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ACCESSIBILITY INDICATORS FOR TRANSPORT PLANNING

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Abstract—Both perceptual and measurable specifications of accessibility are reviewed and their relevance to transport planning established. The wide variety of analytical forms which can be used to quantify different aspects of accessibility are categorised and grouped by conceptual basis. The different forms of accessibility index are then related to underlying theories which link consumer demand, evaluation and accessibility.

INTRODUCTION

Transport planning organizations 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. The focus of transport planning is moving from "vehicular mobility" to "personal mobility" (Dalvi 1978) 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 (Hensher 1976). 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 1978). This paper explores some of the various concepts employed to measure accessibility. A closer integration of both accessibility and mobility considerations in transport planning is needed, although we concentrate here on accessibility.

There is a critical distinction between the derivation of "objective" indicators of accessibility, and perceived measures. The first sections of the paper concentrate on the areas of relevance of accessibility measures and a typology of functional forms. A wide variety of measures is drawn from descriptive analyses found helpful in planning. The selection of indicators appropriate for transport plamning is then considerd, 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 (U.K.).

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 1978). With the exception of the third application, the concept of accessibility is equally applicable in rural and urban contexts. In this paper the main emphasis is laid on the urban environment.

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 (Black and Conroy 1977).

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 indiscriminately to refer to both the supply side and the demand side of transport services (Dalvi 1978). 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 not only influences 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, Patton and Clark 1970, Davidson 1973, 1977, Beggs 1976). 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 1978). It 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, 1964) 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 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 of 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 1978).

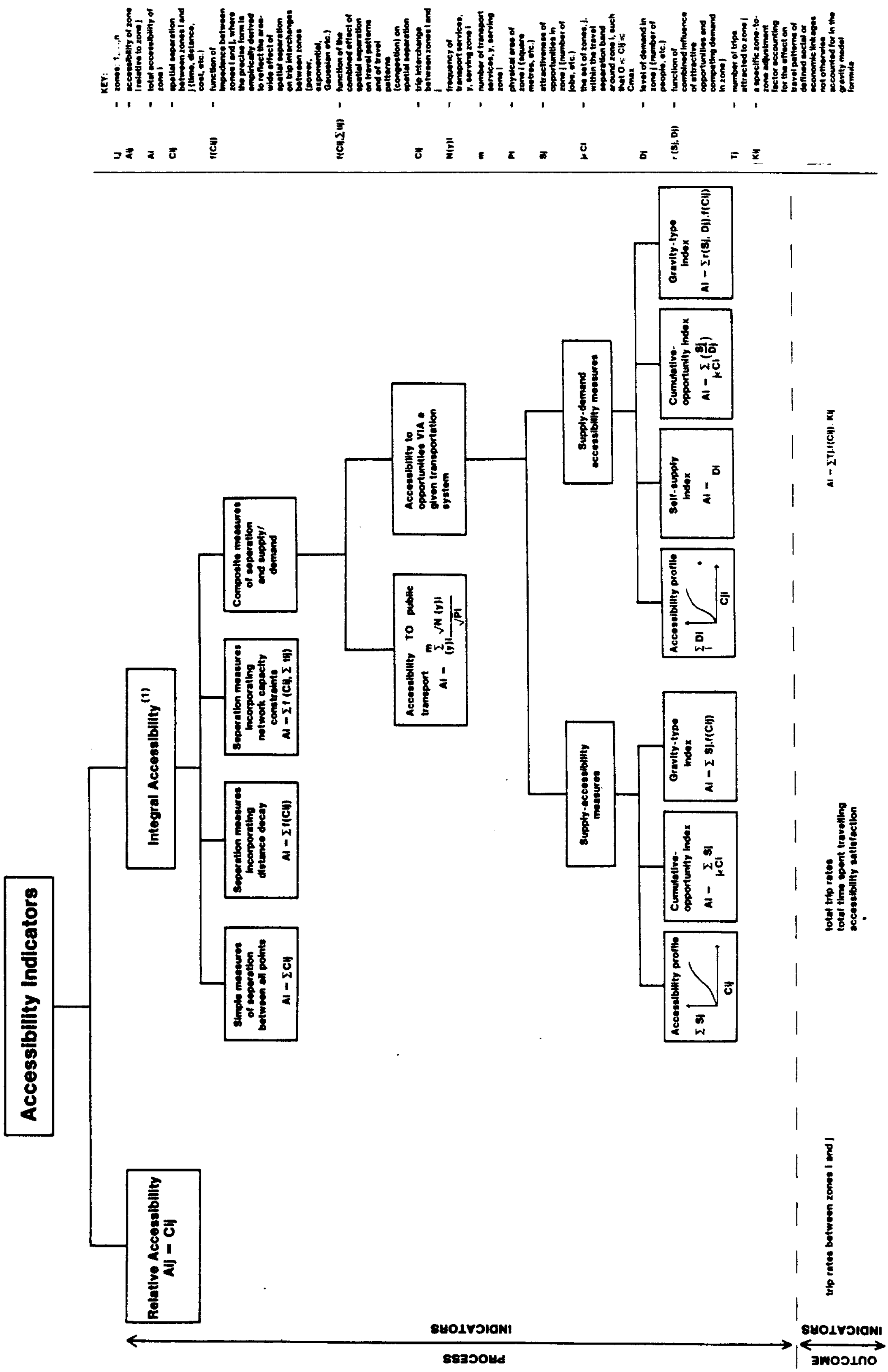
This basic conflict gives rise to a range of accessibility measures which differ in terms of their behavioural component. And yet this represents only one of many sources of variation in accessibility indicators. Since there is no concensus on an operational definition of accessibility, it is necessary 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 1978). Examples of specific formulae and references for further discussion are presented for each terminal class shown in Fig. 1.

