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# ACCESSIBILITY INDICATORS FOR TRANSPORT PLANNING

J.M. MORRIS
SCIENTIFIC OFFICER
AUSTRALIAN ROAD RESEARCH BOARD, VICTORIA

P.L. DUMBLE
RESEARCH SCIENTIST
AUSTRALIAN ROAD RESEARCH BOARD, VICTORIA

M.R. WIGAN
DIVISION HEAD
AUSTRALIAN ROAD RESEARCH BOARD, VICTORIA

*ABSTRACT:*

*The relevance of accessibility as a concept in transport planning is established, emphasising the difference between perceptual and measurable variables. A range of analytical forms used to quantify accessibility is reviewed and categorised into a coherent summary. Consumer demand theory is used to give behavioural justification for the inclusion of accessibility into the travel modelling process. Some new analyses of the Ballarat Transportation Study data are interspersed to demonstrate both the potential and the limitations of these readily available sources, and to highlight the limitations of the current modelling process.*

# ACCESSIBILITY INDICATORS FOR TRANSPORT PLANNING

## INTRODUCTION

Transport planning organisations have historically adopted a view that transport problems and transport solutions can be treated without considering non-transport aspects of urban life. This view is reflected in the highly selective nature of traditional transport planning solutions - solutions which, by and large, set out to improve and accommodate an ever-increasing flow of vehicles, not necessarily even improving the flow of people (Hillman, Henderson and Whalley, 1973, 1976). But perceptions of transport planning objectives have changed substantially in recent years. Attention has shifted from plans catering for a continuation of existing trends, to plans which attempt to substantially alter those trends - by encouraging the use of public transport and non-motorised methods of travel, and by attempting to integrate transport with land-use planning. At the same time much greater emphasis is being given to distributional questions, and evaluation of alternative land-use/transportation plans is no longer based entirely on efficiency criteria. In toto, the focus of transport planning is moving from 'vehicular mobility' to 'personal mobility' (Dalvi 1977) and from 'traffic congestion' to 'accessibility provision' (Wilson 1972).

These changes have undoubtedly led to a more comprehensive view of travel, and to questioning of many assumptions at the base of transport planning. But there has also been much confusion over terminology and over the precise role that these new concepts should be assigned in the planning process (Dalvi 1977). This paper explores some of the various concepts employed to measure accessibility. A closer integration of accessibility and mobility considerations in transport planning is needed, although we concentrate here on accessibility.

There is a critical distinction between the manipulation of data to specify 'objective' measures of accessibility, and the construction of models to calculate perceived measures. The first part of the paper concentrates on a typology of functional forms largely drawn from descriptive analyses found helpful in planning, and the areas of relevance of these measures. The selection of indicators appropriate for transport planning is then considered, with special reference to the combined influence of land-use and transport. Selected theoretical frameworks for considering accessibility are related to the models of behaviour and perception used for forecasting. Empirical illustrations are provided by a simple analysis of transportation study data for the Victorian City of Ballarat, and some traffic restraint studies in Coventry (UK).

## POTENTIAL APPLICATIONS

Accessibility has generally been defined as some measure of spatial separation of human activities. Essentially it denotes the ease with which activities may be reached from a given location using a particular transportation system. Several broad applications of accessibility indicators may be identified, including evaluation of the transport/land-use system, modelling travel choice situations, modelling urban development, and summarising spatial structure (Wachs 1977). With the exception of the third application, the concept of accessibility is equally applicable in rural environments as in urban contexts; however, primary emphasis is placed on the latter in this paper.

## System Evaluation

Accessibility is already important as an evaluation criterion. Evaluation of alternative transport plans is best considered in relation to the activities of interest to individuals and groups because most daily travel owes its existence to the spatial separation of activities. Since accessibility is a function of both land-use patterns and the performance of the transport system, it is a particularly appropriate criterion for evaluating the service provided by the transport system to different categories of users (Koenig 1977, Black and Conroy 1977). A useful feature of accessibility indicators is their ability to *generate* remedial solutions and to *influence* the plans being developed, by indicating which areas or groups are currently under-provided. Such solutions may not necessarily involve modifications to the transport system; and in some cases improvements in accessibility may be achieved more effectively by reorganising the distribution of activities in space and/or time. Accessibility indicators may also be used to monitor changes in the urban system, irrespective of whether such changes are planned or unplanned.

Despite these advantages of accessibility indicators there is currently some debate on whether accessibility or mobility should be the objective in transport planning. This issue is compounded by the fact that the concept of mobility has been used rather indiscriminantly to refer to both the supply side and the demand side of transport services (Dalvi 1977). For the purpose of the present study, personal mobility is interpreted to mean the ability of individuals to move from place to place: this depends principally upon the availability of different modes of transportation, including walking (see Hillman *et al.* 1973, 1976). When defined in this sense, mobility is conceptually distinct from actual travel; and the argument over mobility or accessibility as an objective in transport planning is seen to be a futile exercise. Mobility and accessibility *together* influence an individual's capacity to travel in daily life. It is important to recognise, however, that *perceived* accessibility and *perceived* mobility - the real determinants of behaviour - will be at variance with 'objective' indicators of accessibility and mobility.

## Travel Demand Models

Accessibility indicators may also be used as input variables in modelling travel choice situations. Travel involves costs in time, money and human effort which must be borne directly by the community. Consequently, accessibility may not only influence the distribution of travel costs within the community but may also affect levels of service use and participation in desired activities. It has been suggested that individuals make a set of mutually dependent choices or decisions which are highly dependent upon individual household members' perceived accessibilities to various opportunities by a given transportation system (Ben Akiva and Lerman 1975). Such decisions include, for example, where to live, how many cars to own, and what trips to make at what times by which modes (Burns and Golob 1976). Accessibility, therefore, represents an important element to be considered in virtually all choice issues relevant to transport planning. Once again, however, there is a fundamental problem of measuring perceived values.

### Urban Development Models

This third application of accessibility is closely related to the second, although it represents a somewhat more longstanding interest held by transport planners. This concerns attempts to model the relationship between accessibility and urban development (Clark 1951, Hansen 1959). Here the focus is not so much on modelling individual choices but on modelling urban form in the aggregate.

### Description

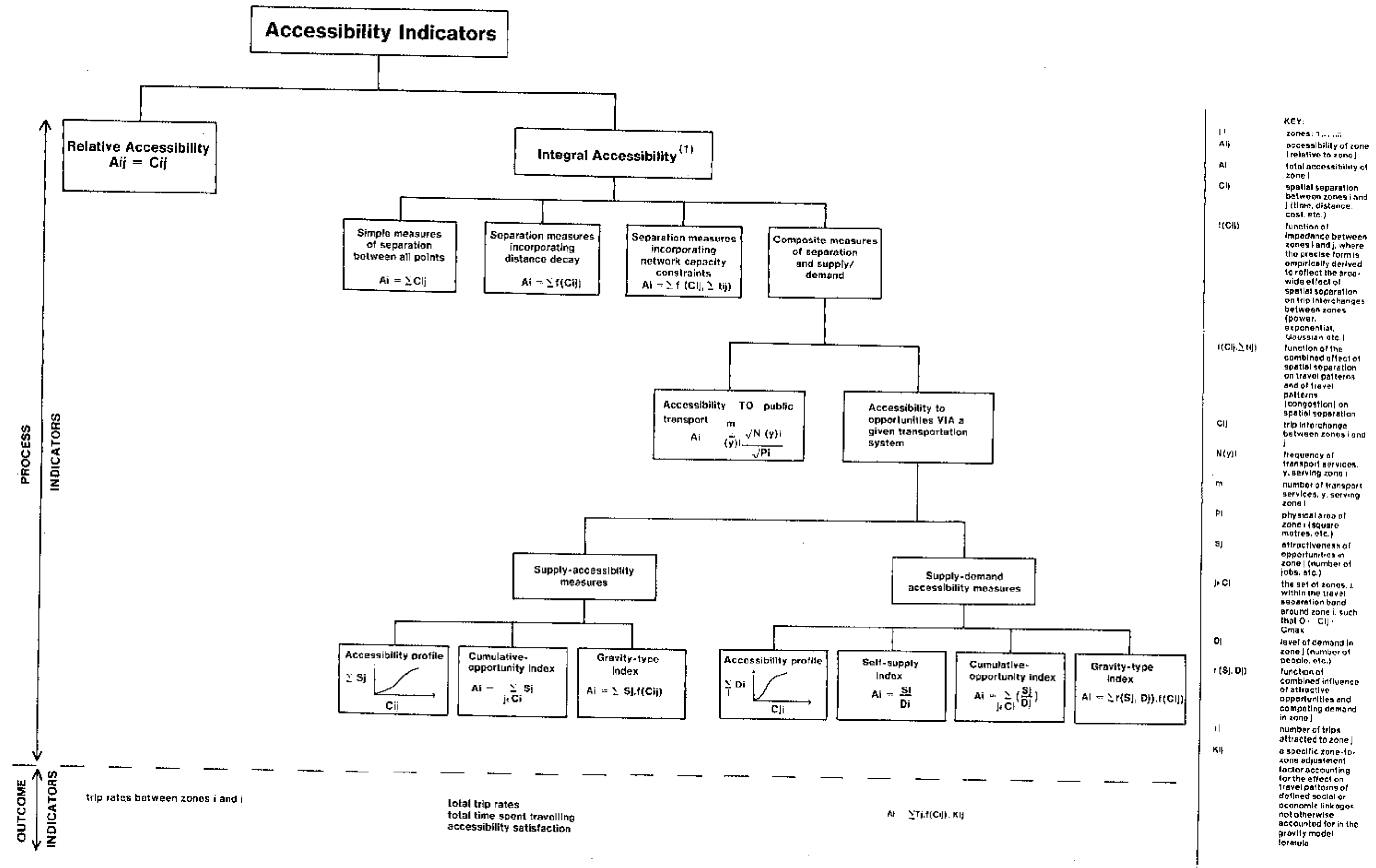
Accessibility indicators provide possibly the most useful and appropriate means of summarising a great deal of information on the location of households in relation to the distribution of urban activities and the transport system that connects them (Wachs 1977). In so doing accessibility indicators are important descriptive measures of urban spatial structure and performance.

