Part 1: Measures of accessibility

1. INTRODUCTION

Accessibility is a term often used in transport and land-use planning, and is generally understood to mean approximately ’ease of reaching'. However, the detailed definitions used vary. It is the aim of this master thesis to survey the ranges of definitions and measures of accessibility that have been used, to evaluate these measures and to give some indication of the usefulness of the concept of accessibility.

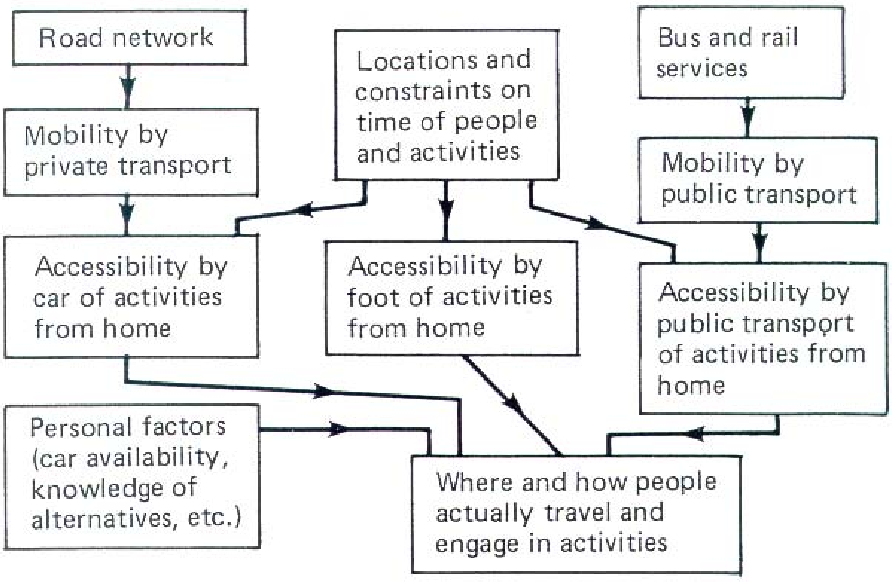
The related terms ’accessibility' and ’mobility' are the subjects of considerable confusion, and it is useful here to describe their distinct meanings.

Mobility is the ability of an individual, or type of person, to move about. This involves two components. The first of these depends an the performance of the transport system, which is affected by where the person is, the time of day and the direction in which he wishes to travel. The second component depends an the characteristics of the individual such as whether he has a car available, can afford taxi, bus, rail or air fares, is able to walk or use public transport, or has knowledge of the options available to him. In other words, the first element is concerned with the effectiveness of the transport system in connecting spatially separated locations and the second element is concerned with the extent to which a particular individual or type of person is able to make use of the transport system.

Accessibility is concerned with the opportunity that on individual or type of person at a given location possesses to take part in a particular activity or set of activities. It is a function of the mobility of the individual or type of person, of the spatial location of the opportunities relative to the starting point of the individual, of the times at which the individual is able to participate in the activity and of the times at which the activity is available (Figure 1). Thus accessibility is concerned not with behaviour but with the opportunity, or potential, provided by the transport and land-use system for different types of people to engage in activities.

The advantages of including the concept of accessibility in transport and land-use planning are two-fold.Firstly, it allows recognition of the interrelation of transport and land-use. Thus, on the one band it enables account to be taken of the deterrent effect of travel on participation in activities and on the other hand, it allows travel to be treated as a derived demand; that is, it recognises that in general, people travel in order to reach activities rather than desiring travel for its own sake. Secondly, it enables account to be taken of variations in types of people, in terms of, for example, their abilities to use different methods of travel, their needs or desires to participate in different activities, and the constraints on their time.

Fig. 1. Relation between mobility, accessibility and travel



2. ACCESSIBILITY AND BEHAVIOUR

As a preliminary to the descriptions of the range of definitions and measures of accessibility in Sections 4-7, this Section and the next are concerned with the relevance and usefulness of the concept of accessibility. This Section describes the findings of a number of studies that have sought relations between accessibility and various aspects of behaviour. These relations will be indirect since accessibility, as was noted earlier, is concerned with the opportunity to reach activities rather than directly with behaviour. Thus accessibility may be one of several factors involved in a person's choice of a particular type of behaviour.

2.1 Travel patterns

2.1.1 Trip Rates. Some evidence is available on the variation with accessibility in overall trip Rates, in the Rates by various modes and in the Rates for various purposes. Doubleday (1979) found that the numbers of work and of shopping trips by women increased as their accessibility to these activities increased. Koenig (1978) found a good correlation between the non-work trip rates of non-working people and their accessibility to tertiary employment centres (that is, shops and services).

2.1.2 Trip lengths. Black (1977) found that for most purposes (school, shopping, leisure, social, recreational, medical, personal business) people made shorter trips (in distance and in time) as their accessibility increased; it appeared that in general they chose the nearest facility available. For work trips this was not so, but high accessibility to work was found to reduce the proportion of very long work trips.

2.2 Car ownership

Several authors have considered the relation between on area's accessibility and its level of car ownership. Dunphy (1973) found a significant correlation between accessibility to employment by public transport and car ownership. Shindler and Ferrari (1967) obtained a significant correlation between car ownership and the ratio of employment accessibility by public transport to that by private transport.

2.3 Residential location

Traditionally there has been a tendency to regard access to work or to the town centre as the most important accessibility factors affecting residential location. Thiebault et al (1973) suggested, however, that access to the town centre is fairly unimportant and that access to activities such as primary school or shopping centre may be as important as access to the workplace. There is also evidence that accessibility to a range of activities is valued more by poorer people than by richer people, who are prepared to trade off good accessibility against other factors such as a pleasant environment.

To summarise, it appears that access to some activities may be on important limiting factor in a person's choice of, and may also affect his satisfaction with, his residential location, but that good accessibility is able to be sacrificed to gain other attributes.

2.4 Residential land development

Hansen (1959) investigated, in Washington, the relation between the rate of residential development and access to each of employment, population and shopping. The rate of residential development from 1948 to 1955 was measured by the ratio of the number of residential sites newly developed in the second year to the number of empty sites available in the first year. Good correlations were obtained between this development ratio and measures of accessibility to employment and population.