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

†The term relative accessibility is sometimes used to describe an integral measure which has been normalised in order to facilitate temporal or spatial comparisons. For instance, the measure may be normalised to correct for changes over time in the number of opportunities (see Patton and Clark 1970) or for spatial variations in the competing pressures of demand for the relevant opportunities (Morris 1976).



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

Fig. 1. A typology of accessibility indicators.

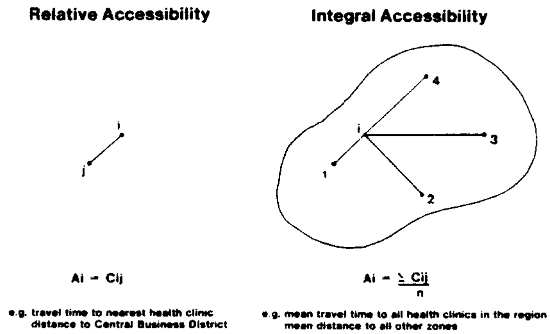


Fig. 2. Relative and integral accessibility.

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 emergence of a large range of measures of integral accessibility is essentially 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.

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. However, these aspects are 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 criterial 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 accessibility 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 inordinately heavy data input 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. 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. 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 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. Consequently 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 ac-

†The difference between the freedom of movement of the car owner and the captive public transport user is not entirely a matter of speed. Rather it relates to the loss of time at terminals and junctions and to the channelled nature of the public transport network (which limits the number of opportunities that can be conveniently reached).

cessibility 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 specified by Weibull (1976).

The final selection of an appropriate operational form of accessibility may be governed by technical considerations of operational simplicity and ease of comprehension. There is a distinct trade-off between the behavioural relevance and the operational simplicity of accessibility indicators. 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 universally accepted theoretical basis on which to select the correct function. Moreover, calibration requires heavy data input and there are major difficulties in identifying the "true" value of the separation decay exponents (Wilson 1971, Curry 1972, Ewing 1974, Dalvi and Martin 1976). A further difficulty may arise in the context of evaluation if different separation decay exponents are used for different population groups. Conroy (1978) argues that this introduces bias into the evaluation process.

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 relates to the property of distance substitution: for any given set of spatially distributed activities S located at time t from the origin i, there is an equivalent set of activities S′, which if located at the origin would give an equal accessibility value (Weibull 1976, Black and Conroy 1977).