With these broad applications in mind, let us now turn to examine the various concepts and measures of accessibility which may be of value in transport planning.

## DEFINING AND MEASURING ACCESSIBILITY

Accessibility measures are based on the premise that space constrains the number of opportunities available. Beyond this point, definitions of the concept differ widely. There is considerable variation in the other elements which may be included, and in how they are measured and combined. As Gould (1969, 64) has noted, "accessibility .... is a slippery notion .... one of those common terms which everyone uses until faced with the problem of defining and measuring it".

To some degree, variations in accessibility measures are inevitable since the appropriate definition will depend upon the intended application. However, most of the confusion stems from fundamental differences of opinion. There is a basic dilemma in choosing between 'process' indicators (measures of the supply characteristics of the system and/or




1. Unless otherwise stated ∑ refers to a summation over all j.

FIG. 1 A Typology of Accessibility Indicators individuals) and 'outcome' indicators (such as actual use and levels of satisfaction). On the one hand accessibility may be interpreted as a property of individuals and space which is independent on actual trip making and which measures the *potential* or *opportunity* to travel to selected activities. Alternatively, it may be held that 'proof of access' lies in the use of services and participation in activities, not simply in the presence of opportunities. Consequently there is a tendency to want to measure accessibility in terms of actual behaviour (Wachs 1977).

This basic conflict gives rise to a range of accessibility measures which differ in terms of their behavioural component. And yet this represents only one of many sources of variation in accessibility indicators. Since there is no concensus on an operational definition of accessibility, it is necessary to develop a broad classification of accessibility measures before any meaningful attempt can be made to evaluate them.

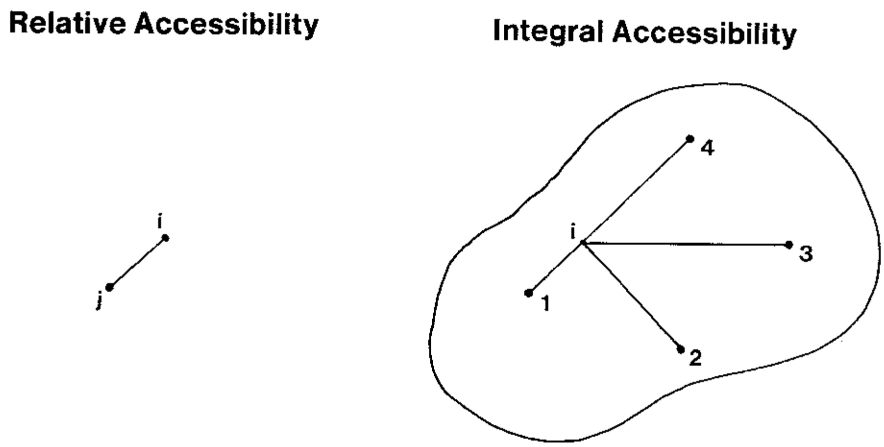
## A Classification of Accessibility Indicators

A useful classification of accessibility indicators is given in Fig. 1. This is largely an amalgamation of previous attempts to classify accessibility measures (Ingram 1971, Briggs and Jones 1973, Wachs 1977). Examples of specific formulae are presented for each terminal class shown in Fig. 1, and supporting references are contained in Morris, Dumble and Wigan (1978), which is a fuller version of the present paper.

The two principal bases of classification are the behavioural dimension mentioned earlier, and a distinction between 'relative accessibility' and 'integral accessibility' developed by Ingram (1971). Relative accessibility describes the relation or degree of connection between any two points, whereas integral accessibility describes the relation or degree of interconnection between a given point and all others within a spatial set of points (see Fig. 2). Essentially, relative accessibility is a measure of the effort involved in making *a* trip; while integral accessibility is some measure of total travel opportunities (Oberg 1976). The former undoubtedly gives rise to the simplest measures of accessibility, although operational measures of integral accessibility vary considerably in complexity.

The large range of measures of integral accessibility is basically the result of continuing attempts to link accessibility with behavioural theories. These attempts have concentrated mainly on three aspects: first, the choice of an appropriate measure of impedance to reflect the perceived cost of travel; second, assumptions about the perceived choice set of opportunities; and third, the choice of appropriate attractiveness variables to reflect the availability of opportunities at destinations to satisfy the particular wants and desires of travellers. Consideration of the latter effectively differentiates the 'process' indicators into two groups:

those which simply describe the ease of traversing space via a given transport system (public or private); and those which measure accessibility to selected activities or opportunities using a given transportation system.




$A_i = C_{ij}$

e.g. travel time to nearest health clinic
distance to Central Business District

$A_i = \frac{\Sigma C_{ij}}{n}$

e.g. mean travel time to all health clinics in the region
mean distance to all other zones

FIG. 2 Relative and Integral Accessibility

Although the distinction between 'relative' and 'integral' accessibility was originally developed in relation to 'process' indicators, it is equally applicable to measures of actual behaviour (such as trip rates and travel times) which are in some sense measures of accessibility. Simple behavioural measures of relative accessibility include standardised trip rates between specific areas. Likewise, the trip distribution pattern in a given region may be used to compute a measure of total accessibility. Such measures assume that revealed travel patterns are good indicators of how people value accessibility when they choose their destinations (Zakaria 1974).

In reality, the range of possible accessibility indicators is almost endless, and only a broad outline is presented in Fig. 1. For example, the composite indicators which in themselves constitute a large family of measures, may be modified in a number of ways. These include varying the unit of separation, time of day, mode of travel, measure of attractiveness of opportunities, measure of demand, and level of disaggregation. In addition, the 'gravity type' indicators, as introduced by Hansen (1959), lend themselves to a variety of functional forms of impedance (power, exponential, Gaussian, etc.); and most indicators may be modified to allow for 'barrier effects' arising from administrative restrictions on the use of services or participation in activities (see Oberg 1976). The problem, then, is to choose the most appropriate form from the mass of alternatives.

## CHOOSING APPROPRIATE INDICATORS FOR EVALUATION

It is clearly outside the scope of this paper to prescribe suitable measures of accessibility for every conceivable application in transport planning. We confine our attention here to the broad area of system evaluation, and give detailed consideration in the next section to the use of accessibility indicators in modelling travel demand. These aspects are, however, closely related, as are all potential applications of accessibility indicators: irrespective of intended application, the practical value of accessibility indicators depends upon the extent to which they reflect behaviour and perception.

The principal differences in selecting suitable measures of accessibility for evaluation rather than for some other purpose are, first, the level of disaggregation of the population and activities, and second, the weight given to ease of operation and interpretation of the measure. Four general guidelines may be identified to assist in the selection of accessibility indicators for evaluation:

(1) The indicator should incorporate an element of spatial separation which is responsive to changes in the performance of the transport system.

(2) The measure should have sound behavioural foundations.

(3) The indicator should be technically feasible and operationally simple.

(4) The measure should be easy to interpret, and preferably be intelligible to the layman.

These criteria are occasionally in conflict with one another. Nevertheless all should be considered to some degree in the selection procedure.