3. APPLICATIONS OF ACCESSIBILITY

Accessibility is a useful technique for both planning and research. In planning, it has been used, or proposed, as a tool (often in conjunction with other techniques) for both transport and Land-use problems. In transport planning it has been used, for example, in the evaluation of several alternative bus systems, of a proposed commuter rail linel, of two proposed urban relief roads (Koenig, 1975) and in-the general development of the transport policy of on area (Ochojna and Brownlee, 1977) -the present study in this master thesis is on example, focusing on the road network-. In land-use planning it has been used, for example, in identifying the best locations for major facilities such as schools, hospitals, major administrative centres and recreation centres. Most of the examples given above are concerned with the use of additional resources but accessibility is equally useful in considering the best use of existing resources or how to allocate reduced resources. A particular benefit of the use of accessibility in planning is that it enables transport planners to consider non-transport (such as land-use or organisational) solutions to their problems.

4. DEFINITIONS OF ACCESSIBILITY

One of the problems of making sense of the mass of indices to which the term "accessibility measure“ has been applied is that the underlying definitions of accessibility vary widely, and these definitions are not always given explicitly. Therefore, this Section aims to sketch the range of meanings that have been given to the word accessibility.

1. Some studies have been concerned solely with the *spatial separation* of one point from another, or from all other points (de Lannoy, 1978). Typical definitions are `the accessibility of a point in a system is a function of its location in space with respect to all other points in the system (Hack, 1976) and accessibility will imply relative nearness either in the sense of a direct linkage or a minimum expenditure of travel cost or time.

2. Some papers have defined accessibility in terms of the *travel cost* of observed or expected trips (Savigear, 1967).

3. Some studies have been concerned with the *opportunity which an individual or type of person at a given location possesses to take part in a particular activity* or set of activities (Hansen, 1959).

4. Some studies consider additionally the characteristics of the population actually resident in the study area, and these define the accessibility of on area as the *average opportunity which the residents of the area possess to take part in a particular activity* or set of activities (Wachs and Kumagai, 1972). The average opportunity is a weighted average over all person types and it uses as weightings the number of people of each person type in the study area.

5. Finally, a few studies have identified accessibility with the consumer surplus, or *net benefit, that people achieve from using the transport and land-use system* (Leonardi, 1978). The consumer surplus is the difference between the amount of money a person pays for a quantity of goods and the total benefit he obtains from the goods. In this case the goods are trips and the gross benefit of a trip is the gross benefit obtained at the destination of the trip.

5. MEASURES OF ACCESSIBILITY

5.1 Introduction

In surveying the range of indices to which the term accessibility measure has been applied it is possible to identify three main categories of measure. Measures in the first category are concerned with the spatial separation of points or with the linkages between points as a result of their relative locations on a network: they are closely related to the first meaning of accessibility given in Section 4. Measures in the second category (Section 5.3) are concerned with the amount of travel that takes place and are related to the second meaning of accessibility given in Section 4. Measures in the third category (Sections 5.4 and 5.5) are concerned with consequences of the combined distributions of transport and Land-uses: these reflect the remaining three meanings described in Section 4. This category can be divided into those measures that combine the elements of separation and attraction into a single index (Section 5.4) and those that keep these elements separate within the measure (Section 5.5).

The term `travel cost' occurs frequently in the following description of the measures and this expression needs some clarification. It refers to whatever is a deterrent to travel and is most often measured by time or generalised cost.

5.2 Network Measures

Network measures are concerned solely with the transport network and their approach is based on that of mathematical graph theory. The network is usually a simplified road network (as used in traffic models) although the techniques are also applicable to the public transport network.

5.2.1 Simple network measures. The network is usually described as being composed of links which meet at nodes. Various properties of the network have been proposed as measures of relative or integral accessibility.

(1) The associated number of a node: with distance measured by the number of links, the associated number of a node is the distance between it and the node furthest away from it in the network

(2) The number of other nodes reachable from a given node within a given time by travelling on the network

(3) The Shimbel measure: this measure considers the node in relation to all the other nodes in the network. It measures the accessibility of a node (i, say) as the total travel cost to all other nodes; that is

The accessibility of node i = $\sum_j c_{ij}$ [1]

where $\sum_j$ indicates a summation over all nodes in the network

c_{ij} = the travel cost (usually measured by the number of links or distance) from node i to node j

5.2.2 Ingram measure. Ingram (1971) generalised the Shimbel measure by recognising that the deterrent effect on travelling of the cost or difficulty of travel cannot necessarily be identified with the travel cost itself; rather it is, in general, some function of the travel cost. He also extended the basis of the study beyond the network by dividing the study area into zones and calculating the accessibility of each zone. Ingram proposed that the relative accessibility of one zone i to another zone j be measured by the deterrence to travel of the cost of travelling from i to j; that is

$$A_{ij} = f\,(c_{ij})$$

Where c_{ij} = travel cost from zone i to zone j

$f(\ )$ = some function to represent the deterrent effect of travel cost

Thus the integral accessibility of zone i = A_i = $\sum_j f(c_{ij})$ [2]

where $\sum_j$ indicates the sum over all zones in the study area.

5.3 Measures of travel

The two Indexes described here are closely related and are concerned with measuring amounts of travel; that is, they are concerned with on aspect of travel behaviour. The first is concerned with observed travel, the second with predicted travel.

(1) The average cost of observed trips leaving a zone has been suggested by Savigear (1967) as a measure of the inaccessibility of that zone: that is

$$I_i = \frac{\sum_j c_{ij} T_{ij}}{\sum_j T_{ij}} \qquad [3]$$

where I_i = inaccessibility of zone i'

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

c_{ij} = travel cost from zone i to zone j

(2) A similar approach has been to consider the probability of a trip taking place between each pair of zones. The following has been proposed by Knudsen and Kanafani (1974) as a measure of inaccessibility:

$$I_i = \sum_j p_{ij}\ c_{ij} \qquad [4]$$

where I_i, c_{ij} are as above

p_{ij} = probability of a trip going from zone i to zone j

It has been suggested that this probability be calculated using gravity model or intervening opportunities approaches.

5.4 Aggregate measures of combined transport and land-use System

5.4.1 Hansen-type measures. The approach of this type of measure to the calculation of a zone's accessibility is to add together the opportunities available in each other zone, weighted by a function of the difficulty of reaching that zone; that is, the opportunities available in each zone are discounted (or reduced) according to the difficulty of reaching that zone.