Accessibility-related comparative indices have been employed by Flowerdew (1977) to avoid this problem. These correct the scalar effects between alternatives A and B, by checking to see if option A is still better if the costs/times of option B are used in A, and vice versa. The package provides both time and generalised cost indices. Flowerdew (1977) comments on the difficulty of finding the best method of measuring accessibility, noting that a weighted average of costs or times (in which the weights are numbers of trips) may increase even when all costs (times) have decreased. This is because travellers may, as a result, make longer trips. Flowerdew (1977) used Laspeyre and Paasche type indices. The Laspeyre indices measured whether it would have been cheaper/more expensive (quicker/slower) to make the journeys in configuration A with the generalised costs of configuration B instead of A. The Paasche indices were the same but based on the journeys of configuration B Indices of less than 100 represent improvement. The forms of the indices used in the Sao Paulo package are:

Laspeyre

$$(\Sigma T_a C_b / \Sigma T_a C_a) \times 100$$

or

$$(\Sigma T_a t_b / \Sigma T_a t_a) \times 100$$

Paasche

$$(\Sigma T_b C_b / \Sigma T_b C_a) \times 100$$

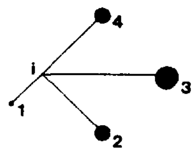
or

$$(\Sigma T_b t_b / \Sigma T_b t_a) \times 100$$

where suffices a and b refer to the configurations A and B being compared, T denotes trips, C generalised cost and t time. The summations are carried out over the appropriate population group—e.g. for consumers in specific areas using public transport and travelling to any destination.

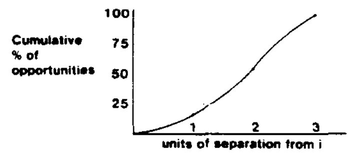
Other researchers have turned to cumulative-opportunity indices or accessibility profiles as measures of accessibility (see Fig. 3). The principal disadvantage of a graphical measure is that it does not produce a single value of accessibility which can be used to immediately compare alternative land-use/transportation 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.

†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.



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:

$$Ai = \sum_{j \in Ci} Sj$$

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

Gravity-type index:

$$Ai = \sum Sj.f(Cij)$$

If we follow Hansen (1959) $f(Cij) = \frac{1}{cij^2}$

$$\therefore Ai = \frac{30}{1} + \frac{40}{4} + \frac{90}{9} + \frac{40}{4}$$

$$= 30 + 10 + 10 + 10$$
$$= 60$$

Fig. 3. Sample calculations of some accessibility indicators.

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 (1976), and has been shown to give 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).