### The Unit of Spatial Separation

The question of the appropriate measure of spatial separation is not independent of the issue of the behavioural basis of accessibility measures, but is treated separately here for the sake of convenience. Spatial separation may be measured in terms of travel time, distance, cost, or some combination of these or other characteristics of the transport system. In turn, each of these may be derived in different ways. For instance, estimates of travel time may be either measures of perceived travel time, as reported by respondents in home interviews, or estimates of network travel times obtained from shortest path algorithms. Unfortunately, systematic errors are associated with every approach, and the problem becomes one of choosing the measure which best suits the problem at hand from the available alternatives.

While a measure of perceived separation is attractive on behavioural grounds when modelling individual responses, some form of actual separation is preferable for evaluative purposes. Moreover, measures (such as time, cost and convenience) which monitor network quality and performance are more satisfactory than measures of network distance, especially in urban areas. Koenig (1977), for example, employs a generalised cost function based on the time, cost and effort involved in travelling by different modes.

## Behavioural Foundations

Behavioural considerations influence two major choices when selecting appropriate accessibiltiy indicators for evaluation: first, the choice between 'outcome' and 'process' indicators; and, second, the choice between indicators of accessibility *to* the transport system, and indicators of accessibility to opportunities *via* the transport system.

'Outcome' versus 'process' indicators. The concern for a sound behavioural foundation does not automatically imply a preference for 'outcome' indicators, since planning strictly on the basis of observed behaviour can be attacked on many grounds. Observed behaviour is simply the response to current circumstances, giving only a single point on a demand curve of unknown shape. In consequence, modelling on the basis of observed behaviour can be interpreted as tautological: it leads to self-justification (Vickerman 1974), and existing inadequacies merely become self-fulfilling prophecies for the future. Moreover, it requires inordinantly heavy data inputs and is descriptive rather than explanatory in the formal sense.

The major disadvantage of using measures of actual behaviour to evaluate the transport/land-use system is that it is difficult to disentangle the influence of choices and constraints. For instance, an increase in the total time spent travelling *may* represent an improvement in community well-being if it is linked to increased levels of participation in *desired* activities. Alternatively, the increase may denote a worsening situation if it arises purely because a given set of activities is harder to reach (see Koenig 1977). Likewise, higher trip generation rates do not necessarily denote increased well-being. Indeed, a desirable outcome for both individuals and society may well be one in which activities can be pursued with minimum travel effort, rather than one which involves the largest number of trips.

While actual behaviour is in itself an inadequate basis for transport planning, there is a critical need to understand the relationship between supply factors and actual behaviour. Indeed, implicit in the use of 'process' indicators in modelling and evaluation is the assumption that outcomes are in some way affected by them. A detailed analysis of actual travel patterns gives some indication of the behavioural constraints operating on different groups in the population, and also provides a meaningful basis for classifying the population. As will be shown later, socio-economic, demographic, and mobility characteristics exert a strong influence on the demand for travel, and consequently it is important to control for these effects when examining the relationship between accessibility and travel behaviour. This is best tackled by stratifying the population into relatively homogeneous groups, and calculating accessibility for each group separately (see Turner 1972, Koenig 1977, Black and Conroy 1977, Mitchell and Town 1977).

The mode of transport available to individuals is a particularly vital element in calculating accessibility. Countless studies have highlighted the marked discrepancy between the number of opportunities which may be reached by car within a given time period, as compared with those which may be reached by public transport (Wachs and Kumagai 1973), or on foot (Hillman *et al.* 1973, 1976). Accordingly, the short-run impacts of particular land-use/transportation plans may depend substantially upon the mobility characteristics of the population. The findings of a Sydney study are a case in point: Black and Conroy (1977) found that a dispersed arrangement of workplaces improves accessibility to employment for residents of outer suburbs, especially those who have access to private transport (notably men and higher socio-economic status women); while improved public transport favors women more than men by reducing, but not eliminating, differences in accessibility.

In recognition of the importance of mobility considerations, some researchers have proposed composite 'mobility' indices, or measures of 'access to opportunities', derived by weighting accessibility indices by actual travel behaviour (*viz.* relative use of different transportation modes and trip purpose frequencies) (see Wickstrom 1971, Briggs and Jones 1973, Popper and Hoel 1976). Such indices, however, are subject to the same criticisms as outcome indicators. Also the indices apply specifically to areal units, and thus do not permit detailed consideration of distributional effects. The fact remains, however, that the more satisfactory alternative i.e. constructing separate mode-specific accessibility indicators depends upon knowledge of actual travel patterns - only in this way can mode-availability be inferred on a large scale. For a variety of reasons, therefore, an analysis of observed behaviour is a necessary (but by no means sufficient) condition for the modelling of accessibility.

Accessibility to transport, or to opportunities? Since most travel is a means to an end, an accessibility measure which reflects the distribution of activities within the city is preferable to a measure which simply describes the ease of traversing space via a given transport system. There may yet be a place for measures of connectivity of the transport network or measures of accessibility to public transport - such measures may be useful in pinpointing glaring deficiencies in the transport system. But for most of the broader issues tackled in present-day transport planning these measures must be rejected on behavioural grounds. Indicators of travel time, distance or cost fail unless supplemented because they reflect only one of the components of the satisfaction an individual may derive from his travel. Account should also be taken of the probable interest of the destination reached.

Hence, the range of choice narrows considerably to the set of 'process' indicators which describe accessibility to opportunities via the transport system. In most cases this amounts to a choice between the various forms of composite indicators shown in Fig. 1; but in some cases a simple 'relative' accessibility index may be more appropriate. For instance, when services have administratively defined catchment areas the 'choice' of destination is not an issue, and accessibility may be more meaningfully measured by the 'effort' involved in reaching the prescribed activity centre. Simple measures of proximity to the nearest opportunity may even be more appropriate for some very local activities, especially if the potential destinations are fairly homogeneous. In the majority of cases, however, consumer choice prevails, and the destinations vary considerably in potential utility. Accordingly, composite indicators are the most appropriate since they not only reflect transport conditions but also the wealth of choice provided by urban structure (Koenig 1977).

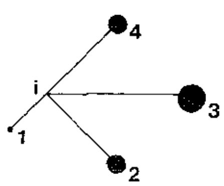
The choice of appropriate attractiveness variables for inclusion in a composite indicator will depend upon the specific activity or group of activities under study. Such an indicator should normally include simultaneous consideration of supply and demand elements. For example, accessibility to employment not only depends upon the number of relevant job opportunities available within a given area, but also upon the number of persons competing for those job opportunities. This aspect is incorporated in the modified gravity index developed by Weibull (1976).

Notwithstanding, the final selection of an appropriate operational form of accessibility may be governed by technical considerations of operational simplicity and ease of comprehension. In fact there is a distinct trade-off between the behavioural relevance and the operational simplicity of accessibility indicators. Thus a composite measure which incorporates the perceived cost of travel and the level of competing demand is the most acceptable on behavioural grounds, but is undoubtedly the most difficult to apply.

## Technical Considerations

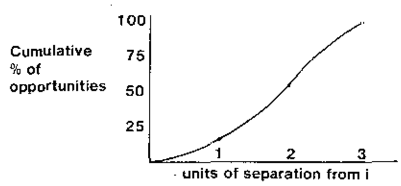
The selection of an appropriate impedance function is essentially a technical issue There is no theoretical basis on which to select the correct function: rather the form should fit the available data. However, calibration requires heavy data inputs and there are major difficulties in identifying the 'true' value of the separation decay exponent (Curry 1972, Ewing 1974). A further difficulty arises in the context of evaluation if different separation decay exponents are used for different population groups. This is because the value weightings are 'hidden' or 'latent' in the single composite value of accessibility thus derived. Whitbread (1972) suggests that a further disadvantage of gravity-type indicators is that they implicitly weight one unit of separation as equivalent to one unit of attraction. This criticism is related more to the way in which these accessibility indicators have been applied in practice, rather than to intrinsic features of the indicators, themselves. Vickerman (1974) represents one of the few attempts to determine the independent influence of attraction on travel behaviour.