The original idea was formulated by Hansen (1959) who proposed that the accessibility of zone i measured by:

$$A_i = \sum_j \left(B_j / d_{ij}^a\right) \qquad [5]$$

where B_j = the opportunities at zone j for a given purpose

d_{ij} = distance from i to j

a = some constant

A difficulty with this index is its measurement of the deterrence to travel by a negative power function of distance (l/d_{ij}^a). Distance is, not necessarily the best measure of travel difficulty, and the deterrent effect of this difficulty could be measured by functions other than the negative power function proposed by Hansen. Therefore, the idea has been extended to the `generalised Hansen measure which has a more generalised measure of travel difficulty:

$$A_i = \sum_j B_j f\left(c_{ij}\right) \qquad [6]$$

where B_j = as before

c_{ij} = the travel cost from i to j

$f()$ = some function to represent the deterrent effect of the travel cost

Thus the original Hansen measure is a particular case of the generalised Hansen with $f(c_{ij})$ = $1/c_{ij}^a$ and c_{ij} = distance from i to j. For the sake of simplicity this generalised Hansen index (which is the form in which it most commonly appears) will henceforth be referred to simply as the Hansen index.

There are two fairly common variations of the Hansen measure that are often, rather confusingly, referred to simply as Hansen measures. In order to clarify the position these are described here and are given the names 'normalised Hansen' and 'population weighted' Hansens. The 'normalised Hansen' is

$$A_i = \frac{\sum_j B_j f(c_{ij})}{\sum_j B_j} \qquad [7]$$

Thus, instead of using the absolute number of opportunities B_j in zone j, it uses the proportion of the opportunities in the entire study area which zone j possesses, namely $B_j / \sum_j B_j$ .The other is the `population weighted Hansen':

$$A_i = P_i \sum_j B_j f(c_{ij}) \qquad [8]$$

Thus this type of measure identifies accessibility with the opportunity which the residents of the study area possess to take part in a particular activity or set of activities (that is, the fourth definition given in Section 4).

5.4.2 Revealed value measures. Roughly speaking, this approach aims to measure accessibility by looking at how much people are prepared to pay for it. There are two sides to this approach; one is land use based (Section 5.4.3) and the other is transport based (Section 5.4.4) but both use the idea that people seek to maximise the net benefit or consumer surplus that they obtain from the transport and Land-use system.

5.4.3 Rents, salaries and accessibility. Tanners used consumer surplus approach to the locations of homes and jobs and the ways in which they are linked to give a pattern of journeys to work and suggested that rent and salary differentials (where all other factors are equal) can be regarded as accessibility measures.

Whitbread (1972) described some work done for West Midlands Regional Study on identifying a measure of access to employment. A Hansen index was used with a negative exponential deterrence function and with a zone's attraction measured by the number of jobs it contained. A multiple linear regression was carried out of the residential Land value of a zone on its access to employment and other variables unrelated to employment accessibility. On the basis of this the value of the coefficient b in the Hansen Index ($\sum_j B_j e^{-bc_{ij}}$) was calculated together with the contribution made by employment accessibility to residential land value.

5.4.4 Travel behaviour and consumer surplus. Most of the measures that have been described in this Section were developed using largely intuitive arguments. There have been several attempts to put accessibility on a sounder theoretical footing by using the concept, taken from economic theory, of consumer surplus and it has been shown that a form of the Hansen accessibility Index is essentially a measure of consumer surplus.

The underlying principle of the approach is that the benefits that people derive from changes in the transport or Land-use facilities provided for them may be deduced from the way they behave. Consumer surplus is defined as the difference between the rum people have to pay for a quantity of goods and the rum they would be prepared to pay or equivalently as the difference between the cost of the goods and the total (or gross) benefits people obtain from them. The Marshellian measure of the change in consumer surplus accompanying a fall from c1 to c2 in the cost of a good is

$$S = -\int_{c1}^{c2} D(c)dc \qquad [9]$$

where *D(c)* = demand for good, a function of its cost c
S = change in consumer surplus

The goods to be considered here are trips. As was described in Section 4, the gross benefit associated with a trip is the benefit available at its destination and its cost is simply the cost of travel. The change S_{ij} in the consumer surplus of trip makers accompanying a fall from $c_{ij}^{(1)}$ to $c_{ij}^{(2)}$ in the cost of travel from zone i to zone j, assuming all other costs are constant, is given by

$$S_{ij} = -\int_{c_{ij}^{(1)}}^{c_{ij}^{(2)}} T_{ij}(c)dc \qquad [10]$$

where T_{ij} *(c)* = number of trips from i to j when the cost of a trip from i to j is c
S_{ij} = travel demand function

Provided that the negative exponential form of the deterrence function is used, the gravity model formulation of the travel demand function has been shown (See Cochrane, 1975) to be derivable (if certain assumptions are made) by considering people as making trips which maximise their consumer surplus. Thus the gravity model is on appropriate demand function to use to evaluate consumer surplus.

5.5 Disaggregate measures of combined transport and land-use system

5.5.1 Contour measures. These are the most common family of disaggregate measures of the combined transport and land-use System. For each zone a series of travel cost (usually, but not necessarily, travel time) contours are drawn and the numbers of relevant opportunities within each is counted. This is shown in figures 2, 3 and 4.

