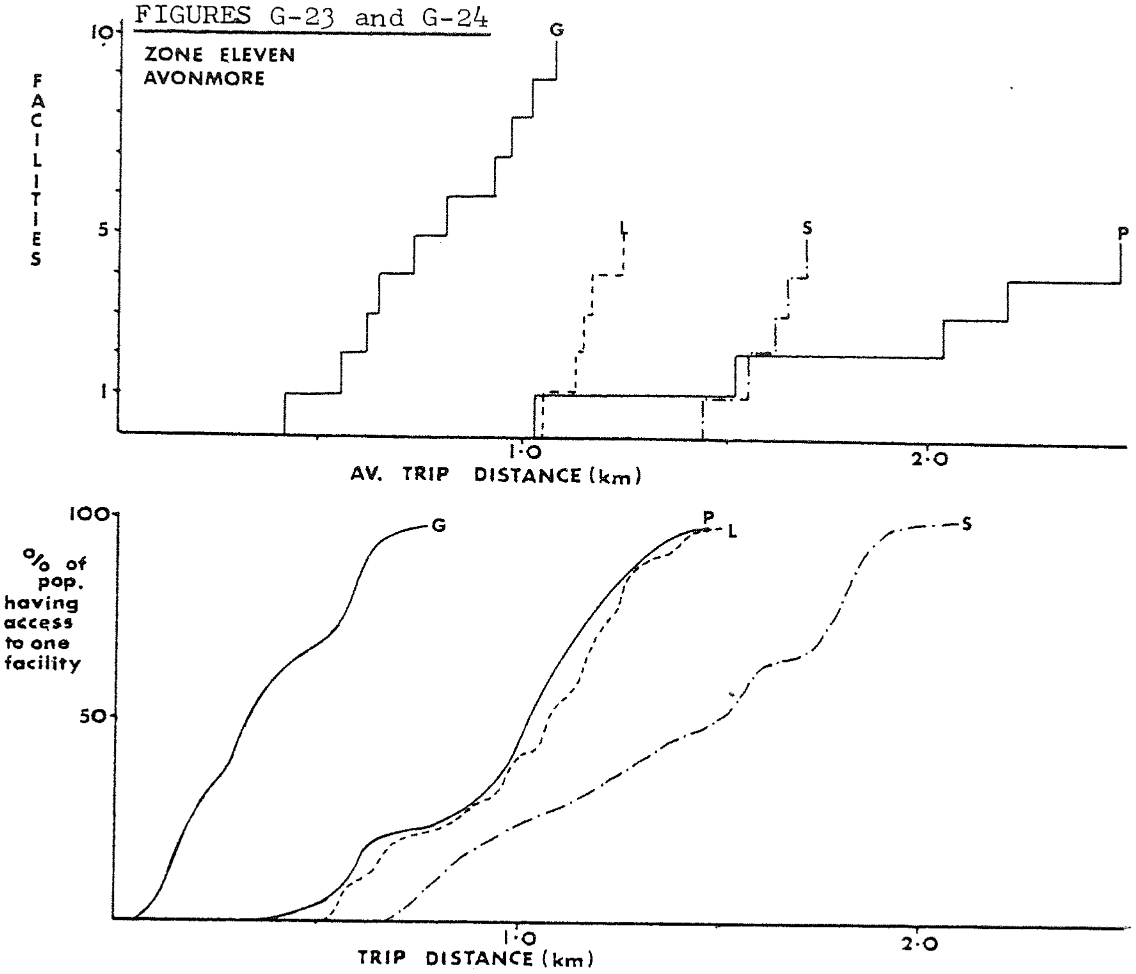


FIGURES G-19 and G-20

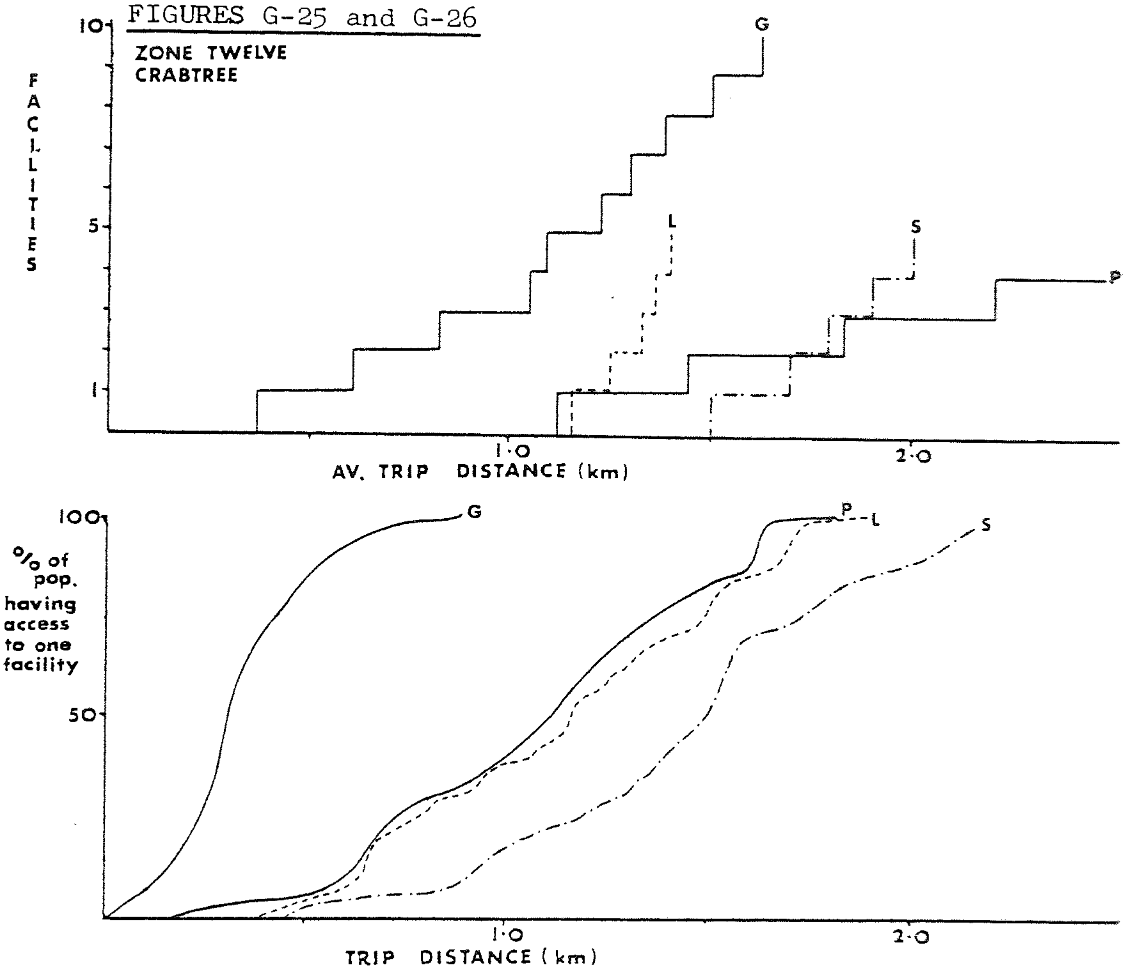


FIGURES G-21 and G-22



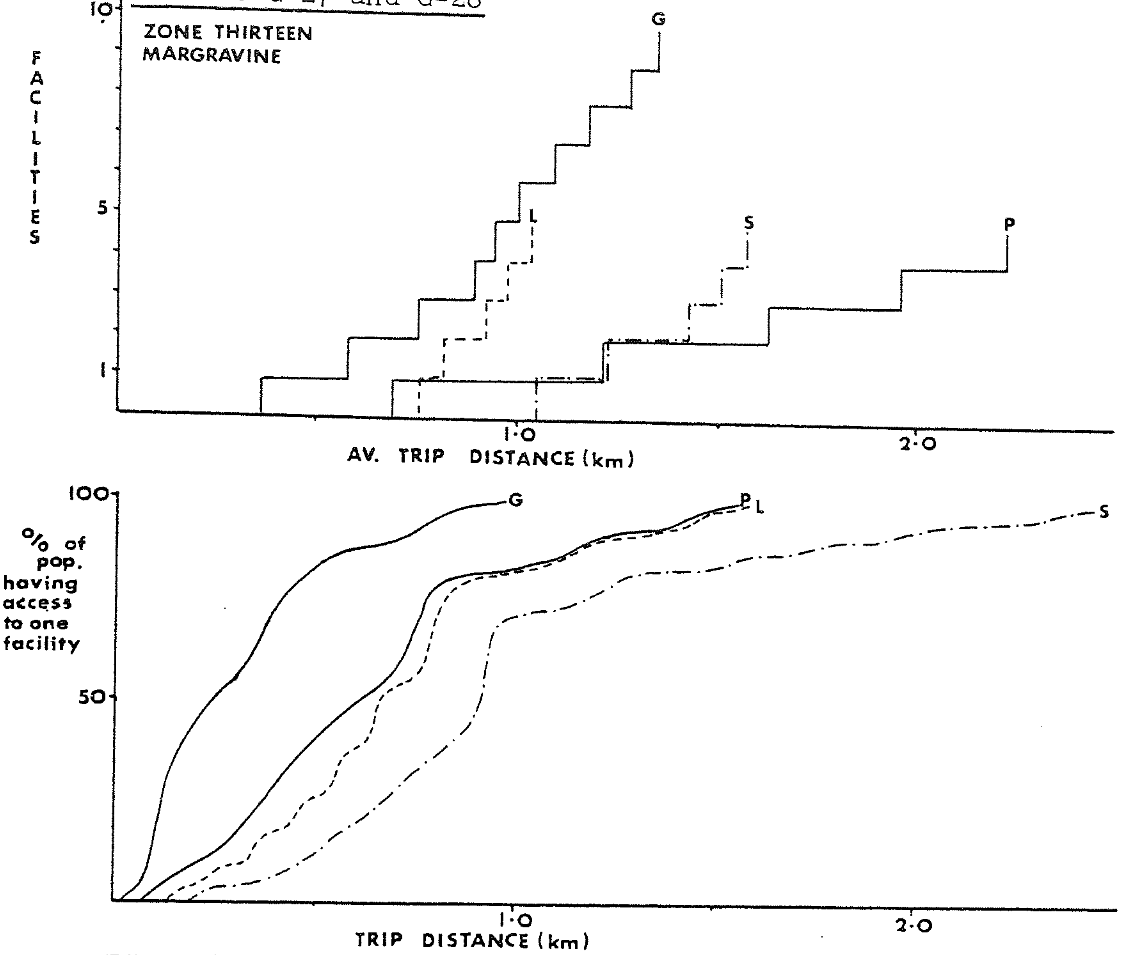


FIGURES G-23 and G-24

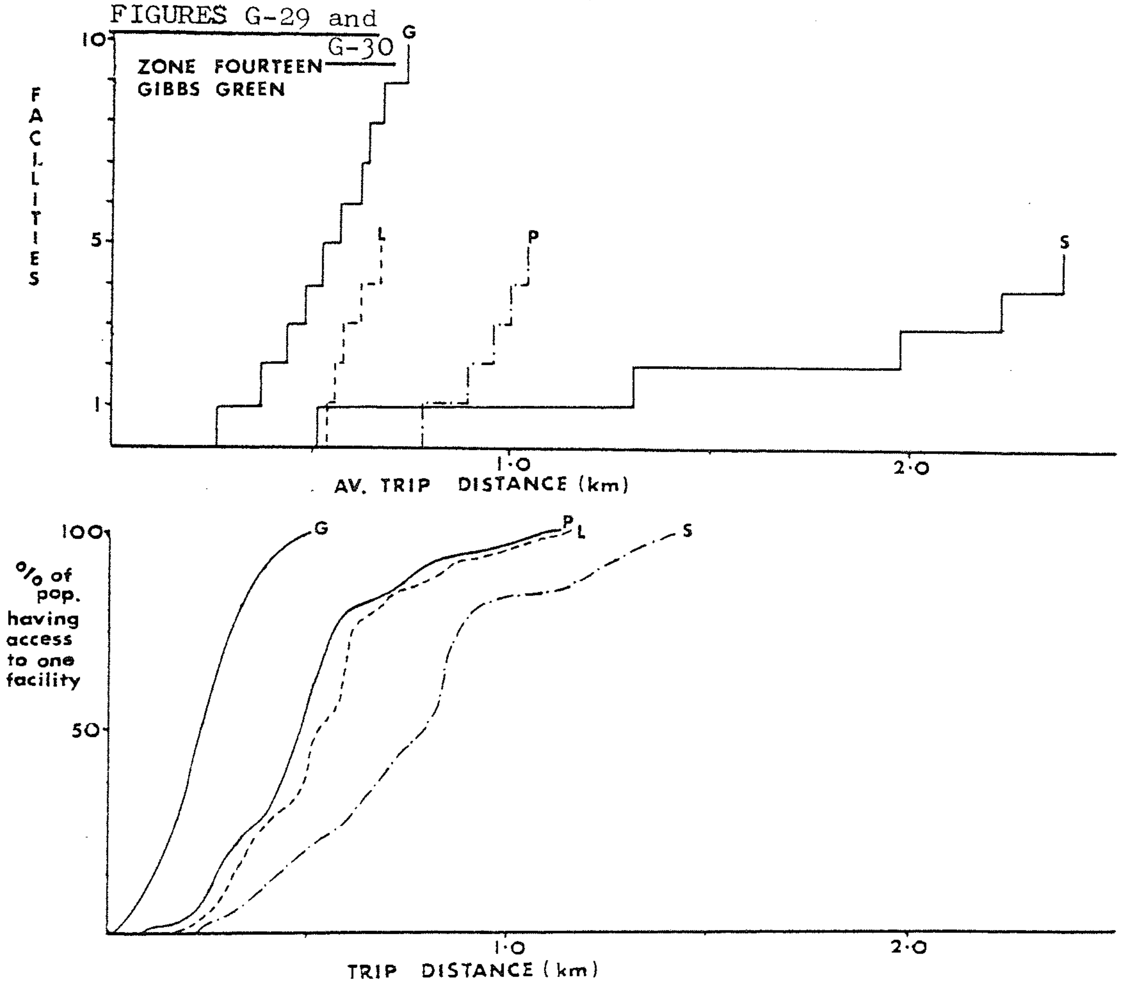


FIGURES G-25 and G-26