Accessibility-related comparative indices have been employed by Flowerdew (1976) to avoid this problem when evaluating alternative plans. The indices control for any tendency for travellers to make *longer* trips as travel times or costs decrease. This is accomplished by comparing weighted indices of spatial separation for option A when the times/costs of option B are used in A, and vice versa. Nonetheless, the indices are based on actual trip making patterns and are more useful for comparing specific plans rather than describing accessibility (and hence *generating* remedial solutions).




| potential destination (j) | attractiveness of opportunities in destination zone (Sj) | units of spatial separation from origin i (Cij) |
|---|---|---|
| 1 | 30 | 1 |
| 2 | 40 | 2 |
| 3 | 90 | 3 |
| 4 | 40 | 2 |

**Accessibility Profile:**




**Cumulative-opportunity index:**

$$A_i = \sum_{j \in C_i} S_j$$

If Cmax = 1 Ai = 30
If Cmax = 2 Ai = 110
If Cmax ≥ 3 Ai = 200

**Gravity-type index:**

$$A_i = \sum S_j . f(C_{ij})$$

If we follow Hansen (1959) $f(C_{ij}) = \frac{1}{c_{ij}^2}$

$$A_i = \frac{30}{1} + \frac{40}{4} + \frac{90}{9} + \frac{40}{4}$$
$$= 30 + 10 + 10 + 10$$
$$= 60$$

FIG. 3. Sample Calculations of Some Accessibility Indicators

Other researchers have turned to cumulative-opportunity indices or accessibility profiles as measures of accessibility (see Fig. 3). The principal disadvantage of a graphical measure is that it does not produce a single value of accessibility which can be used to immediately compare alternative land-use/transportation plans. It does, however, offer three advantages. First, the value weightings of the relative importance of separation and attraction are made explicit. Second, the distribution of opportunities with increasing distance from a given location is apparent and may be compared for different areas, modes and socio-economic groups. Third, graphical measures enable standards to be more clearly specified (e.g. S opportunities within C units of spatial separation) in terms which are readily intelligible to the layman (Whitbread 1972, Briggs and Jones 1973). To some extent this third feature also applies to cumulative-opportunity indices of accessibility, but such measures are based on an artificial boundary and there is a problem in deciding where to set the limit.

Nevertheless, the similarities between the various types of composite indicators are more notable than their differences (see Weibull 1976). Indeed, Black and Conroy (1977) have devised an accessibility measure which combines the relative advantages of graphical and numerical indicators: specifically, a numerical value or index of accessibility may be derived by integrating the area under the cumulative opportunity curve bounded by a given spatial separation limit. Unlike other cumulative-opportunity indicators this index preserves information on the distribution of opportunities within the chosen separation band. The index also conforms with the six axioms of accessibility postulated by Weibull, and has been shown to given empirical results which agree closely with those produced by a Hansen-type index (Conroy 1978). But the index is still based on an artificial boundary; and, as presently applied, does not allow for variations in demand at the supply points.

## An Applied Accessibility Indicator

The complications in definition and application of different accessibility indicators should not be allowed to confuse the issue: accessibility even as a simple relative, or uncomplicated integral, measure (see Fig. 1) is an effective addition to our assessment armoury. A practical example is given to illustrate this point. Figure 4 shows four different diagrams on a common geographical basis, that of the city of Coventry in the U.K. The results are drawn from work (Wigan *et al.* 1974) done for the U.K. Department of the Environment (1977) Traffic Restraint Study, where a wide range of different traffic restraint policies were examined using an equilibrium model (including elastic travel demand for private and public passenger travel and goods transport).

The key point is that while two of the policies shown in Fig. 4 produce closely similar net benefits, the spatial accessibility impacts are very different. The accessibility diagrams illustrate simple measures of total separation (i.e. $\Sigma C_{ij}$, as shown in Fig. 1). The social indicators diagram provides a basis for the social appraisal of these spatial differences, and is based on a weighted ranking of life cycle, age group, immigration, household and public facilities, car ownership, employment and socio-economic characteristics. The higher the score, the greater the disadvantaged nature of the district.


FIG. 4 Accessibility Variations for Otherwise Comparable Policies (Coventry) After (Wigan *et al.* 1974)

By comparing the different diagrams in Fig. 4 it becomes evident that a disadvantaged area would suffer heavy restraint under supplementary licencing (requiring an extra licence to operate a vehicle in the central area of "the railway triangle"). This is not a simple result to interpret. If the resident did not own cars (likely, in this area), then the sharp traffic reduction would be a key benefit. But if all the employment in the area was unsuitable for the residents, they would be suffering a large reduction in accessibility to their jobs. Further questions then arise on the degree of balance between residents and jobs in the area, and the average length of journey to work.

The detailed result of matching the different diagrams provides several illustrations of these distributional questions. Supplementary licensing and parking produce a very wide range of effects, and consequently pose numerous awkward distributional questions (Wigan *et al.* 1974). In both cases the central area is the worst hit, and it is interesting to note that this is the area most socially disadvantaged. It might therefore be argued that the triangle restraint area (which forms the boundary for the application of all the policies discussed) is too large as it extends into areas beyond the central business district of Coventry (a small area at the bottom of the triangle).

The accessibility changes for the cordon policy show the lowest generalised costs (i.e. best accessibility) of the policies applied to the railway triangle, and even lower costs under restraint in the central area than in the unrestrained state. This is a result of greater freedom of movement for trips solely within the triangle, which therefore escape charging at the cordon.

The parking costs show cost reductions for a very large primary residential area to the north and west of the triangle (as a direct consequence the number of trips rise for this area). This has implications not only for land use but also for the public transport system which would suffer reciprocal decline in passengers. It may be concluded that:

(1) Supplementary licencing produces the least progressive effect by placing the greatest accessibility shift in the three central wards (i.e. the triangle), and the least on the peripheral areas to the north, east and west.

(2) Parking charges produce the same general patterns as supplementary licencing but the range of accessibility shifts is not so large, and in some areas, the charges actually induce traffic.

(3) Cordon charging actually produced progressive effects, and might therefore be rated more highly as a result. The less advantaged areas retain their mobility and are affected least, while the outer areas suffer the revenue.

The general social distributional impacts are clearly highlighted by this analysis. The change in emphasis of the assessment produced by the extra information provided by a simple accessibility indicator is substantial, in the light of the close economic comparability between cordon and supplementary licencing.

However, it is clear that *none* of the established measures of accessibility satisfy all of the requirements for transport evaluation. Typically, simple measures fall down on behavioural grounds, while indicators with stronger behavioural foundations are complex and difficult to apply in practice. More importantly, even though some indicators have a stronger behavioural basis than others, none are completely acceptable on behavioural grounds. This is because the established measures do not *explain* why increased accessibility should lead to increased trip-making. Since this probably represents the major stumbling block for accessibility indicators, the following section gives detailed consideration to the theoretical underpinnings of accessibility indicators.

## MICRO-ECONOMIC THEORY, TRAVEL DEMAND AND ACCESSIBILITY

A perceived change in accessibility either affects travel behaviour directly or alters levels of satisfaction with the new transport/land-use system that caused the perceived change. Various theories, founded on models of micro-economic consumer behaviour have been specified to express this implied causal relationship mathematically. Empirical results in support of these theories are reviewed here together with the essentials of the theories themselves.

Some analyses were carried out on a household travel survey executed in Ballarat in 1970 as part of the Ballarat Transportation Study (Harris Lange-Voorhees 1971). Unfortunately it was not at the time possible to compute the different indices listed in Fig. 1. Ballarat was chosen because the sample size was small enough to be manageable - 1284 households containing 3804 persons over the age of 5 - and the survey included data on all trips made, including walk and bicycle modes. Systematic under-reporting of walk trips is expected to have occurred, as only one mode was recorded for each trip. Where two or more modes were used, the access mode (often walking) was eliminated at the trip linkage stage. Such conventions of 'dominant mode' coding ignores key information on access modes which is now being realised to be of central importance in mobility and market segmentation approaches to modal choice.

### The Approach of Koenig

Koenig (1977) suggested that accessibility and travel demand were related through the concept of utility. An individual perceives some net utility, $U_{ij}$, in travelling from i to j and pursuing an activity at j. This net utility is composed of a gross utility, which Koenig postulates is proportional to the natural logarithm of some indicator of the relative number of perceived opportunities for carrying out the desired activity, and a disutility term associated with the perceived separation of i from j. Thus:

$$U_{ij} = \log_e A_j + \text{constant} \tag{1}$$

where $A_j = \dfrac{S_j \, e^{-\lambda C_{ij}}}{\sum S_j}$ a 'relative' Hansen index of

the accessibility of j relative to i, and $\lambda$ is a constant parameter. The associated 'integral' utility of i is then given by:

$$U_i = \log_e A_i + \text{constant} \tag{2}$$

where $A_i = \dfrac{\sum S_j \, e^{-\lambda C_{ij}}}{\sum S_j}$ an 'integral' Hansen index.