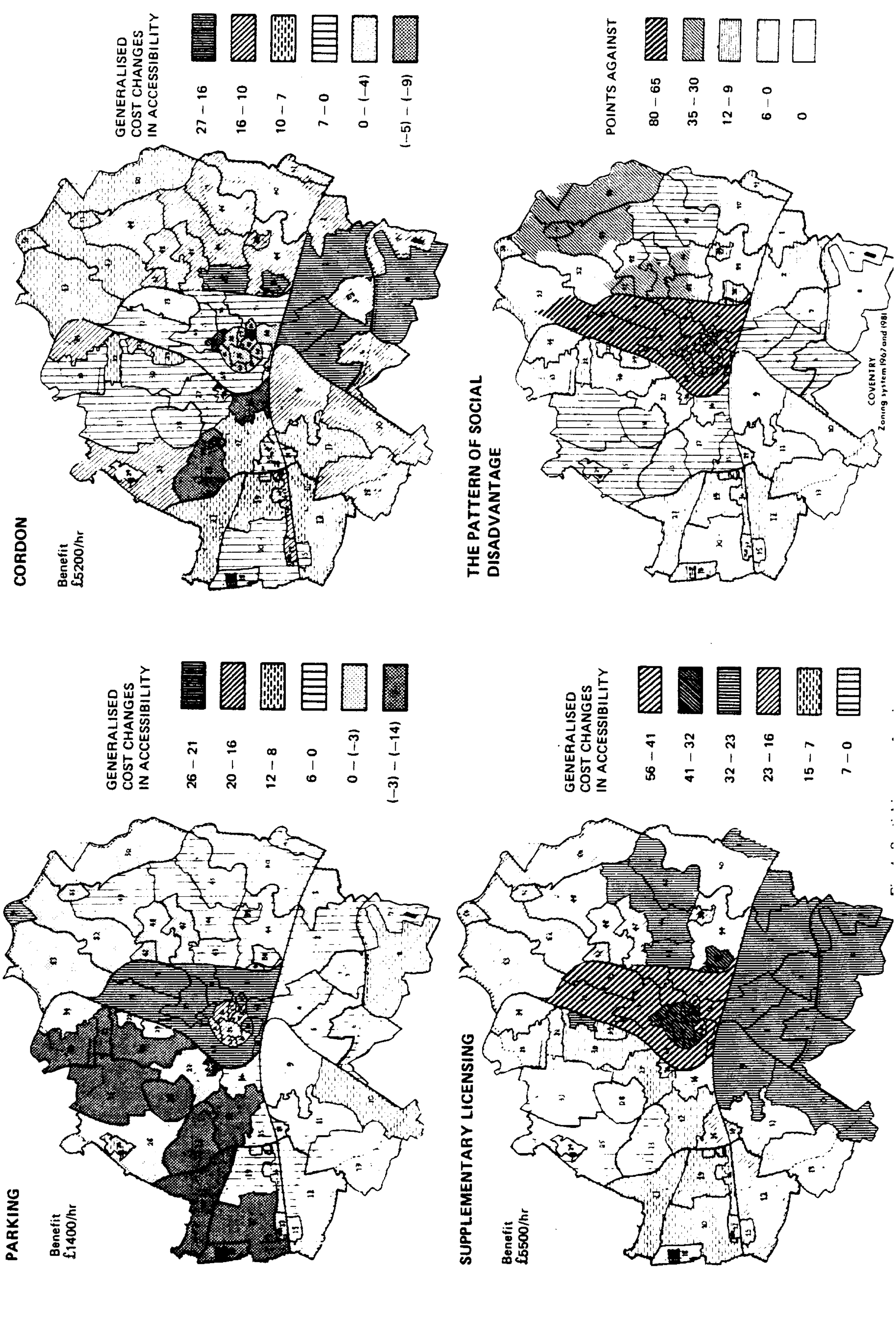
The key point to be drawn from the diagram is that while two of the policies shown produce closely similar net benefits, the spatial accessibility impacts have very different forms. The diagrams illustrate simple measures of total separation (i.e. ΣCij, as shown in Fig. 1). The social indicators diagram provides a basis for the social appraisal of the 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.

By comparing the different diagrams in Fig. 4 it becomes evident that a disadvantaged area would suffer heavy restraint under supplementary licensing (requiring an extra licence to operate a vehicle in the central area or "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


CORDON
Benefit £5200/hr
GENERALISED COST CHANGES IN ACCESSIBILITY
27 – 16
16 – 10
10 – 7
7 – 0
0 – (–4)
(–5) – (–9)
THE PATTERN OF SOCIAL DISADVANTAGE
POINTS AGAINST
80 – 65
35 – 30
12 – 9
6 – 0
0
COVENTRY Zoning system 1967 and 1981
PARKING
Benefit £1400/hr
GENERALISED COST CHANGES IN ACCESSIBILITY
26 – 21
20 – 16
12 – 8
6 – 0
0 – (–3)
(–3) – (–14)
SUPPLEMENTARY LICENSING
Benefit £5500/hr
GENERALISED COST CHANGES IN ACCESSIBILITY
56 – 41
41 – 32
32 – 23
23 – 16
15 – 7
7 – 0

the triangle (as a direct consequence the number of trips rise in 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 licensing produces the least progressive effect; inducing the greatest accessibility shift in the three central wards (i.e. the triangle), and the least in the peripheral areas to the north, east and west.

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

(3) Cordon charging actually produces 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 licensing.

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 transport/land-use system. 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.