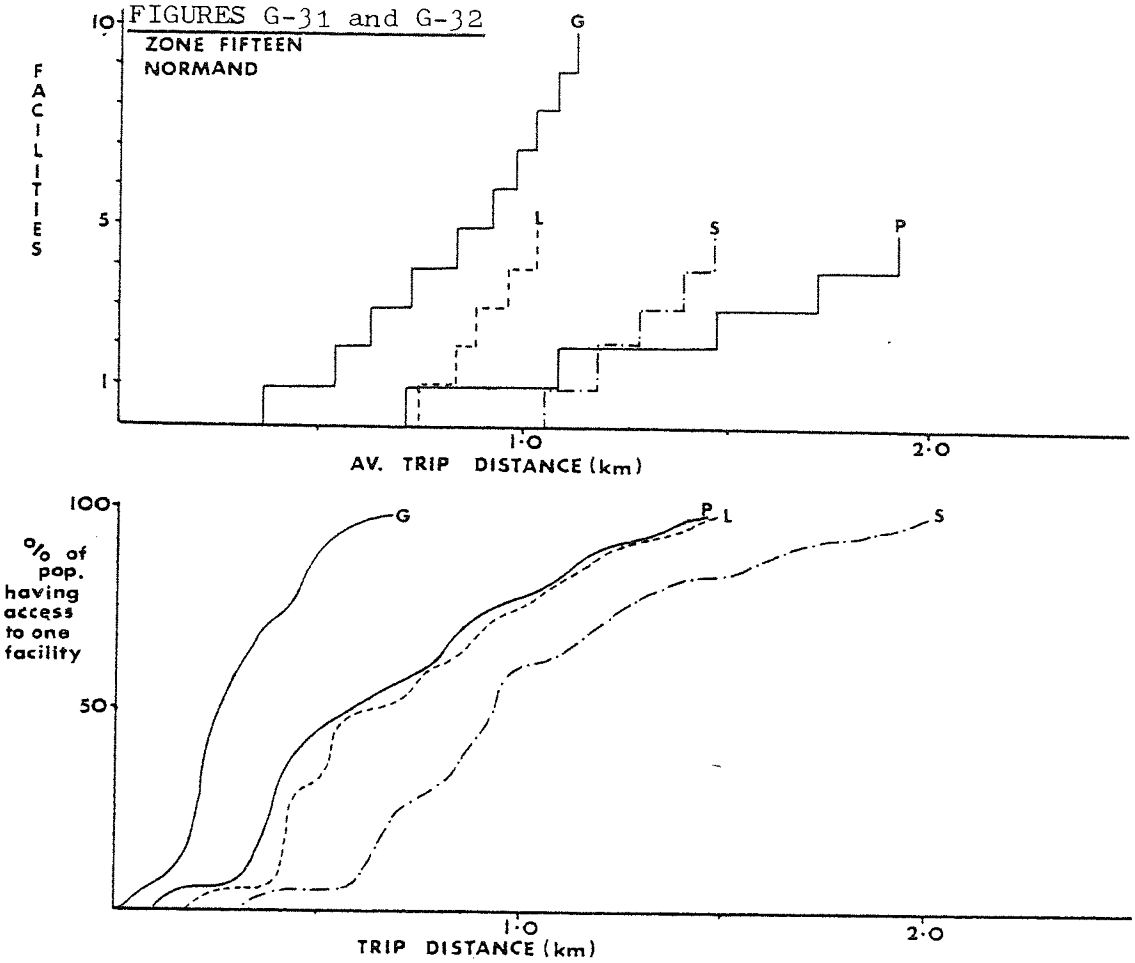
FIGURES G-27 and G-28



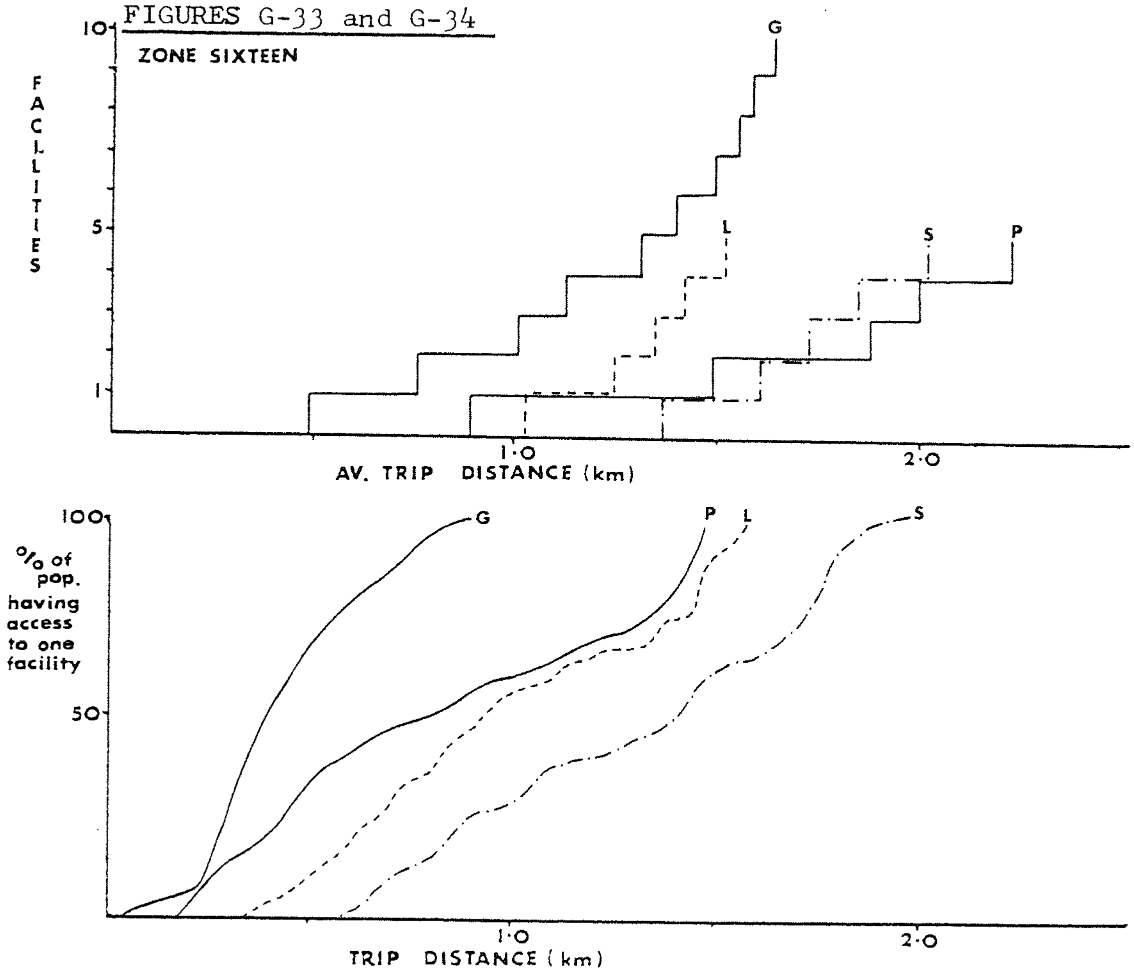
FIGURES G-29 and G-30



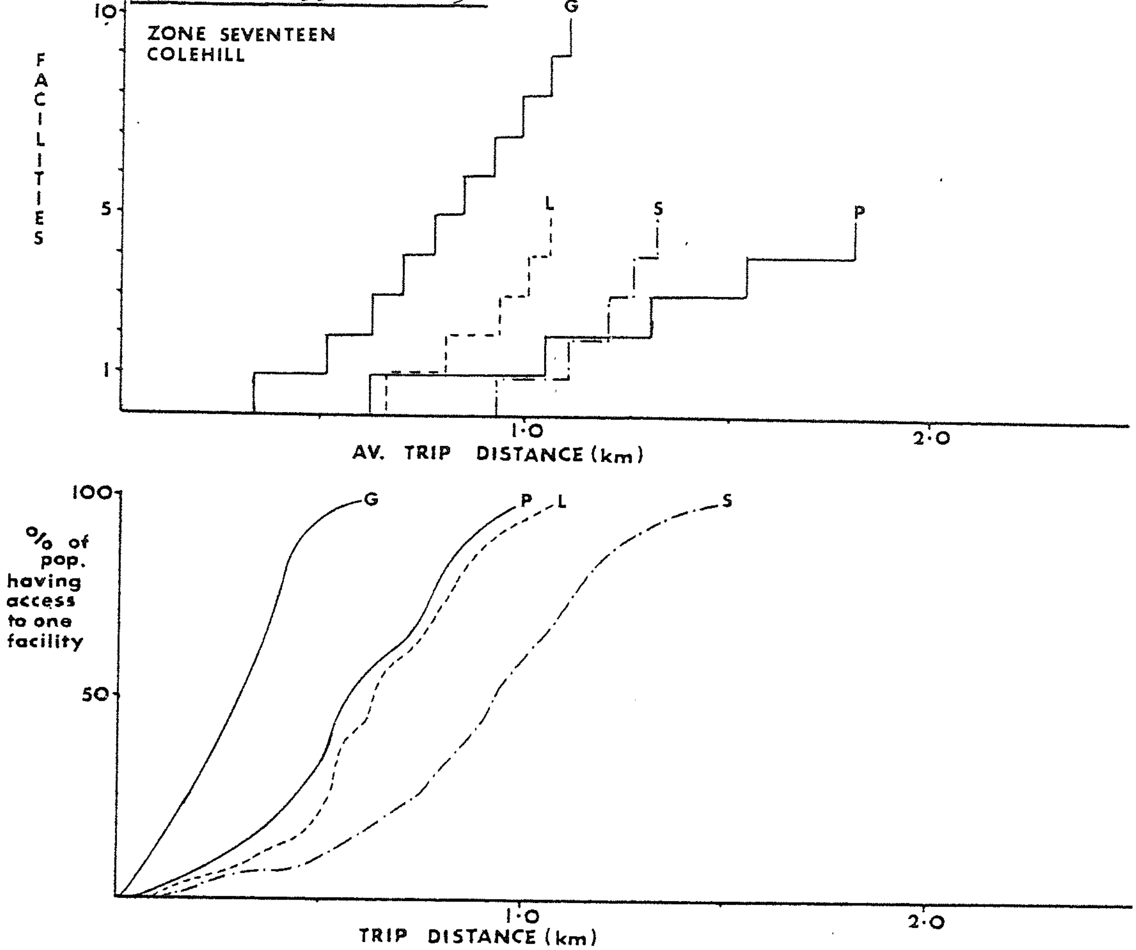
FIGURES G-31 and G-32



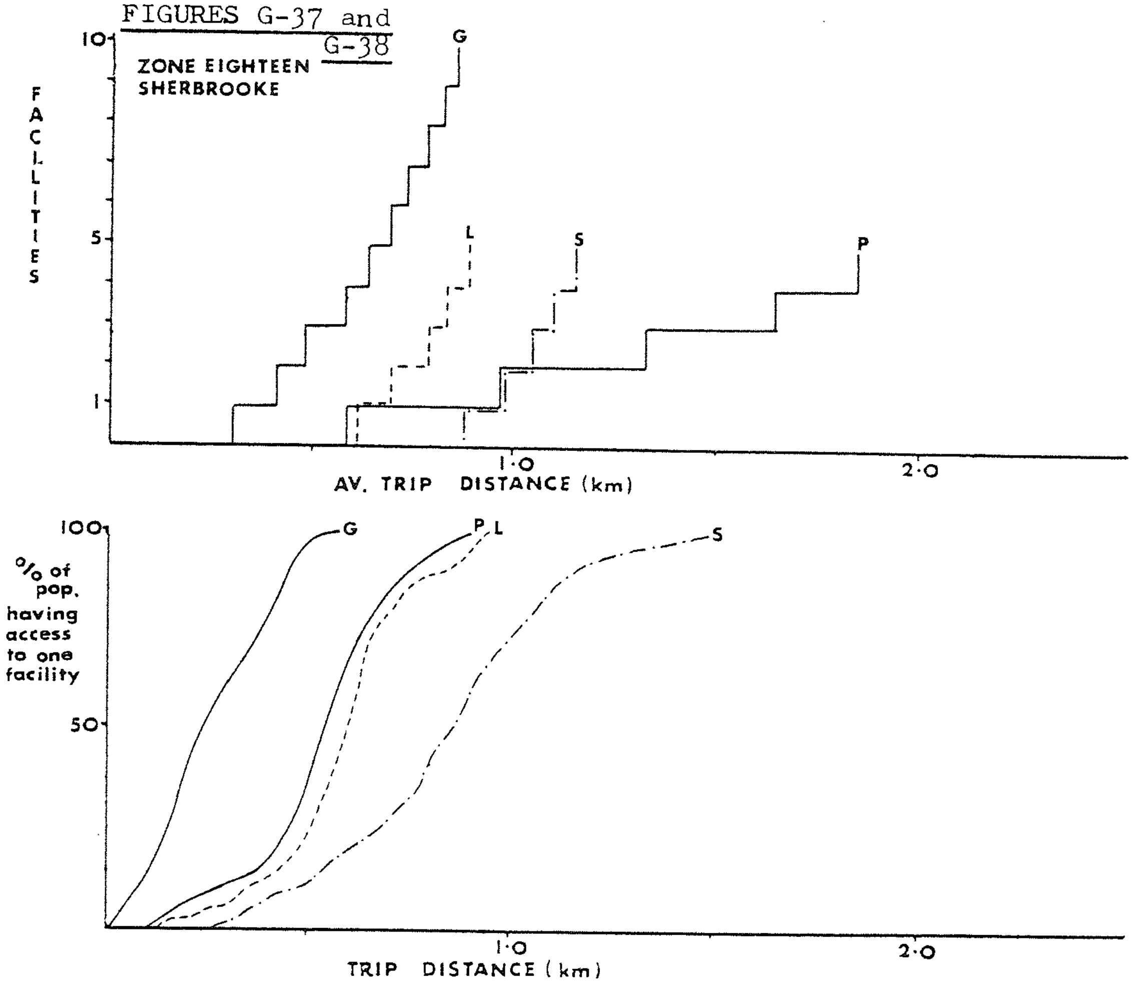
FIGURES G-33 and G-34