If one conceives the travel choice process as one of ranking all possible trips in order of decreasing net utility, then the individual will make those trips down to the point at which the gross utility derived from making the last trip exactly offsets the disutility of making it. The trip generation rate of an individual at i, $T_i$, is then a function of the 'integral' accessibility of i, $A_i$. Specifically:

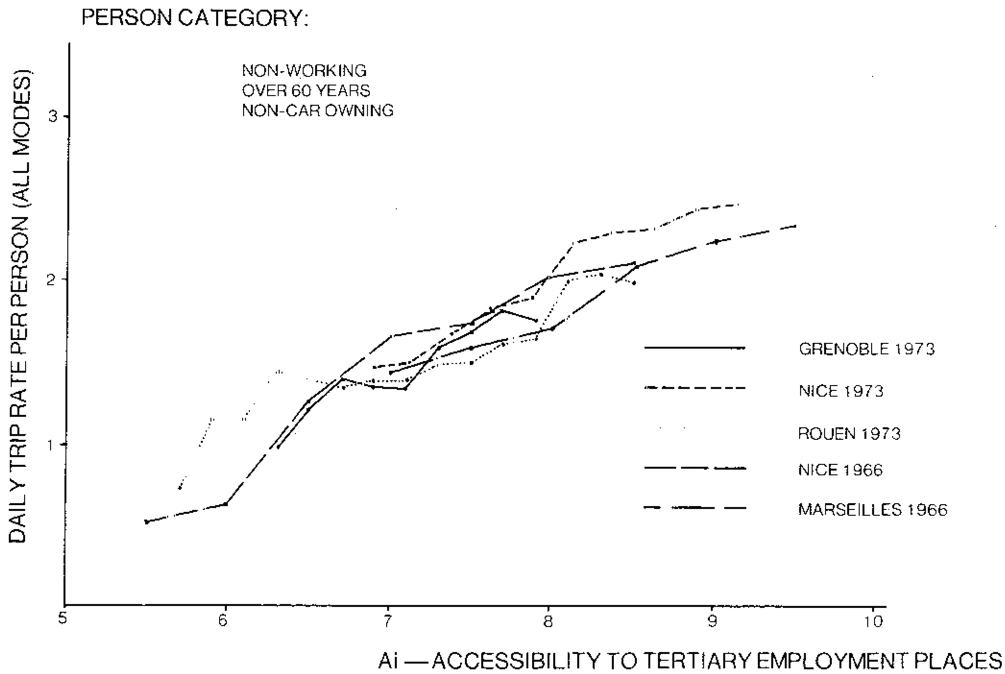
$$T_i = f\,(U_i) = g\,(\log_e A_i) \tag{3}$$

Practical weight is given to this derivation by Fig. 5. This shows plots of daily trips per person (all modes) versus accessibility to relevant opportunities for a particular person category in some French cities (Koenig 1977). Fig. 5 shows an increase in observed trip generation rate with an increase in the chosen accessibility index, when both are defined and calculated for this relatively homogeneous group of individuals.

An attempt was made to approximate the effect of varying accessibility on trip generation rate by subdividing Ballarat into a series of concentric rings (on the assumption that accessibility to virtually all opportunities will decrease with distance from the centre of Ballarat). The results are indicative but not conclusive (Morris *et al.* 1978), and are therefore being pursued further.

## Fundamental Assumptions Underlying Koenig's Approach

Several assumptions underly Koenig's formulation, which may limit the effectiveness of the whole approach when it comes to incorporating it into a working trip generation model.




SOURCE: KOENIG (1977 Fig 8)

FIG. 5. The Effect of Accessibility on Trip Rate (Some French Cities)

One general assumption is that the zoning system chosen has no influence on parameter estimates. According to micro-economic consumer choice theory the individual perceives a set of alternatives open to him (Henderson and Quandt 1971) and each alternative has associated with it a certain level of ordinal utility. In this case the set of alternatives for destination choice is the set of zones. It is therefore necessary that the individual perceives the spatial distribution of activities as this discrete pattern of zones. This is perhaps unlikely, except for trip purposes such as shopping for high order goods which are available only at a very limited number of locations. It has been shown that accessibility indices are sensitive to the type of zoning system used (Dalvi and Martin 1976).

Another general problem may be caused by the necessity to construct separate indices for different modes. This requires some previous knowledge of the chosen mode; knowledge which does not become available in the sequential approach to travel demand modelling until after the trip distribution (destination choice) stage. Some commentators have suggested a mode specific approach to trip generation to overcome this drawback (Vickerman 1974, Burns and Golob 1976), given the marked effect of car availability (defined at the time the decision is made to make, not to make, or to delay making, a trip).

One other important, yet tacitly accepted, assumption in Koenig's formulation is that all travel is of a simple nature, i.e. is composed solely of two stage journeys; starting at home, going to a single destination for a single purpose and then returning home. As the paper will show a large proportion of travel is accounted for by multi-stage journeys. This may undermine the behavioural veracity of most trip generation models in current use, due to the difficulty in specification of mode and purpose in multi-stage journeys and the mutual influence of each stage on perceived accessibiltiy relevant to preceding and succeeding stages.

One deficiency specific to Koenig's model is that the theory involved in the formulation does not provide us with a behaviourally based functional form. That is, while we know (equation 3) that:

$$T_i = g(\log_e A_i)$$

we are left with no clues as to what the function may be. It would seem that increasing accessibility leads to an increasing trip rate, *ad infinitum*, as equation (1) suggests that the net utility derived from making any particular trip is independent of the number of such trips already undertaken in the time period under consideration. The concept of satiation with increasing trip rate must somehow be introduced. In micro-economic utility theory this corresponds to the requirement that marginal utility be a positive, but decreasing function of the quantity consumed (Henderson and Quandt 1971):

$$\frac{\partial U_i}{\partial T_i} > 0 \quad \text{and} \quad \frac{\partial^2 U_i}{\partial T_i^2} < 0 \tag{4}$$

Other derivations using the same framework as Koenig (and thus containing the same general assumptions) have been proposed which attempt to incorporate such a satiation effect.

Niedercorn and Bechdolt's Approach

Niedercorn and Bechdolt (1969) adopt the approach of maximising the utility of individuals with respect to their travel requirements subject to the constraints of limiting the total amounts of time and money that individuals are willing to spend on travel. This arises in the context of deriving the gravity model from micro-economic theory.

As a first approximation they assume that the net utility derived by an individual at i from travel $U_i$ is a function of the number of trips undertaken to each destination $T_{ij}$, and the potential for interaction at each destination. Thus:

$$U_i = a \sum A_j f(T_{ij}) \tag{5}$$

where a is a constant of proportionality

and $A_j$ is the perceived attractiveness of j for interaction.

A simpler problem statement is obtained by modifying the constraint term slightly to cover only a time constraint (i.e. a travel time budget),

$$\text{maximise} \quad U_i = a \sum A_j f(T_{ij}) \tag{6}$$

$$\text{subject to} \quad H_i > \sum t_{ij} T_{ij} \tag{7}$$

where $H_i$ is the total time allocated to travel
$t_{ij}$ is the travel time from i to j
$T_{ij}$ is the number of trips from i to j.

Niedercorn and Bechdolt produce a solution assuming a logarithmic function:

$$U_i = \log_e ( T_i ) \tag{8}$$

which obeys the first and second order requirements (equation 4).

The logarithmic assumption leads eventually to the result[1].

$$T_i = \frac{H_i \; A_i}{\sum t_{ij} \; S_j \; e^{-\lambda t_{ij}}} \tag{9}$$

Thus the total trip generation rate is an increasing function of the level of accessibility, although not directly proportional to it as might appear from a first glance at equation (9).

The effect of the accessibility term ($A_i$) is dampened by the denominator. Thus if $A_i$ increases due to a fall in any or all $t_{ij}$'s, the denominator will also increase, but not by as much as $A_i$, hence $T_i$ will increase at a slower rate than $A_i$. Similarly if $A_i$ increases due to a redistribution of opportunities in favour of locations closer to i, the increase in the denominator will be dampened by the $t_{ij}$, which is smaller, hence carries less wieght, for the closer zones than it is for the more distant zones.

One consequence of Niedercorn and Bechdolt's approach is that each individual has set amounts of time and money (or, using the generalised cost approach to travel analysis, a set amount of both when combined into quanta of the same unit) which he devotes to travel. This amount is fixed irrespective of the total number of interactions he wishes to make provided that this number always exceeds the number he can actually make. A general improvement in the transport system will not cause an individual to spend more or less time travelling. Thus each individual's time budget is simply obtained by observing his travel behaviour, i.e. the amount of time he wished to spend travelling equalled the amount he actually travelled.

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1. The full derivation is not reproduced here: the reader is referred to the original article (Neidercorn and Bechdolt 1969) and to Morris *et al.* (1978).

The average time spent travelling daily by residents of Ballarat was grouped according to various characteristics. In doing so it was possible to establish, amongst other things, which grouping gave the greatest between-groups variation. The results for all individuals are presented below in Table 1.