Figure 2.Travel time contours by bus and walk in a hypothetical town

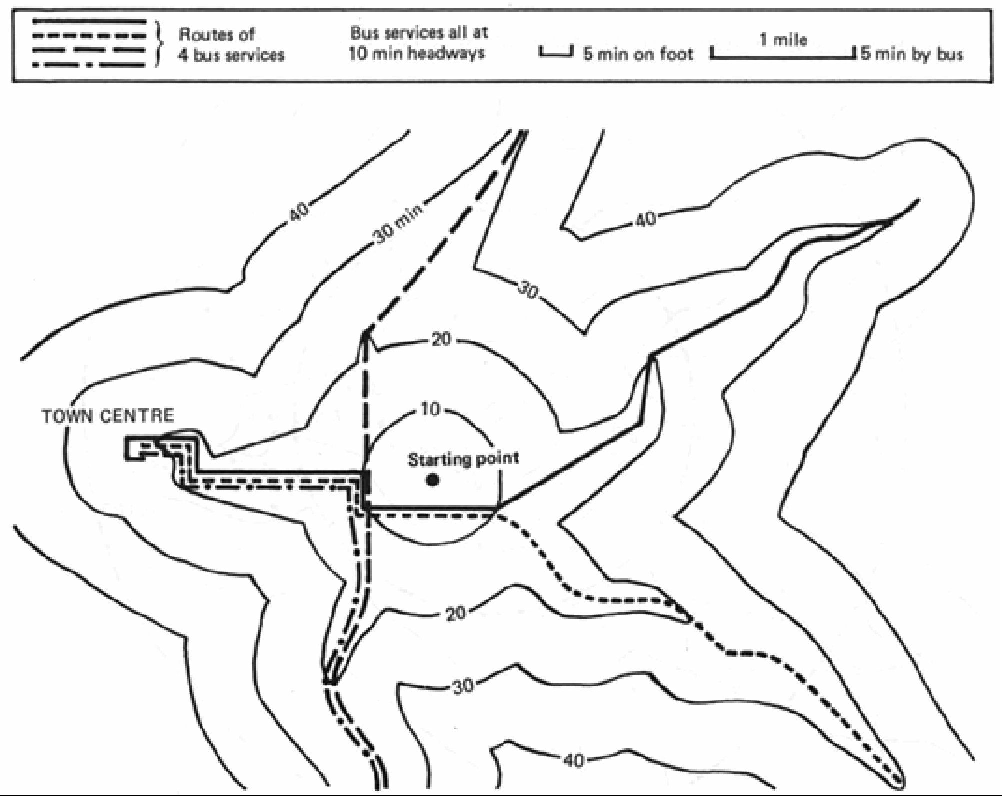


Figure 2.Graph of relation between number of jobs reachable and travel time, from fig.3

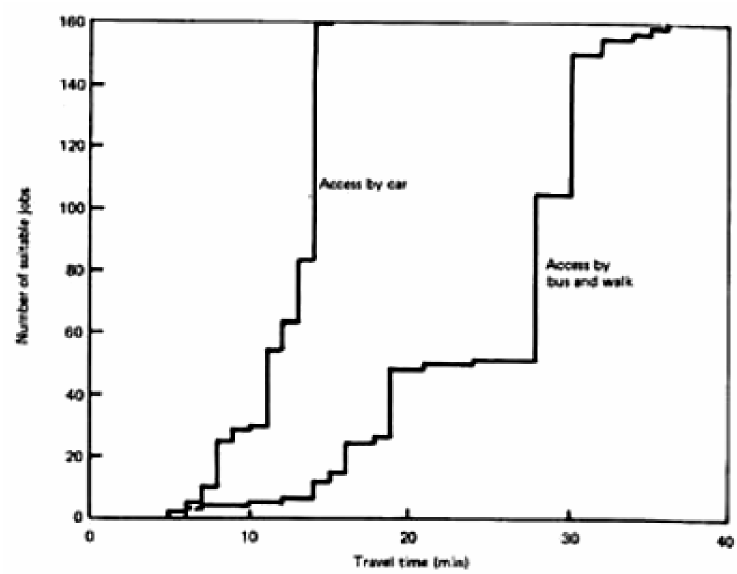
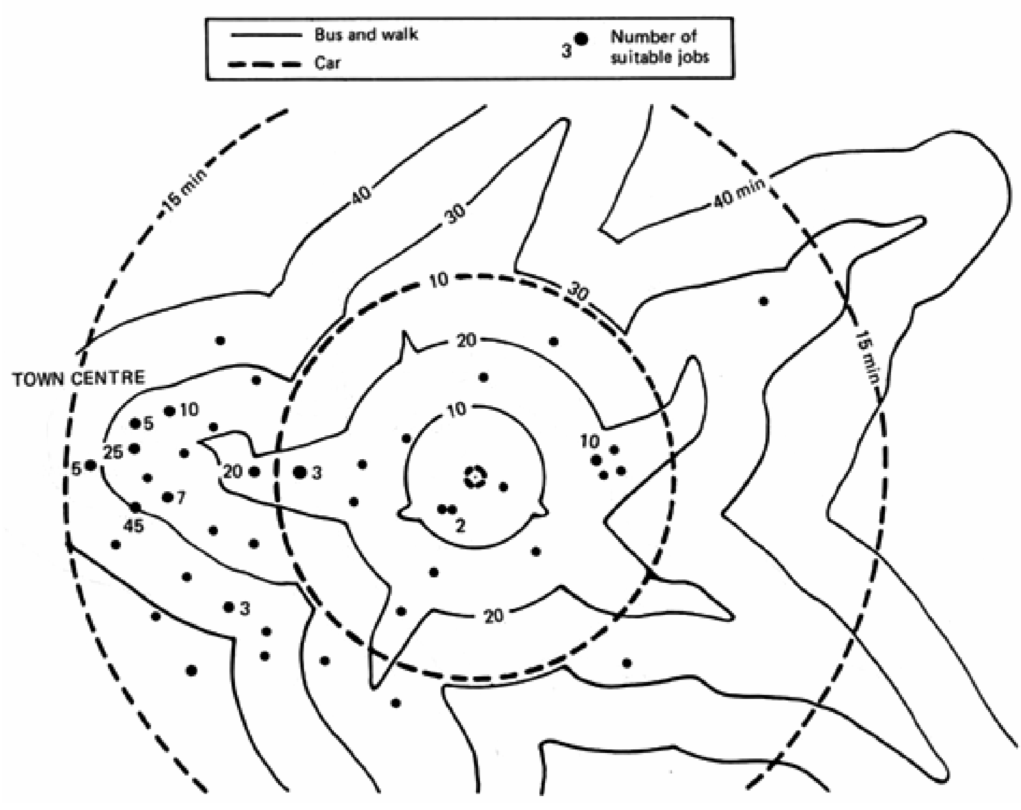


Figure 3.Relation of jobs to travel time contours in a hypothetical town



This measure can take either of the following forms:

(a) the number of opportunities reachable within a given cost, or the numbers within various costs
(b) the cost required to reach a given number (or various numbers) of opportunities

Measure (a) can also be expressed, for zone I and contour C, as

$$\sum_j B_j h(c_{ij}) \qquad [11]$$

where B_j = the number of opportunities in zone j

$h(c_{ij}) = 1$ *if* $c_{ij} \leq C$
0 *if* $c_{ij} > C$

Thus it is a special case of Hansen measure

$$\sum_j B_j f(c_{ij}) \qquad [12]$$

Some possible contour measures are:

- number of grocery shops within 10 minutes, 15 minutes, 20 minutes walk;
- (for villages) shortest time by bus to a town with a given range of facilities;
- the generalised cost (that is, a combination of time and money costs) by the cheapest of walk, bus and train to reach15.000, 30.000, 45.000 clerical jobs.