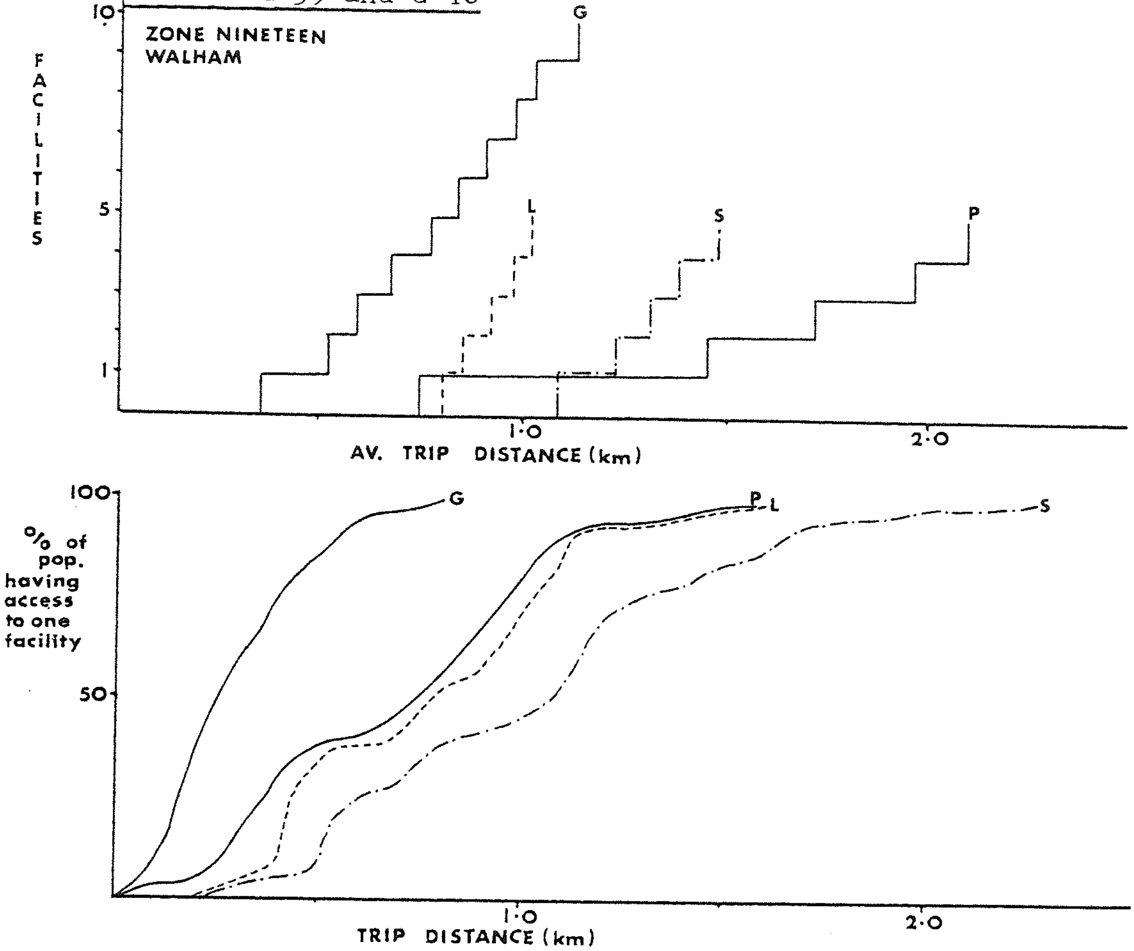
FIGURES G-35 and G-36



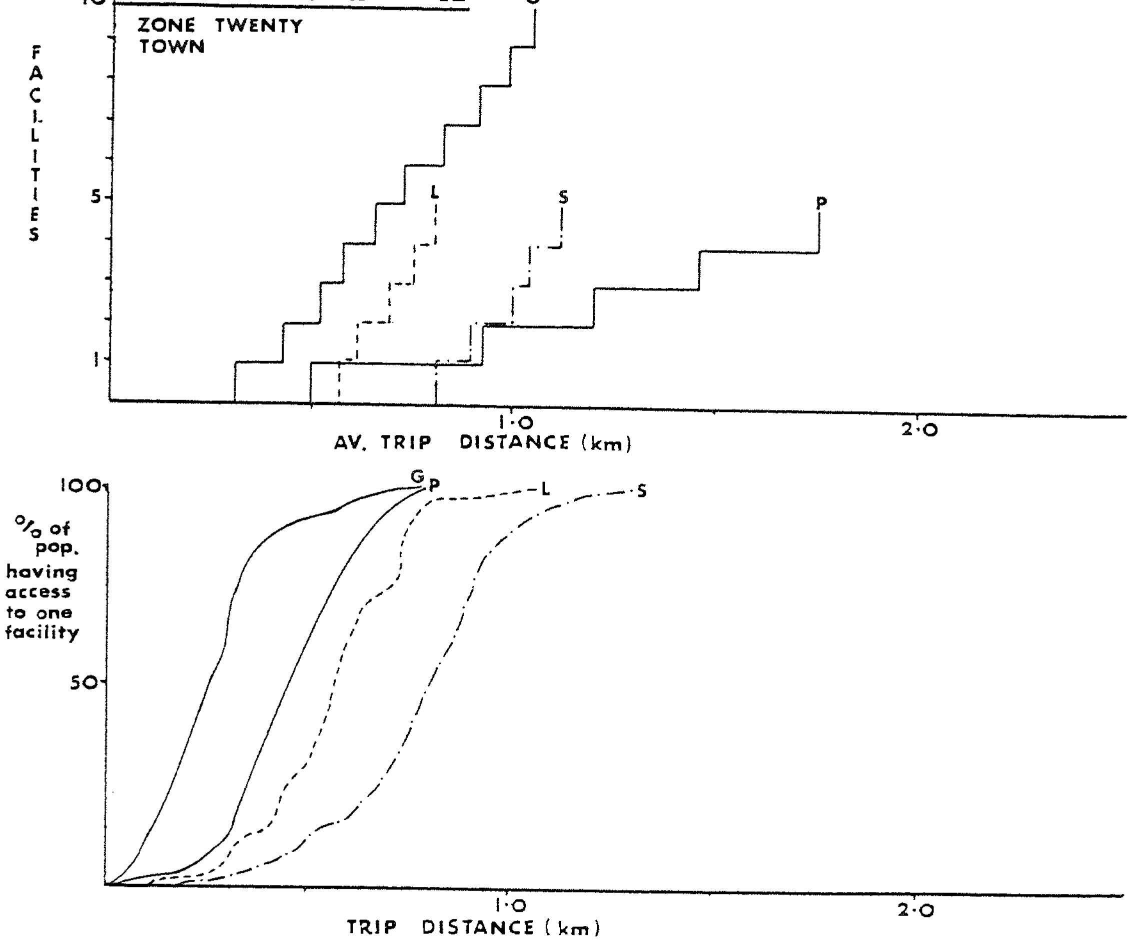
FIGURES G-37 and G-38



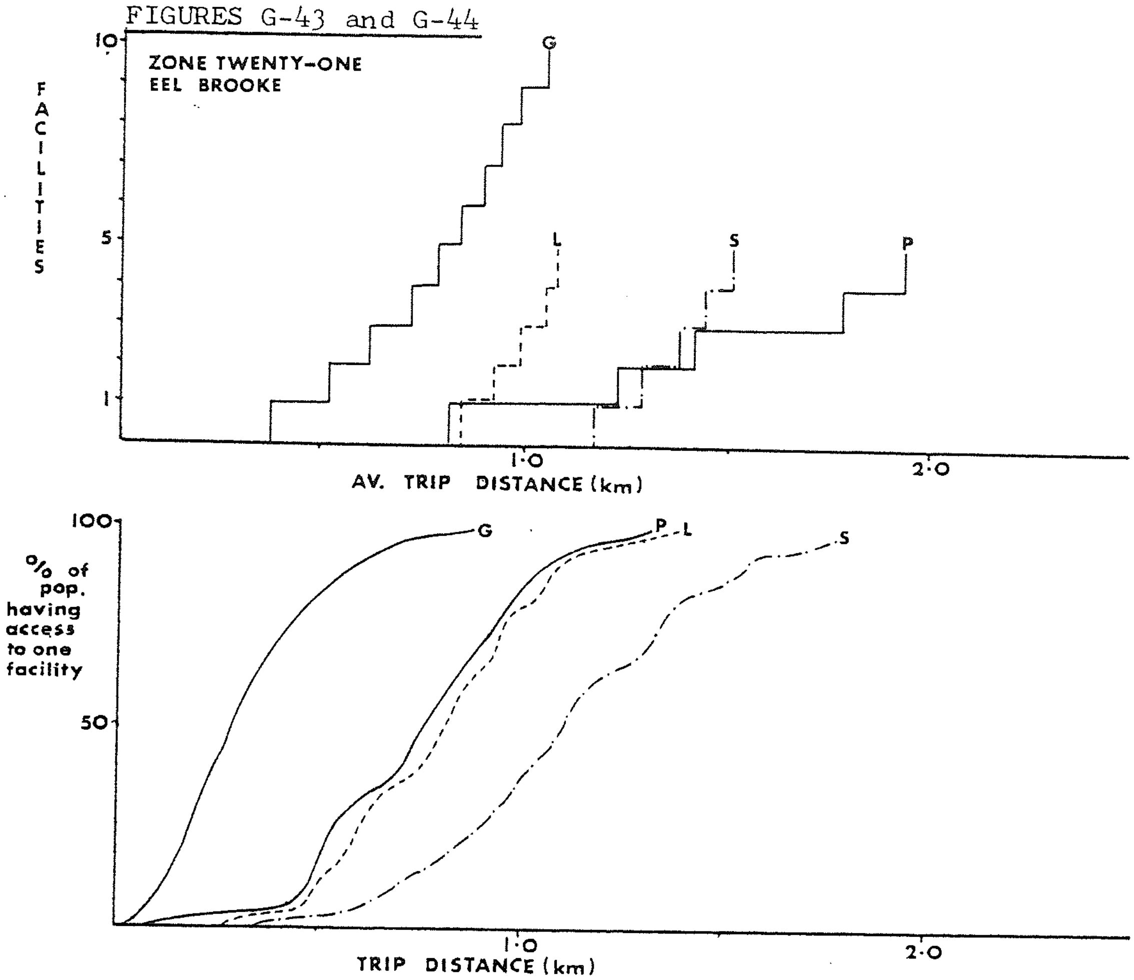
FIGURES G-39 and G-40



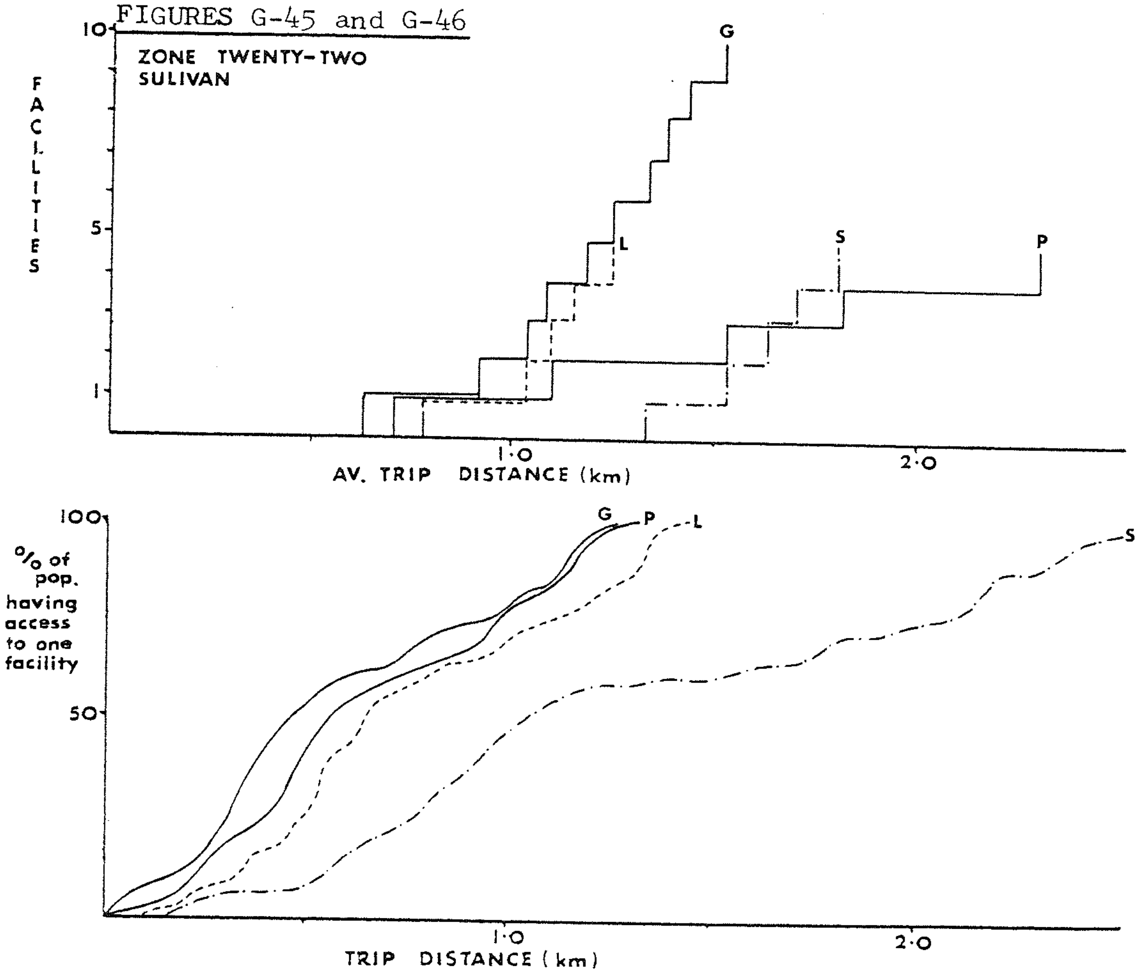
FIGURES G-41 and G-42