TABLE 1

MEAN DAILY TRAVELLING TIME[(a)]
PER PERSON IN BALLARAT (1970)

| PRIMARY MODE | Time (Mins) | DESTINATION PURPOSE | Time (Mins) |
|---|---|---|---|
| Car Driver | 29.3 | Home | 28.9 |
| Car Passenger | 13.2 | Work | 11.3 |
| Tram | 3.6 | Employers Business | 1.5 |
| Bus | 2.4 | Social/Recreational | 9.0 |
| Taxi | .5 | Eat Meal | .5 |
| Truck Passenger | .2 | Medical/Dental | .7 |
| Walk | 10.5 | Personal Business | 1.7 |
| School Bus | .2 | Shopping - Convenience | 4.2 |
| Other (Bicycle) | 5.0 | - Comparison | 1.5 |
| | | School | 5.5 |
| TOTAL | 65 | TOTAL | 65 |

NOTE:

(a) The travel time for each trip made by each individual was stated (in terms of a beginning time and an ending time) on his/her travel diary. These *stated* times are used throughout this section.

A method of stratification which showed a large amount of between-group variation, was a combination sex/age grouping. One group (males, between the ages of 18 and 24 inclusive) exhibited a daily travel time budget of almost 93 minutes (43% above the average), while another group (males, less than 10 years) exhibited a daily travel time budget of only 39 minutes (40% below the average). Fig. 6 shows the results for all sex/age groups. Included on Fig. 6, for interest mainly, are the daily travel times allocated to car driving and walk mode for the various sex/age groupings.

The graph for time spent walking is quite similar in shape to that obtained from an analysis of a National Travel Survey (NTS) of the United Kingdom by Daor and Goodwin (1976). In particular, the small amount of time spent walking daily by men in the age range 20 to 50 is observable in both Ballarat and NTS results. The most obvious difference between the two analyses is the relatively low amount of time spent walking in Ballarat; 10.5 minutes compared to 18. This is partly explained by the method of 'dominant mode' coding adopted in Ballarat.

Some interesting sociological influences on observed mobility are observable in Fig. 6. For instance, the tendency of men, at all age levels, to spend more time

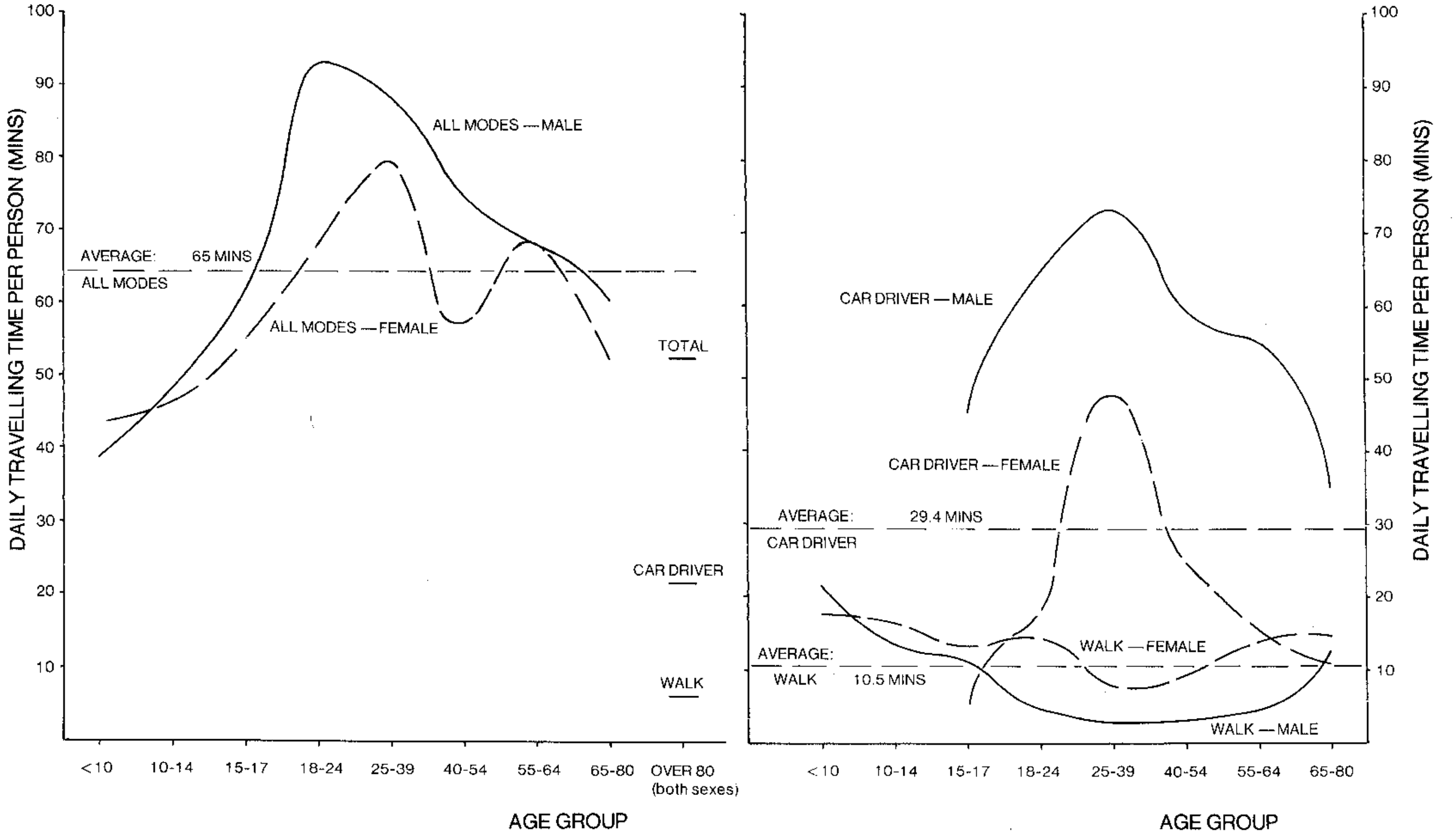


FIG. 6 Daily Travelling Time per Person (Ballarat 1970)

travelling than women. The difference is more than accounted for by the discrepancy in car usage, i.e. when time spent travelling as a car passenger (not shown) is added to that spent driving, men still spend more time travelling than women in all age groups. A second feature is the drop in total time spent travelling by women in the 40 to 55 age bracket. This may possibly be due to women in this group no longer needing to accompany their children on trips. They may even send their children on errands as they become old enough to accomplish these tasks by themselves. These and other similar observations rapidly lead one to realise that the travel demand of individuals cannot be considered in isolation from their role in the household.

Niedercorn and Bechdolt's approach, whilst retaining the desirable feature that accessibility be considered on an individual basis[1] also manages to dampen down, but not prevent the ever-increasing trip rate effect of increasing accessibility in Koenig's model. However any general deficiencies and underlying assumptions inherent in Koenig's model will still be present.

## The Approach of Cochrane

The approach of Cochrane (1975) could be considered almost as begging-the-question in relation to his treatment of accessibility and trip generation. His underlying assumptions are very similar to Koenig's as expressed by equations (1) to (3), but Cochrane introduces the concept of satiation, albeit in a somewhat arbitrary manner, by assuming that the demand for trips between i and all j by an individual, is related to a factor $G_i$ (which is really a saturation level of trip making) as well as to $A_i$.

Cochrane then derives[2] the following expressions for $T_{ij}$ and $T_i$:

$$T_{ij} = G_i \, (1 - e^{-K A_i}) \, \frac{S_j \, e^{-\lambda C_{ij}}}{A_i} \qquad (10)$$

$$\text{and } T_i = G_i \, (1 - e^{-K A_i}) \qquad (11)$$

where $G_i$ can be thought of as a saturation trip rate, and K is a parameter.

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1. i.e. equation (9) can be disaggregated by person type, mode and purpose - although it could be stretching credibility too far to suggest that individuals have travel time budgets for each travel purpose.

2. The derivation is not presented here, but it appears in the original article under the Section: "THE UNCONSTRAINED MODEL" (Cochrane 1975). Note that his symbols stand for quantities different to ours.

Once again, this trip generation sub-model is best applied to relatively homogeneous groups of individuals and can then be mode and purpose specific. An iterative Ordinary Least Squares (OLS) procedure would typically be used to estimate G and K. Rough estimates of $G_i$ and K were made for the results depicted in Fig. 5 for the City of Nice (1966):

$$G_i = 4.7 \quad \text{(daily trips per person)}$$
$$\text{and } K = 0.068$$

Cochrane's model is perhaps the most useful from an operational standpoint. The model also has the theoretical nice ty that it obeys the requirement of decreasing marginal utility of consumption. It remains to be seen how well it performs in practice, although this will depend on the method adopted for stratifying the population into homogeneous groups. The idea of a saturation trip rate is an intuitively appealing way of overcoming the major deficiency of Koenig's formulation. However, the general assumptions underlying current modelling processes have not really been questioned in the Cochrane model, nor in any others.

## LINKAGE OF TRIPS AND ACTIVITIES

The Ballarat data was examined to check on the proportion of multi-stage journeys. Fig. 7 shows that the incidence of multi-stage journeys in Ballarat was up to 50% for some groups and similar figures have been found elsewhere.