Specifically, we concentrate on the trip generation sub-model. This represents an area where it has long been recognised that accessibility (or supply) conditions have a genuine influence, although previous attempts to model this relationship have not been particularly encouraging. Daor (1975), for example, concluded that the level of accessibility to relevant activities (when measured by a Hansen-type index) produced insufficient improvement in the trip generation sub-model to warrant inclusion. The Victorian Ministry of Transport (MoT) included levels of accessibility, measured by a cumulative opportunities index, as one dimension of the category analysis matrices produced (Don 1975); the cell by cell (household) trip production rates varied with the level of accessibility, but in no consistent manner. Both studies, however, adopted an aggregate approach to accessibility measurement (i.e. all persons in an origin zone were assigned the same level of accessibility). Accessibility, as pointed out earlier, will vary from individual to individual and zonal aggregation provides an inadequate basis for reproducing variations between individual circumstances. Individuals, or relatively homogeneous groups of individuals, should be adopted as the basic unit throughout the modelling process and should not be introduced solely at the evaluation stage.

Several relatively succesful attempts have been made to formulate models of travel behaviour based upon the principles of micro-economic consumer demand theory, particularly in the realms of travel choice (see McFadden (1973) for an excellent treatment). Some of these represent explicit attempts to formulate trip generation sub-models on micro-economic bases. For example Koenig (1977), after accepting that the exponential formulation of the gravity model was the correct model for trip distribution, demonstrated that the trip generation rate was a function of accessibility. Burns and Golob (1976) demonstrated how an accessibility measure can be incorporated into several of the travel choice areas. Niedercorn and Bechdolt (1969) and Cochrane (1975), in attempts to give the gravity model a micro-economic basis (using vastly different assumptions and approaches), produced trip generation sub-models which incorporated what could be considered to be accessibility measures. Lastly, Williams (1977) in a rigorous theoretical treatment of travel demand models once again deduced the same result by indirect means.

Each of these direct or indirect approaches to accessibility and its importance in travel demand modelling can be classified into one of the four approaches identified by Koenig (1977):

(a) Common sense (e.g. Hansen 1959)
(b) Axiomatic (e.g. Weibull 1976)
(c) Consumers surplus (e.g. Neuberger 1971)
(d) Behavioural utility (e.g. Koenig 1977).

Distinctions between the approaches are blurred, particularly between the latter two, and often, depending on the vitial assumptions, lead to the same result. It is not, however, the aim of this paper to indulge in a theoretical and abstract discussion on the merits of each of the often highly mathematical treatments given to some of these approaches. Rather the intention is to demonstrate that there are accepted theories of micro-economics which suggest that trip generation is likely to be influenced by accessibility. In particular we will examine the attempts of Koenig (1977), Niedercorn and Bechdolt (1969) and Cochrane (1975) to demonstrate this point. These are supported here with some empirical results.

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). 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 demonstrates (on the assumptions briefly outlined above) that the net utility (i.e. benefit) U_i^k, derived from a trip is, average for an individual of type k living in zone i, given by the expression†:

$$U_i^k = \frac{1}{x}\log_e A_i^k + \text{constant} \quad (1)$$

where

$$A_i^k = \frac{\Sigma S_j^k e^{-x^k c_{ij}^k}}{\Sigma S_j^k}$$ an "integral" (normalised) Hansen index (2)

and S_j^k is the number of potential destinations for invividuals of type k in zone j. x^k is the exponential parameter associated with the destination choice decision for individual k. C_{ij}^k is the "cost" of travel between i and j for the individual of type k. From now on the suffix k will be removed, but it is implicit in all formulae.

The reasoning behind this hypothesis implies that if the individual at i were to rank all potential trips in decreasing order of perceived net utility, then he would travel just enough to ensure that the gross utility derived from making the last trip was exactly offset by the disutility of undertaking it. That is, as well as the usual assumption that the trip rate for an individual at zone i is a function of his socio-economic characteristics, $\bar{E}_i$, expressed mathematically as:

$$T_i = f(\bar{E}_i) \quad (3)$$

eqn (1) implies that it is also a function of the average net utility, hence of accessibility, to be gained from making a trip. Thus eqn (3) becomes:

$$T_i = f(\bar{E}_i, U_i) = g(\bar{E}_i, \log_e A_i). \quad (4)$$

It should be made clear that this derivation focusses on the individual. Hence the accessibility measure to be used should be the accessibility as perceived by the individual (and therefore dependent on the mode upon which they rely).