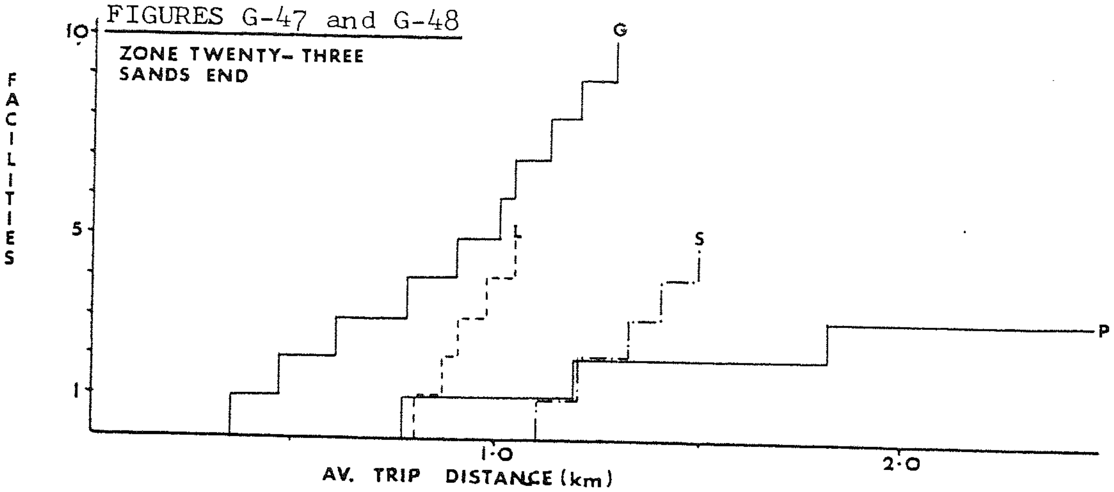
FIGURES G-43 and G-44

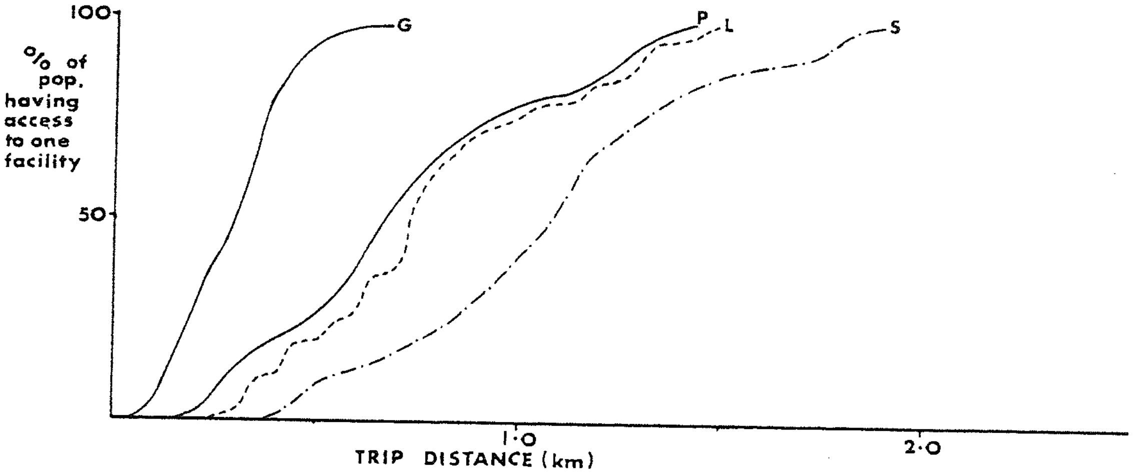


FIGURES G-45 and G-46



FIGURES G-47 and G-48





APPENDIX H

THE SENSITIVITY OF THE SPEARMAN RANK CORRELATION COEFFICIENT TO THE NUMBER OF PAIRS IN THE COMPARISON

In order to determine the extent to which the level of the Spearman rank correlation coefficient is sensitive to the high number of pairs for comparison (that is, 23) in analysing the rank order of zones based on different accessibility measures, the zones are divided into two groups based on the north and the south of the Borough. The zones in each group are ranked according to the mean average distance to the nearest and fifth nearest post office and the nearest, fifth nearest and tenth nearest grocers as shown in Table H - 1.