5.5.2 Tipes of contour measure

(1) Both contour measures have been proposed with the number of opportunities replaced by the percentage or proportion of the study area's opportunities

(2) An analysis of how to use the type (a) contour measures has been made by Breheny (1978) who identified three versions according to which elements (population, opportunities or costs) were varying and which constant:

(a) fixed population; the average (over the population) of the number of opportunities available within various travel costs;

(b) fixed opportunities; the number of people able to reach at least a fixed number of opportunities within various cost limits;

alternatively, the average (over the population) cost to reach a given number of opportunities;

(c) fixed costs; the number of people able to reach various numbers of opportunities within the fixed cost limit.

(3) Another analysis was made by Wytconsult (1977) for the West Yorkshire Transport Study. They identified the following as possible measures depending on the type of activity being accessed:

- travel cost to the nearest facility of given type;
- travel cost to the nearest of a group of similar facilities;
- travel cost to a given number of facilities of a given type;
- travel cost to a given number of facilities within a group of similar facilities;
- travel cost to a given number of similar facilities with at least specified numbers of particular types.

(4) Population weighted forms of contour measures have been suggested: for example, Breheny (1978) proposed the average (over the population) travel cost to reach a given level of opportunities. Wachs and Kumagai (1972) used the average (over the population) number of opportunities reachable within a given travel cost. The West Yorkshire Transport Studies (1979) calculated on average travel time for on area by weighting the travel times for different modes and activities by the number of people using each mode and the activity needs of different types of people.

(5) The contour measures have also been reversed, with the concern being the number or percentage of the population rather than the number or percentage of opportunities; for example, the percentage of the population within a given travel cost of important metropolitan activities or the percentage of a rural population within a given travel cost of a town with larger than a stated population (see Sherman et al.,1974).

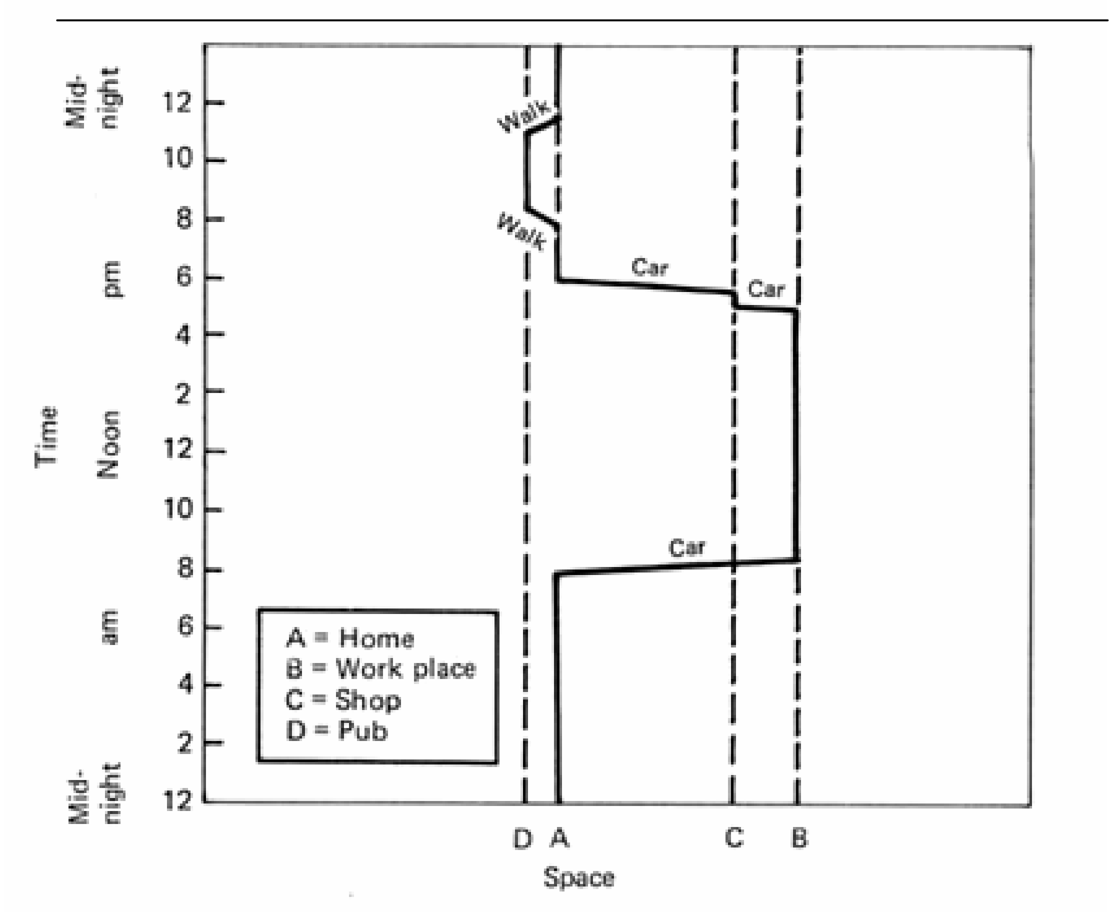
(6) Balanced opportunity. Wickstrom (1953) proposed on extension of the concept of the type (a) contour to that of the `balanced opportunity' of a zone for a given purpose and mode. This is defined as the ratio of the desired to the actual numbers of opportunities reachable in a given travel time from the zone (that is the ratio of desired to actual accessibility indices) weighted by various factors. These factors (designed to reflect the relative importance of the zone, mode and purpose) are the proportion of the study area's population in the zone, the proportion of trips made by the mode

from the zone and the proportion of trips made for the purpose under consideration from the zone.

5.5.3 Time-space geography. A few approaches to the measurement of accessibility have been based on the ideas of time-space geography; this is on approach to the modelling of society which regards time as equally important as space. Fundamental to the approach is the concept of a person's 'life path'; that is the set of locations in time and space which the person occupies.