The simple calculation of the different accessibility indices is materially complicated by the inclusion of linked trips. There are two distinctly different problems. The first is the practical coding of the data at the initial stage of transport surveys, where trip stage and sequence tend to be dropped. The coding conventions themselves can cause the loss of critical data: the choice of a single dominant mode - usually omitting the access mode - in a complex journey is of special significance. Further information may be ignored at the analysis stage: for example the undue aggregation of purpose codings results in significant loss of detail within a trip sequence. Nevertheless information is retrievable by going back to the basic survey data.

The second problem is conceptual, and posed by the treatment of behaviour: i.e. is travel sequential or simultaneous in nature? Accessibility and mobility are both indicators designed to summarise actual or perceived potential for travel, and are therefore closely linked to hypotheses of modal and destination choice. This link is difficult to specify given the need to relate both travel behaviour and accessibility concepts to individual utility specifications. The first level of aggregation poses the problem of differentiating behavioural, perceived, and resource (actual) determinants of travel utility,and has been treated in detail in transport evaluation (Wigan 1971). At the level of zonal aggregation involved in mobility and accessibility calculations, such differentiation is more relevant to general evaluation issues than to individual utility questions, and though more familiar to transport analysts, must be treated later in the chain of analytical procedures.

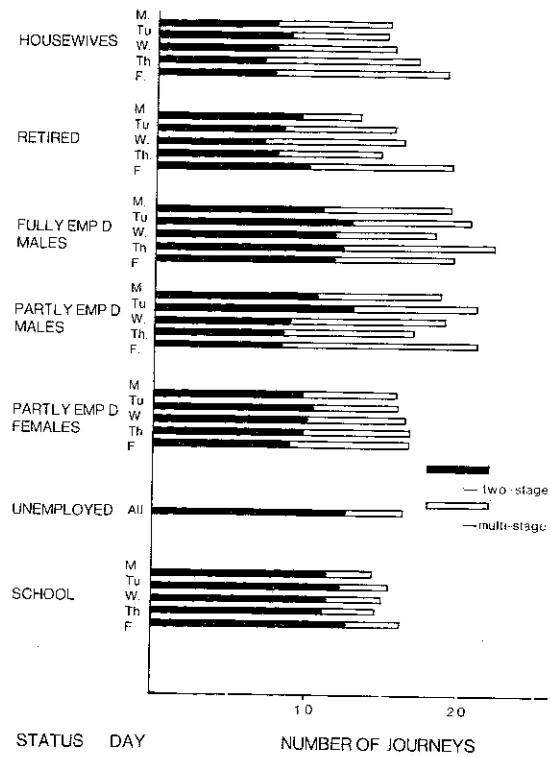


FIG. 7 The Incidence of Journey Making (Ballarat 1970).

The fundamental issue is that of utility specification for individuals, and the manner in which this conditions and structures the functional forms at a level aggregated enough for practical choice analyses. Williams (1977) has reviewed a family of such necessary consequences in functional forms, showing how both the unrestrictive assumptions on entropy calculations - which contain no specific utility assumptions or specifications other than the range of random combinations of choices, but solely aggregate constraints - and the cumulative choice probabilities from specified utility functions lead to families of choice models of very similar form (but with critical underlying constraints inherent within their structure).

The choice of destination and of mode is frequently assumed to be a (simultaneous) single decision, but in fact represents two separate choice functions which may or may not correspond to a single simultaneous choice function. The separability of the multiple logit function is frequently exploited in this way, to overcome such problems as are raised by different behavioural models for destination and mode choice. This assumption is most important. The development of any utility-based choice model covering destination choice inevitably imposes constraints on the evaluation framework. It should also include or develop a summary measure of destination opportunities (or accessibility) which affects both the level of trip demand and its' geographical potential. Williams (1977) illustrates this point by a minor observation that "if a trip production model is developed from an underlying utility structure, then the appropriate measure of net utility, which involves level of service variables in the logit approximation, is proportional to the log transform of a modified Hansen measure of accessibility of similar structure to the index proposed by Koenig (1977)". Precisely the same sort of requirement arises from the inclusion of accessibility measures in category analysis procedures (Dalvi and Martin 1976), where the link is drawn at the evaluation stage when the resultant elastic trip end model must be integrated.

The weight of Williams' (1977) synthesis is towards sequential models of choice, due to the readier resolution of consistency questions arising from the underlying base of individual utility in the construction of a formalism. The concept of accessibility is related most naturally to a simultaneous view of travel and destination demand and choice, where the combinations of mode and destination may be seen to define the accessibility to the home base of the journey. This view can be reconciled with sequential choice models of mode and destination fairly easily for out-and-back home based journeys, but as we have already seen earlier in this section a significant fraction of journeys are part of a longer linked sequence.

The following questions may now be posed:

(1) Is accessibility to be attributed to the *homebase* of a trip sequence?

(2) Or to each successive zone visited?

In the latter case there are further choices for attributing the accessibility so calculated: either by zone by zone recalculation where each zone in the sequence is treated as a 'home base' with access opportunities one stage away: or by an accumulation of such calculations and the total attributed either to the home base or credited to *every* zone visited in the sequence.

If a simultaneous decision model is adopted, then all of these choices collapse to a cumulative accessibility value allocated only to the home base. The zonal sequence merely complicates the calculation, although other variations could be embraced which would then include some non-home based relevance. If a sequential model is adopted, the relevant accessibility calculations become further ill-defined, and strongly influenced by the precise models adopted whatever the index of accessibility desired.

The loss of specific linkage labels on multi-stage journeys in conventional transport models does not necessarily rule out 'correct' accessibility calculations in *all* these cases: the case of sequential models with zone by zone accessibility calculations with no accumulation will give the same results, although requiring the recovery of the information that a new *un*linked trip is actually to be treated as 'home based' for this purpose. These close inter-relationships between elastic travel demand, travel and destination choice hypotheses, accessibility, and the unifying effects of individual utility theories have the net result of further constraining our freedom to chop and change models between different stages of the transport analysis process. The emergent importance of trip linkage in this web shows up clearly yet further constraints on the transport planning process as so often carried out.

This link between modelling analyses and accessibility assessment binds different activities together through the multi-stage trip and through the fundamental links between destination choice and the activities at those destinations which provide the motive for movement. The most closely related area of special concern is that of directly representing activity linkages, without the intermediary of links between trip stages. Descriptive models of the multi-stage trip and the chained activity structure involved have been built using Markov and transition matrix formats (Wigan and Richards 1974). Such descriptive models are inadequate for more than pragmatic use, and causal hypotheses are needed to complete the network of motives and constraints for travel behaviour.

CONCLUSIONS

The limitations to current practice brought out by our review of accessibility indicators are now summarised:

1. The current travel demand modelling practice of treating trips as separate events sets the limits of our ability to explain behaviour in the following areas;

   (a) Trip generation, whether accessibility is used as a production variable or not, due to the inability of intermediate stages to influence the decision to make a trip, and

   (b) modal choice, due to the inability of intermediate stages of trip to influence this decision (Bowyer and Tao 1978).

2. Household surveys of travel are deficient in the following areas:

(a) trip purpose - only one destination and origin purpose for each trip is recorded, when in fact more than one activity may be pursued at any particular destination, including home,

(b) the scope of the travel diary - frequently only one day of travel is recorded, which is inadequate to cover the full range of frequent and regular activities pursued by the household's members, individually and cooperatively, and

(c) the management of travel within the household - details of decisions regarding the allocation of cars between the licenced drivers in the household or who will undertake the travel necessary for the collective well being of the household are not recorded.

It is possible to reduce the effect of these constraints by inverting the traditional approach to transport planning. This is to adopt the view that travel is simply brought about by the physical separation of people from some of the activities that they desire to participate in: the activity linkage view of travel (Jones (1976),1977, Bentley *et al.* 1977, Hanson 1977). Moving from travel *per se* to personal and household activity patterns and aspirations in general, must eventually lead to a better understanding of individual reactions to transport policy. Indeed, it may be found that particular 'transport problems' can best be solved by non-transport or instutional methods, which allow for the re-arrangement of institutionally determined travel patterns.

Unfortunately, whilst the data requirements for the activity linkage approach are reasonably clear (Dix 1975), the type of models required is far less so. Consumer choice models of activity demand treating the value of travel time savings (Becker 1965, De Serpa 1971, de Donnea 1971) provide a starting point. Heggie (1976) gives some of the necessary conditions with which new travel demand models would have to comply. However, we are still some way from satisfactory working models of activity linkage in travel demand. We are currently proceeding on the basis that research should concentrate on two fronts:

First; simple descriptive analyses of journey making behaviour and, if the data can be obtained, of activity patterns pursued by persons and households in an attempt to improve our understanding of behaviour.