ZONES	RANK ORDER ACCORDING TO THE MEAN AVERAGE DISTANCE TO:				
	a	b	c	d	e
	NEAREST POST OFFICE	5TH NEAREST POST OFFICE	NEAREST GROCER	5TH NEAREST GROCER	10TH NEAREST GROCER
NORTH					
1	7th	11th	9th	8th	11th
2	9th	4th	11th	6th	5th
3	3rd	6th	3rd	11th	8th
4	1st	3rd	2nd	1st	1st
5	10th	9th	7th	7th	4th
6	6th	7th	10th	9th	9th
7	2nd	2nd	4th	5th	7th
8	4th	1st	1st	3rd	2nd
9	8th	8th	5th	4th	6th
10	5th	5th	8th	10th	10th
11	11th	10th	6th	2nd	3rd
SOUTH					
12	12th	11th	10th	10th	11th
13	5th	8th	9th	9th	9th
14	2nd	10th	1st	1st	1st
15	7th	4th	7th	7th	6th
16	11th	7th	11th	12th	12th
17	4th	2nd	4th	5th	5th
18	3rd	3rd	2nd	2nd	2nd
19	8th	6th	6th	4th	7th
20	1st	1st	3rd	3rd	3rd =
21	10th	5th	8th	6th	3rd =
22	6th	9th	12th	11th	10th
23	9th	12th	5th	8th	8th

TABLE H - 1 Accessibility Rank Orders for Zones in the North and South of the Study Area

The coefficients of correlation for each of the following comparisons, both before and after the number of zones are divided into two groups, are calculated as shown in Table H - 2.

RANK ORDER COMPARISONS BETWEEN COLUMNS	ZONE GROUPS	SPEARMAN'S RANK CORRELATION COEFFICIENT (r_s)	SIGNIFICANCE LEVEL (%)	EQUIVALENT SIGNIFICANCE LEVEL FOR r_s FOR ALL ZONES
a - b	NORTH	0.70	99.0	99.5
	SOUTH	0.48	-	
c - d	NORTH	0.46	-	99.9
	SOUTH	0.93	99.9	
c - e	NORTH	0.55	-	99.9
	SOUTH	0.91	99.9	
d - e	NORTH	0.83	99.05	99.9
	SOUTH	0.94	99.9	

TABLE H - 2 Spearman's Rank Correlation Coefficients for Comparisons Between Rank Orders for Zones in the North and South of the Study Area

It is noted that by reducing the number of pairs for comparison, the coefficient of correlation falls and indicates a significant correlation at the 99.9% level in only three of the rank order comparisons. In the south of the Borough the rank order for different levels of opportunity for the grocers are more closely matched than in the north of the Borough or for post office opportunities. It is indicated, therefore, that the degree of statistical significance of the correlation between the ranks is sensitive to the number of pairs in the comparison, although the correlation is still significant at least at the 99.0% level in five out of the eight comparisons.

APPENDIX I

THE SPECIFICATION OF THE LOW AND HIGH ACCESSIBILITY GROUPS AND THE LOW AND HIGH POTENTIAL DISTANCE SAVING GROUPS FOR TESTING HYPOTHESES H.3, H.4 AND H.5

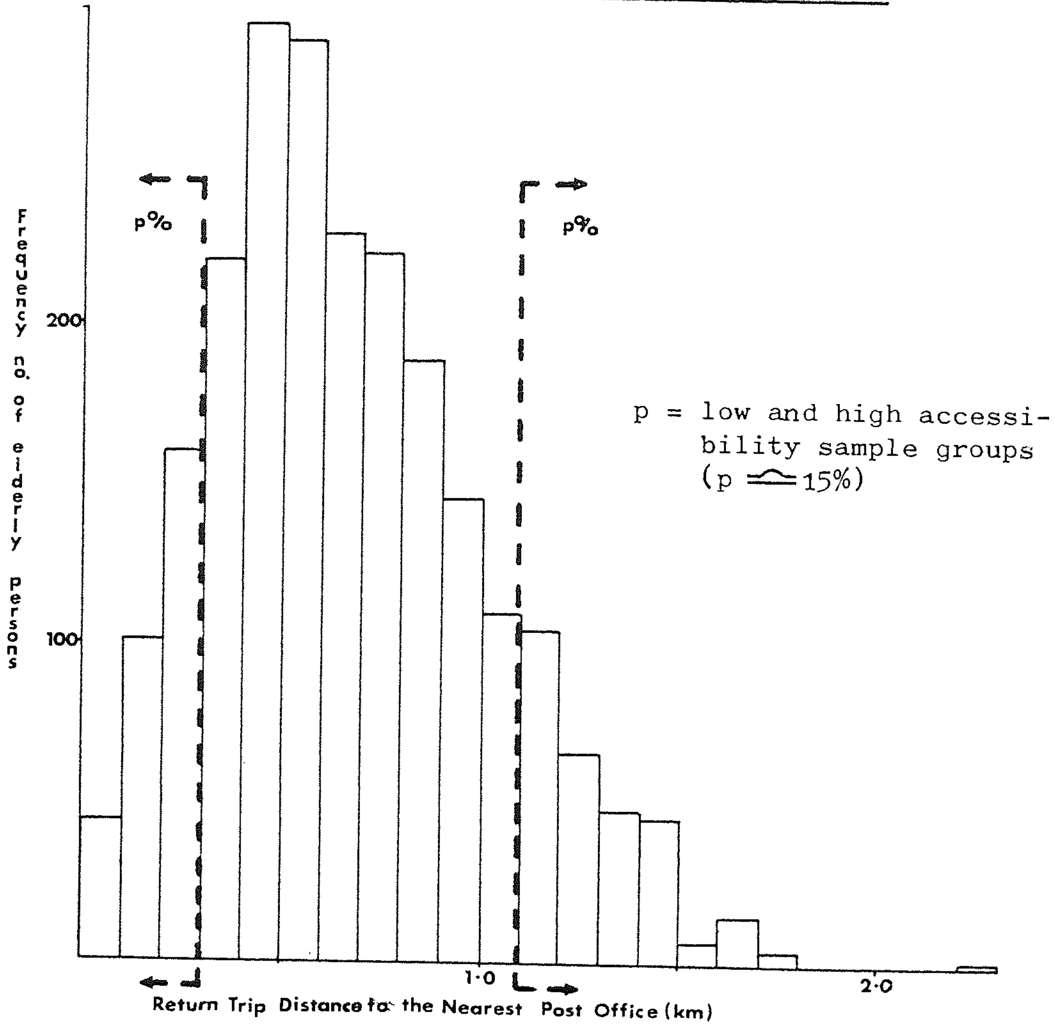


FIGURE I - 1

THE FREQUENCY DISTRIBUTION OF INDIVIDUAL ACCESSIBILITIES TO THE NEAREST POST OFFICE

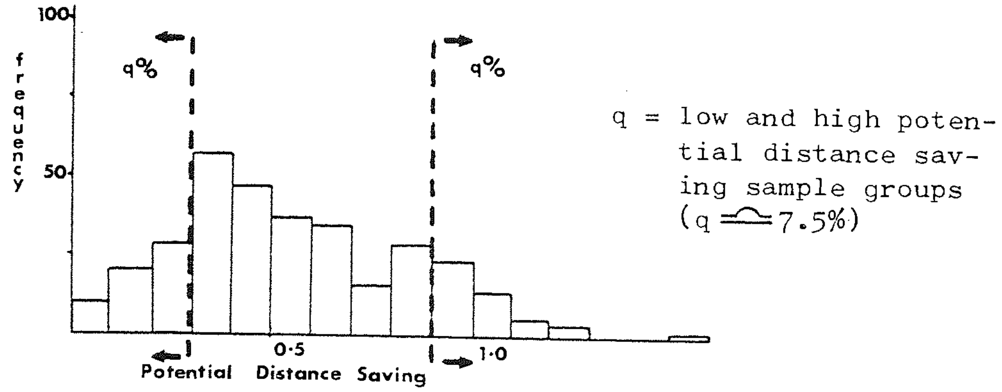


FIGURE I - 2

THE FREQUENCY DISTRIBUTION OF THE POTENTIAL DISTANCE SAVINGS OF INDIVIDUALS WITH LOW ACCESSIBILITY

APPENDIX J

THE TRAVEL SURVEY LETTER AND QUESTIONNAIRE

i) THE LETTER:

THE UNIVERSITY
OF ASTON
IN BIRMINGHAM

Department of Architectural Planning and Urban Studies
Head of Department:
Professor E A Rose MSc, DipArch, DipTP, FRTPI, ARIBA, FRSA

Joint Unit for Research on the Urban Environment
Gosta Green, Birmingham B4 7ET/Tel: 021.359 3611

Head: F E Joyce MA, DipSocAdmin

Dear Sir/Madam,

Hammersmith and Fulham Accessibility Study.