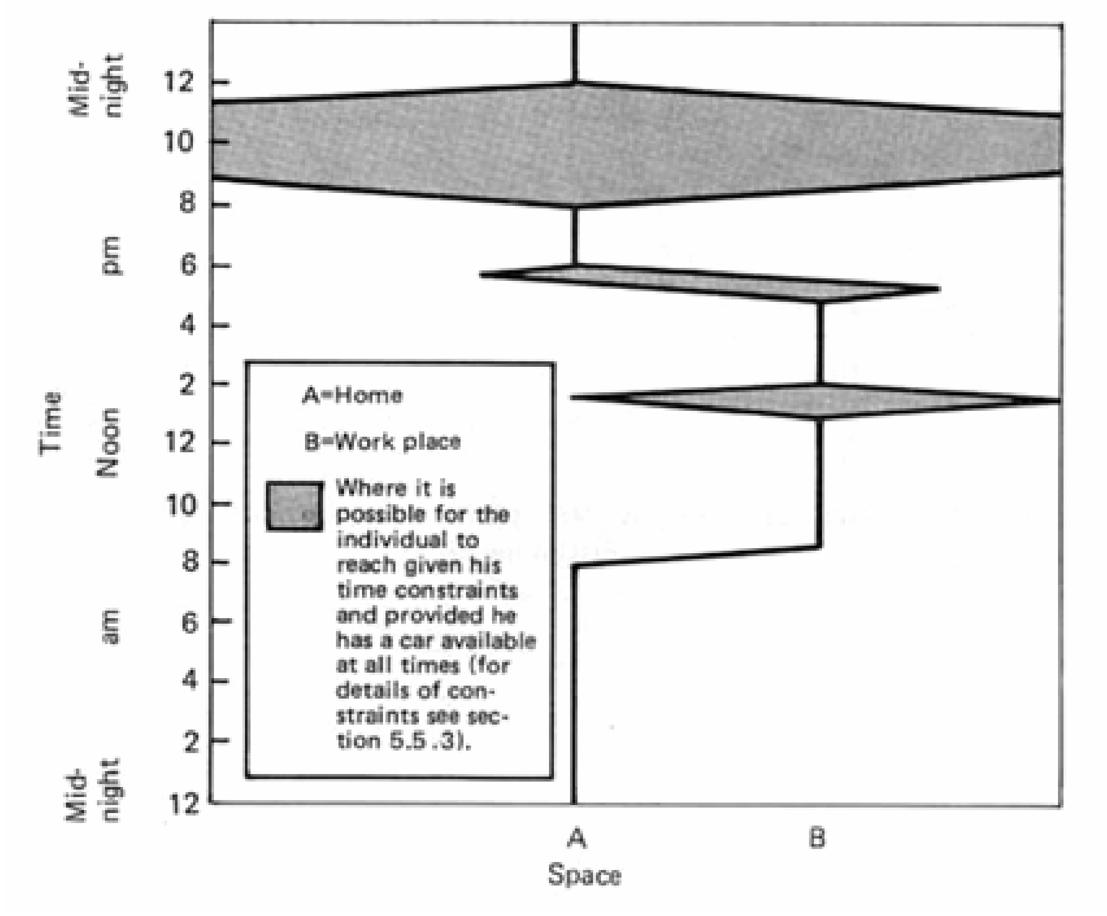
One example of an individual's life path for a particular 24 hour period is given in Figure 5. If only the fixed constraints on a person's time are considered then it is possible to draw a `time-space prism' to indicate where it is feasible for him to be at other times.

Figure 5. An individual's "life path" for one 24 h period



For example, suppose that the individual whose life path is illustrated in Figure 5 has the following constraints on his time; to be at home before 8 am, between 6 pm and 8 pm and after midnight, and to be at work between 8.30 am and 1 pm and between 2 pm and 5 pm; his prisms of available time-space (provided he has a car available at all times) are then as illustrated in Figure 6.

Figure 6. An individual's "time space prism" for one 24 h period



5.5.4 Other disaggregate measures

- Actual time taken, by mode used to reach the destination usually used for a given activity. This type of measure is used in questionnaire-based studies

- Measure of centrality. The measure is the travel cost to the centre of the urban area (in urban areas) or the nearest urban area (in rural areas). Thus this measure could be viewed as a contour measure of the second type with the simplifying assumption that the only destination to which access is required is the urban centre.

6. COMPONENTS OF MEASURES

This Section considers the various ways that have been proposed of measuring the several components involved in most accessibility measures. The First section considers ways of measuring travel cost, the second looks at the functions that have been used to represent the deterrent effect on travel of this travel cost and the third describes ways of measuring the attractiveness of destinations for various activities. The fourth section considers ways in which the effect of competition has been incorporated into accessibility measures.

6.1 Measurement of travel cost

The measurement of travel cost falls into two categories. Some studies have identified it with physical separation and have used measures such as:

- the number of links traversed (Briggs and Jones, 1973);
- straight line distance(Briggs and Jones, 1973);
- rectangular distance (that is, the distance travelled if travel is possible only in two directions which are at right angles to each other) (Ingram, 1971);
- Either of the two previous measures plus allowance for limitations imposed by major physical barriers such as rivers, railways, escarpments (Ingram, 1971);
- road distance

On the other side travel cost can be interpreted in a more widely way as:

- Travel time
- the number of links weighted by length,
- cost of travel and road quality;
- generalised travel cost (that is a combination of money cost, time and other factors such as comfort;
- (for public transport) travel time plus the mean Service interval.

These measures allow a particular mode or route to be studied or the best from several to be identified and used. Travel time and generalised cost are the most commonly used measures of travel cost.

6.2 Functions of travel cost

The purpose of taking a function of travel cost rather than using travel cost unaltered is to represent better the deterrent effect of the difficulty of reaching a facility on its use. Only some of the measures that have been described include such a function. Of the main types of combined measure, the time-space geographic measures do not include it, the contour measures include it to a limited extent (this is discussed further below) and the most general use is in Hansen measures and the consumer surplus approach

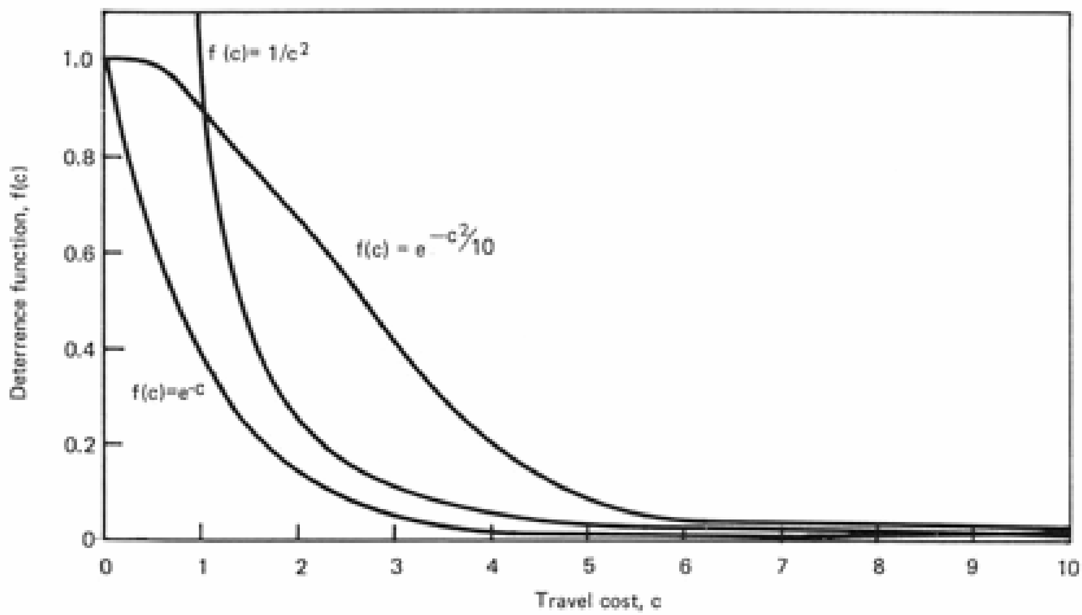
The Hansen measure of the accessibility of zone i is