Second; marginally pushing back the limits of the current models by incorporating accessibility measures into the models, and by other refinements such as allowing the intermediate stages of multi-stage journeys to affect the trip generation and modal choice decisions.

## REFERENCES

Becker, G.S. (1965). 'A theory of the allocation of time', The Economic Journal, Vol LXXV, No. 299, pp 493-517.

Ben-Akiva, M and Lerman, S (1975)*. 'Forecasting models in transportation planning'. A paper prepared for presentation at the Conference on Population Forecasting for Small Areas.

Bentley, G.A., Bruce, A. and Jones, D.R. (1977). 'Intra-urban journeys and activity linkages', Socio-Economic Planning Sciences, Vol. 11, No. 4, pp 213-220.

Black, J and Conroy, M. (1977). 'Accessibility measures and the social evaluation of urban structure', Environment and Planning A, Vol. 9, pp 1013-1031.

Briggs, D.A. and Jones, P.M. (1973)*. 'Problems in transportation planning for the conurbations: the role of accessibility', Institute of British Geographers 1973 Annual Conference.

Bowyer, D.P. and Tao, A (1978). An Appraisal of Travel Structures in Canberra, Australian Road Research Board. Internal Report AIR 289-5.

Burns, L.D. and Golob, T.F. (1976). 'The role of accessibility in basic transportation choice behaviour', Transportation, Vol. 5, No. 2, pp 175-198.

Clark, C. (1951). 'Urban population densities', Journal of the Royal Statistical Society, Vol. 54, No. 4.

Cochrane, R.A. (1975). 'A possible economic basis for the gravity model', Journal of Transport Economic and Policy, Vol. IX, No. 1, pp 34-49.

Conroy, M. (1978) from forthcoming paper in 9th ARRB Conference August, 1978.

Curry, L. (1972). 'A spatial analysis of gravity flows', Regional Studies, Vol. 6, pp 131-147.

Dalvi, M.Q. (1977)*. 'Behavioural modelling, accessibility, mobility and need: concepts and measurement'. Paper presented to the Third International Conference on Behavioural Travel Modelling, Tanunda, South Australia.

Dalvi, M.Q. and Martin, K.M. (1976). 'The measurement of accessibility: some preliminary results', Transportation Vol. 5, No. 1, pp 17-42.

de Donnea, F.X. (1971). 'Consumer behaviour, transport mode choice and value of time: Some micro-economic models' Regional and Urban Economics, Vol. 1, No. 4, pp 355-382.

De Serpa, A.C. (1971). 'A theory of the economics of time', The Economic Journal, December, pp 828-846.

Dix, M.C. (1975). Application of In-Depth Interviewing Techniques to the Study of Travel Behaviour: Some Preliminary Results, University of Oxford. Transport Studies Unit. Working Paper No. 9.

Ewing, G.O. (1974). 'Gravity and linear regression models of spatial interaction: a cautionary note', Economic Geography, Vol. 50, pp 83-88.

Flowerdew, A.D.J. (1976). 'An evaluation package for a strategic landuse transportation planning program', Proceedings: 1976 Leeds Urban Transport Planning Conference, University of Leeds, U.K.

Gould, P. (1969). Spatial Diffusion, Association of American Geographers Resource Paper No. 17, Commission on College Geography, Washington, D.C.

Hansen, W.G. (1959). How accessibility shapes land-use, Journal of the American Institute of Planners, Vol. 25, pp 73-76.

Hanson, S. (1977)*. 'Urban travel linkages'. Paper presented to the Third International Conference on Behavioural Travel Modelling, Tanunda, South Australia.

Harris Lange-Voorhees (1971). Ballarat Transportation Study, Consultants Report to the Study Committee - Chief Planning Engineer, Country Roads Board - Chairman.

Heggie, I.G. (1976). Consumer Choice and Urban Travel Demand. A Revised Theory, University of Oxford. Transport Studies Unit. Working Paper No. 4.

Henderson, J.M. and Quandt, R.E. (1971). Micro-Economic Theory: A Mathematical Approach. Second Edition. McGraw-Hill Kogakusha Ltd.

Hillman, M, Henderson, I and Whalley, A. (1973). Personal Mobility and Transport Policy, Political and Economic Planning, London.

Hillman, M, Henderson, I. and Whalley, A. (1976). Transport Realities and Planning Policy, Political and Economic Planning, London.

Ingram, D.R. (1971). 'The concept of accessibility: a search for an operational form', Regional Studies, Vol. 5, pp 101-107.

Jones, P.M. (1976). Travel as a manifestation of activity choices: trip generation re-interpreted, University of Oxford, Transport Studies Unit Working Paper No. 14, Oxford.

Jones, P.M. (1977)*. 'New approaches to Understanding travel behaviour: the human activity approach', Paper presented to Third International Conference on Behavioural Travel Modelling, Tanunda, South Australia.

Koenig, G. (1977)*. 'Les indicateurs d'accessibilites dans les studes urbaines: de la theorie a la practique', Paper to be published in Revue Generale des Routes, July 1977, together with English translation held at ARRB.

McFadden, D. (1973). 'Conditional logit analysis of qualitative choice behaviour', in P. Zaremka (Ed.) Frontiers in Econometrics, Academic Press, New York, pp 105-142.

Mitchell, C.G.B. and Town, S.W. (1977). Accessibility of various social groups to different activities, TRRL Supplementary Report 258, Transport and Road Research Laboratory, Crowthorne, U.K.

Morris, J.M., Dumble, P.L. and Wigan, M.R. (1978). Accessibility indicators in transport planning. Internal Report No. 1058-3. ARRB.

Niedercorn, J.H. and Bechdolt, B.V. Jr., (1969). 'An economic derivation of the 'Gravity Law' of spatial interaction', Journal of Regional Science, Vol. 9, No. 2, pp 273-282.

Oberg, S. (1976). Methods of Describing Physical Access to Supply Points, Lund Studies in Geography Series B. Human Geography No. 43, Department of Geography, The Royal University of Lund, Sweden.

OECD Road Research Programme (1977). 'Transport requirements for urban communities: planning for personal travel', Final Report of Research Group T11. Paris Appendix D, pp 84-92 (unpublished).

Popper, R.J. and Hoel, L.A. (1976). 'Mobility evaluation for urban public transportation', Transportation Planning and Technology, Vol. 3, pp 131-141.

Turner, C.G. (1972). 'A model framework for transportation and community plan analysis', Journal of the American Institute of Planners, Vol. 38, pp 325-330.

Vickerman, R.W. (1974). 'Accessibility, attraction and potential: a review of some concepts and their use in determining mobility', Environment and Planning A, Vol. 6, pp 675-691.

Wachs, M. (Reporting Chairman). (1977)*. Report on Plenary Session, Workshop H: Behavioural Modelling, Accessibility, Mobility and Travel Need. Third International Conference on Behavioural Travel Modelling, Tanunda, South Australia.

Wachs, M. and Kumagai, T.G. (1973). 'Physical accessibility as a social indicator', Socio-Economic Planning Sciences, Vol. 7, pp 437-456.

Weibull, J.W. (1976). 'An axiomatic approach to the measurement of accessibility', Regional Science and Urban Economics, Vol. 6, pp 357-379.

Whitbread, M. (1972). Evaluation in the planning process - the case of accessibility. Planning Methodology Research Unit, University College London, Working Paper 10.

Wickstrom, G.V. (1971). 'Defining balanced transportation - a question of opportunity'. Traffic Quarterly, Vol. 25, pp 337-349.

Wigan, M.R. (1971). Benefit assessment for network traffic models and application to road pricing, TRRL Report LR 417, Transport and Road Research Laboratory, Crowthorne, U.K.

* Wigan, M.R., Bamford, T.J.G., Broughton, J., Paulley, J., Lynam, M. (1974). 'Two scenarios for traffic restraint: the traffic social and environmental effects', Working paper (unpublished).

* Wigan, M.R., Richards, E. (1974). 'The analysis of journey structure: linkage between different stages of a journey' Working paper (unpublished).

Wilson, A.G. (1972). 'Developing issues in urban transport planning'. Memorandum in Second Report from the Expenditure Committee, HC57, Session 1972-73, Urban Transport Planning Vol. 2 (HMSO, London).

Williams, H.C.W.L. (1977). 'On the Formation of Travel Demand Models & Economic Evaluation Measures of User Benefit' Environment & Planning A Vol. 9 No. 3 pp.285-344.

Zakaria, T. (1974). 'Urban transportation accessibility measures: modifications and uses'. Traffic Quarterly, Vol. 28, pp 467-479.

* References not widely available, but held in the Australian Road Research Board library.