The University of Aston in conjunction with the London Borough of Hammersmith and Fulham is carrying out a survey of travel patterns of residents in this area.

Interview surveys are being carried out with a random sample of residents, and your name has been chosen as part of this sample.

The results of this research will assist in the planning of transport facilities for everyone in the Borough. An interviewer will be calling on you on ___________ and it would greatly assist this work if you would co-operate by answering a few questions dealing with your daily travelling. Any information given will be treated with the strictest confidence. Interviewers will carry a letter of identification, you are entitled to ask to see this letter.

If you require further information, please ring Mr. Dallal, Transport Networks Group, London Borough of Hammersmith and Fulham on 748-3020 Ex. 486.

Thank you for your help.

ii) THE QUESTIONNAIRE

ACCESSIBILITY STUDY

INTERVIEW NO. ☐ REF. NO ☐

RESPONDENTS NAME ____________________

RESPONDENTS ADDRESS ____________________

____

____

PART A. TRIP-MAKING Q.1. HAVE YOU VISITED THE POST OFFICE IN THE LAST MONTH? (tick appropriate box) YES ☐ NO ☐ If YES go to Q.3.	CODING TRIP-MAKER = 1 NON-TRIPMAKER = 2 ☐
If NO ask Q.2. then end interview Q.2. WHY NOT? ____________________ ____________________ ____________________ ____________________	
Q.3. DO YOU NORMALLY DO, OR HELP WITH, THE MAIN FOOD SHOPPING FOR YOUR HOUSEHOLD? YES ☐ NO ☐ If YES go to PART B	TRIP-MAKER = 1 NON-TRIP MAKER = 2 ☐
If NO: Q.4. WHY NOT? ____________________ ____________________ ____________________ ____________________	

PART B. PERSONAL & HOUSEHOLD CHARACTERISTICS.

		CODING
Q. 5.	WHAT IS YOUR PRESENT OCCUPATION? ________	RETIRED = 1 EMPLOYED = 2. ☐
Q. 6.	DO YOU HAVE REGULAR USE OF A CAR DURING THE DAY - EITHER AS A DRIVER OR A PASSENGER? YES ☐ NO ☐	CAR AVAILABLE = 1 CAR NOT AVAILABLE = 2 ☐
Q. 7.	PLEASE CAN YOU TELL ME WHO ELSE LIVES IN THIS HOUSEHOLD? WHAT IS THEIR RELATIONSHIP TO YOU? (List in Table X). TABLE X Persons in household (relationship to the respondent) ________ ________ ________ ________ ________ ________ ________	SINGLE HOUSEHOLD = 1 FAMILY HOUSEHOLD = 2 ☐

PART C. POST OFFICE TRIPS.	CODING
Q. 8. HOW OFTEN DO YOU NORMALLY VISIT THE POST OFFICE? MORE THAN ONCE A WEEK ☐ ONCE A WEEK ☐ ONCE A FORTNIGHT ☐ LESS THAN ONCE A FORTNIGHT ☐	= 4 = 3 = 2 = 1 ☐
Q. 9. WHICH POST OFFICE DO YOU USUALLY GO TO? ____________________ ____________________ (write address)	
Q.10 WHAT MEANS OF TRANSPORT DO YOU USE FOR THIS JOURNEY? ____________________	WALKING = 1 CAR = 2 PUBLIC = 3 OTHER = 0 ☐
Q.11 DO YOU USUALLY MAKE A SPECIAL JOURNEY TO THE POST OFFICE OR DO YOU COMBINE IT WITH A JOURNEY TO SOMEWHERE ELSE? SPECIAL TRIP ☐ COMBINED TRIP ☐ If a SPECIAL TRIP go to PART D If a COMBINED TRIP:	LINKED TRIP = 1 SINGLE-PURPOSE TRIP=2 ☐
Q.12 WHAT OTHER PLACES DO YOU USUALLY VISIT WHEN YOU GO TO THE POST OFFICE? TYPE OF FACILITY ________ APPROX. ADDRESS ________ (If answer SHOPPING note typeof shops) ________ ________ ________ ________ ________ ________	LINKED GROCER TRIP=1 LINKED OTHER TRIP = 2 ☐
Q.13 WHAT MEANS OF TRANSPORT DO YOU USE FOR GETTING BETWEEN THE POST OFFICE AND THESE OTHER FACILITIES? (If more than one, note all modes - including walking) ____________ ____________	WALKING = 1 CAR = 2 PUBLIC = 3 OTHER = 0 ☐

PART D. FOOD SHOPPING TRIPS.

CODING

Q.14. HOW OFTEN DO YOU DO THE MAIN FOOD SHOPPING ?

MORE THAN TWICE A WEEK ☐ = 4
TWICE A WEEK ☐ = 3
ONCE A WEEK ☐ = 2
LESS THAN ONCE A WEEK ☐ = 1 ☐

Q.15. WHICH FOOD SHOPS DO YOU USUALLY GO TO?

TYPE OF SHOP ____________ APPROX. ADDRESS ________________
____________ ________________
____________ ________________
____________ ________________

Q.16. WHAT MEANS OF TRANSPORT DO YOU NORMALLY USE FOR THIS JOURNEY?

____

WALKING = 1
CAR = 2
PUBLIC = 3
OTHER = 0 ☐

PART E. MOST RECTN POST OFFICE TRIP.

CODING.

Q.17.	WHEN DID YOU LAST VISIT THE POST OFFICE? ____________________ (Note date)	
Q.18.	WHICH POST OFFICE DID YOU VISIT? ____________________ ____________________ (Note approx.address)	
Q.19.	WHAT MEANS OF TRANSPORT DID YOU USE FOR THIS JOURNEY? ____________________	WALKING = 1 CAR = 2 PUBLIC = 3 OTHER = 0 ☐
Q.20.	DID YOU VISIT ANYWHERE ELSE ON THIS JOURNEY TO, OR BACK FROM, THE POST OFFICE? YES ☐ NO ☐	LINKED TRIP = 1 SINGLE PURPOSE TRIP= 2 ☐

If NO go to PART F

If YES:

Q.21. WHICH OTHER PLACE(S) DID YOU VISIT BEFORE GOING TO THE POST OFFICE? If more than one - PLEASE CAN YOU RECOUNT THEM IN THE ORDER THAT YOU VISITED THEM? (List in Table Y, column i) If answer SHOPPING, note what type of shops.

Q.22 WHICH OTHER PLACES DID YOU VISIT AFTER GOING TO THE POST OFFICE? If more than one - PLEASE CAN YOU RECOUNT THEM IN THE ORDER THAT YOU VISITED THEM? (List in Table Z, column i)

Q.23 WHY DID YOU VISIT THIS PLACE? (Go through each place in turn. List reasons in Tables Y and Z, column ii).

Q.24. WHAT MEANS OF TRANSPORT DID YOU USE FOR GETTING TO THESE PLACES? (Go through each place in turn, List in Tables Y and Z, column iii. N.B. walking <u>is</u> a mode of transport)

TABLE Y Places visited before the Post Office

Place type	i. approximate address	ii. Trip Purpose	iii Means of Transport

CODING

LINKED GROCER TRIP= 1

LINKED OTHER TRIP = 2 ☐

WALKING = 1
CAR = 2
PRIVATE = 3
OTHER = 0
☐

TABLE Z Places visited after the Post Office.

Place type	i. approximate address	ii. Trip Purpose	iii. Means of Transport

END OF QUESTIONNAIRE

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