$$A_i = \sum_j B_j f(c_{ij}) \qquad [13]$$

The function f most commonly used is the negative exponential, that is $f(c) = e^{-bc}$ for some constant. The only other function used more than occasionally is the negative power, that is $f(c) = c^{-a}$ for some constant. A modified version of the Gaussian function $f(c) = e^{-c2/u}$ for some constant u has also been proposed but has rarely been used. All three types of curves are illustrated in Figure 7. Ingram gave three requirements for a deterrence function:

(1) It should be reasonably flat-topped in the origin
(2) Its descent from the plateau should be smooth
(3) The curve should reach zero at infinity

Figure 7. Some possible deterrence functions for the Hansen index



7. DISCUSSION OF THE MEASURES

7.1 Introduction

The aim of this Section is to discuss, in fairly general terms, the indices described in Section 5 in terms of their usefulness as measures of accessibility. As a starting point for this, six criteria will be set down which it seems reasonable to ask on accessibility measure to satisfy. Several of the indices will be discussed further, taking into consideration their theoretical backgrounds and the ease with which they can be used in practice

7.2 Criteria for accessibility indices

Accessibility is described as being concerned with the opportunity which on individual or type of person at a given location possesses to take part in a particular activity or set of activities. There would therefore seem to be three criteria regarding those factors which any measure of accessibility should satisfy. These are that any accessibility measure should take account of:

(1) The location and characteristics of the individual
(2) The location and characteristics of opportunities for relevant activities
(3) The connecting transport systems

And the measure of accessibility should behave in accordance with these three criteria:

(4) if the number of opportunities for on activity increases anywhere, then the accessibility to that activity from any place should improve or remain constant
(5) if travel by any mode is made quicker or cheaper in on area, then the accessibility to any activity in that area, or from any point within that area should improve or remain constant
(6) improvements to one mode of transport should not alter the mobility (and hence accessibility to any activity) of any individual or type of person not able to use that mode.

These criteria should not be regarded as absolute. For example, if a study is concerned solely with a transport change and it is certain that no land-use changes whatsoever will be involved, then it would not be unreasonable to use a measure which violated criterion 4. But the implications of such a choice must be recognised and the measure should not be used if there is any possibility of land-use changes being included in the study.

7.3 Network measures

The measures described in Section 5.2, the so-called network measures, consider only the transport network and take no account of Either the locations and characteristics of individuals or types of people or of the locations and characteristics of opportunities for relevant activities. Thus they clearly do not satisfy criteria 1 and 2.

7.4 Travel measures

Measures of travel were described in Section 5.3. These can be viewed in two slightly different ways. One is that they define accessibility as the observed (or predicted) amount of travel and the other is that they define accessibility in some other way but feel that this is best measured by the observed (or predicted) amount of travel. They have the advantage of using data that are often readily available but they do not satisfy some of the criteria, as can be seen by considering the following examples. If a new sports centre is built in a town, some people may change the destination of some of their trips to the new centre from a more local playing field and other people may be inspired to take up a sport for the first time. Thus existing travellers may make longer trips and new trips may be generated. Both of these events would be classified by a measure of travel as a worsening of accessibility which conflicts with criterion 4. Criterion 5 also can be seen to be violated by considering the similar effects on travel of the provision of a new bus service to on existing Sports centre. Although other problems with this type of measure could be identified, the crucial one is their assumption that existing levels of travel are the desired levels of travel; in other words that travel is not constrained by the existing transport and land-use system.

7.5 Combined measures

The aggregate and disaggregate approaches described in Sections 5.4 and 5.5 remain to be considered. In their basic form all these measures satisfy all six criteria. However none are completely satisfactory. They were developed to measure several different aspects of accessibility in response to the identification of a number of different problems, and are useful measures provided they are used in on appropriate way for the appropriate type of problem.

There are three quite common variants of several of these measures and it is useful here to describe their consequences. The first is the population weighted measure; that is, the accessibilities of the various categories of people have been added together with Each accessibility weighted by the number of people in that category. It is the approach of this master thesis that accessibility is fundamentally a characteristic of on area, a category of person and on activity or set of activities. One way of assigning the relative importance of the person categories is to weight each by the number of people in that category. However this is not the only way; it may be that only one category is of interest, or that accessibility is seen as having a stronger effect on the lives of some people than on others. Thus it is preferable to calculate accessibility indices for each person-type without regard initially to the characteristics of the population of the study area and then, if it is necessary to amalgamate the indices, to do this by whatever scheme of priorities is deemed most appropriate. However the limitations of the available data may mean that this disaggregate approach is not possible. The second variant is the use of the actual numbers or proportions of people using the different modes or travelling to different destinations or travelling for different purposes. Similar comments to those made on population weighting apply here also. The third common variant is the use of the proportions of the activities of the entire study area in a zone rather than the absolute number. This goes against criterion 4 as can be seen by considering the effect of the introduction of a number of opportunities far from the origin zone. Thus this variation is inappropriate if land-use changes are to be included in the study.

7.5.1 Time-space geography. The emphasis of this approach is on individuals and, in common with some other approaches, it views accessibility in terms of the possibilities for individuals to perform activities. In contrast to most other approaches it recognises the constraints imposed on an individual's accessibility by time as well as by space. Thus time is viewed not merely as a manifestation of the spatial separation of people and activities but as a constraint equally important as spatial constraints in limiting a person's access to activities. As on example of the importance of time constraints, consider the case of a full-time shop assistant who works in a town centre and is thus very close to a large number of shops (good spatial accessibility to shops) but who is at work most if not all of the time that the shops are open (bad temporal accessibility to shops). An important aspect of its concern with the availability of activities in time is its emphasis on the range and frequency of the activities which a person takes part in and whether it is possible to sequence them so that all can be undertaken.

The time-space geographic approach to accessibility is thus a very detailed one requiring information on the time constraints on both people and activities as well as transport and Land-use data. In the case of activities the time constraints may involve such factors as opening hours and working hours. A disaggregate approach is required to the time constraints operating on people. For example it is not sufficient to classify all housewives together as one may be childless with no daytime constraints on her time while another may have a small child requiring to be accompanied to and from infant school.

It enables consideration to be given to a range of factors which may improve a person's accessibility, such as flexible working hours, relocating a facility, altering a bus route, or altering the times of a bus between a village and a town to enable a villager to make a return shopping or work trip to the town. It also enables full consideration to be given to the different access requirements of different types of people.

To summarise, the time-space geographic approach to accessibility is person based and is concerned with the effect of a large range of transport, Land-use and organisational factors on a person's ability to take part in necessary or desired activities. It is a detailed approach allowing many different types of people to be considered. Consequently it requires large amounts of data and effort to implement. The simpler, non-sequential, approach takes fewer factors into account but still allows disaggregation of person types. It is also demanding of data and computing effort but substantially less so than the full time-space approach.

7.5.2 Contour measures. These measures aim to describe the transport and Land-use system from the user's point of view. They incorporate, in a disaggregate way, two important elements of the transport and land-use System; namely the difficulty of travel between places and the location of facilities. Their approach is disaggregate in that no attempt is made to evaluate the combined effect of the competing influences of the attraction of destinations and the deterrence of travelling to them due to their separation. Furthermore, they do not attempt to evaluate the benefit people attach to being able to reach a destination, nor do they evaluate the deterrence attached by people to the travelling required to reach the activity. Consequently the parameters for the contours must be chosen realistically. For example it would be unrealistic to calculate travel time contours of the number of grocers' shops within two hours but it might be reasonable to calculate the number within 10 and 20 minutes. The data required for these measures are comparatively readily available.

The quite detailed nature of these measures enables consideration to be given to the different types of access required by different types of people to different activities. For example in considering working adults it may be of interest to calculate their access to a large number of jobs appropriate to their skills while a study of old people may be concerned about their access to the nearest post Office and the fact that there is little or no choice may not be important.

To summarise, these measures aim to describe the transport and Land-use System from the user's point of view. In doing this they keep the land-use and transport elements separate and do not attempt to evaluate their combined effect. They also tend not to consider the value people put on each of these elements separately. This leads to a readily understandable Index without hidden assumptions about a person's perceptions of transport, land-use and their interaction but unless used carefully confusingly large numbers of results can be produced. They make it possible to study the different kinds of access required by different types of people to different activities and are relatively undemanding of data.

7.5.3 Revealed value measures. Another approach to the measurement of accessibility is to look at how much people are prepared to pay for it. This is a systems approach, which can be described as being concerned with how people respond to the transport and land-use system rather than with how the system affects people.

The first such method, described in Section 5.4.3, aims to do this by looking at property values or rents. The approach is limited to those types of accessibility (such as access to employment) which may affect property values sufficiently for the effect to be measurable. The accurate identification and measurement of the other factors affecting property values is required in order to measure the accessibility element of property values.

The consumer Surplus approach (see Section 5.4.4) is orientated more towards the transport System than the previous approach and has developed from travel demand model. It aims to measure the total net benefit or consumer surplus (i.e. gross benefit less cost of travel) obtained by travellers from the transport and Land-use System. The-principle is that a person will travel to a particular destination only if the net benefit he achieves is positive. If a change is made to either or both of the transport and Land-use systems, changes will be made to the consumer Surplus which some people can achieve and this will be reflected in the trips they make. Thus by studying the changes in trip making as a result of transport or Land-use changes it is possible to measure the associated change in consumer surplus. This method cannot measure the total benefit that travellers achieve from any particular transport and Land-use system, only the change in benefit they achieve when a change is made in either or both of the transport and land-use elements of the system. It can say little about those who use the System neither before nor after the changes.

7.5.4 Hansen measures. Hansen's original index was developed using intuitive arguments about the relation between the attractiveness of destinations and the reduction of this attraction due to the difficulty of travelling to them. The result is a measure of 'equivalent attraction'; that is the number of units of attraction which, if located at the origin, would be equivalent to the attractiveness of the spatially distributed activities.

The Hansen measure for a particular activity is concerned with access to all the relevant opportunities in the study area. This may be appropriate for some activities (jobs, for example) but is less satisfactory for activities (such as hospital, post office) for which the only one of interest is the nearest, or for shops where the nearest few shops may be the only relevant ones.

However the position is confused by the similarity between the generalised Hansen index and the transport gravity model. The transport gravity model is based on arguments analogous to the Newtonian theory of gravity and says that the number of trips between two zones is a function of the number of potential trip makers in the first zone, the number of attractions in the second and the difficulty of travelling between the zones. There are several forms of the model, depending on how closely the model is to be tied to observed travel patterns. One of these is the singly constrained gravity model, in which the number of trips leaving each zone is constrained to the observed value but the distribution of these trips (and hence the number of trips arriving at each zone) depends on the attractions in each zone and the deterrence to travel to each zone due to the difficulty of reaching the zone (See Section 5.4.4).

The general form of the singly constrained gravity model is thus similar to that of the Hansen index in that the basis of each is a product of the opportunities available in each zone and a function of the cost of reaching the zone. Their aims, however, are different and thus the detailed forms differ. In particular the aims of the travel cost functions differ. *In the gravity model the aim of this function is to represent the decay in the amount of travel as the cost of travel increases.* The function is usually a negative exponential, e^{-bc}, where c is travel cost and b is a constant whose value is determined by calibration with the observed distribution of travel in the study area. In the Hansen index, however, this function aims to represent the decline in a person's perception of the attractiveness of on opportunity as the cost of reaching it increases. It is likely that there is some connection between these two concepts but they are nevertheless distinct. The travel decay function from a travel demand model is sometimes used as the decay function in a Hansen index. This would be valid only if the observed distribution of travel were unconstrained and thus the same as the desired distribution, which is generally not so. It is not clear how the Hansen decay function can best be determined.

In summary, the Hansen index uses intuitive ideas about the 'equivalent attractiveness' of spatially separated activities, it is more appropriate to some activities than to others and in practice it tends to be used with variables and functions taken from data collected for travel demand modelling and from the calibration of the model to the observed data.