There is no real reason why accessibility should not also vary between trip purposes. It is conceptually appealing that both the measure of opportunity for interaction and the willingness of an individual to travel should vary with trip purpose.

Figure 5 gives practical weight to this first derivation. This shows graphs of daily home-based trips per person (all modes) vs accessibility to relevant opportunities for a particular person category for some French cities (Koenig 1977). The graphs show an increase in the observed trip generation rate with an increase in accessibility, when both are defined and calculated on the basis of the individual.

It has not been possible to compute similar indices for Ballarat (along the lines of those in Fig. 1), but the effect of varying levels of accessibility has been approximated by subdividing Ballarat into a series of concentric rings. These were numbered sequentially 1–4, outwards from the CBD. The mean trip generation rates for groups of individual were then estimated on the assumption that accessibility, by all modes, to all activities considered to be important trip attractors, declines with distance from the centre of Ballarat. In a city such as Ballarat which has a single centre this assumption appears to be valid, particularly as Koenig (1977) demonstrates that it holds for tertiary employment places in the more complex city of Marseilles.

Figure 6(a) shows the mean trip generation rate for various groups of individuals by the number of the concentric ring in which they reside. For this analysis, individuals were grouped according to their employment status (Harris Lange–Voorhees 1971). The result is inconclusive: the hypothesis that accessibility affects trip generation is not fully supported; but neither can it be rejected, as there are probably several other influences at work. First, the method of stratifying the population is probably not detailed enough to account for factors such as income, socio-economic status, number of cars owned, etc., which also vary systematically with distance from central Ballarat (Harris Lange–Voorhees 1971), and which have previously been found to be strongly related to trip generation rates. Second, the method of approximating the accessibility level by distance from central Ballarat attributes the same accessibility level to every individual resident in any particular concentric ring, contrary to Koenig's assertion that a person's accessibility is dependent on the mode they choose (or are forced) to take (Oenig 1977).‡

Figure 6(b) shows that the non-car trip generation rate is affected by accessibility as postulated. The fall off with decreasing accessibility is most marked for walk trips, while tram§ trips fall off slightly, and bus trips increase marginally. Figure 6(c) snows tne effect of accessibility summed over all person types for trips stratified by mode. This clearly indicates that car travel is the main component which weakens the hypothesis.

†Keonig's formulation has been slightly modified to facilitate easier comparison with other researchers' work.

‡Williams (1977) would argue that accessibility is not to be calculated solely on the basis of chosen mode. His measure is based on composite generalised cost and is internally consistent with his travel demand model. If an individual has (or perceives) no real alternative mode, then Williams' measure reduces to that for the chosen mode.

§Since the Ballarat Transportation Study was carried out in 1970 the tram service has been withdrawn.

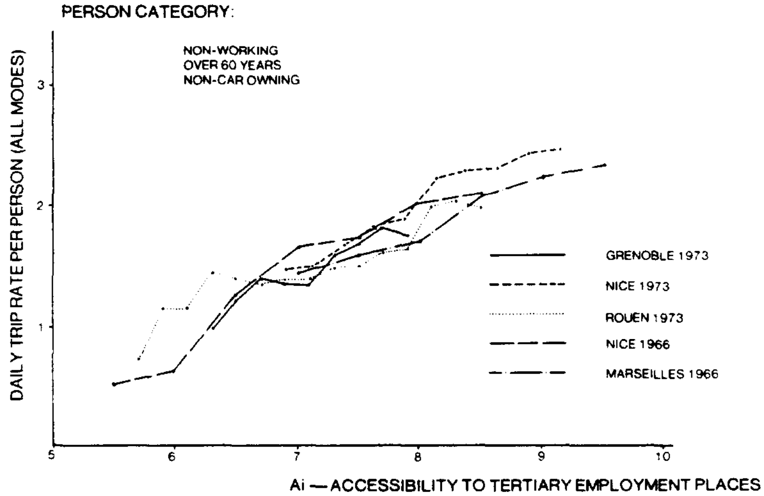


Fig. 5. The effect of accessibility on trip rates in selected French cities.

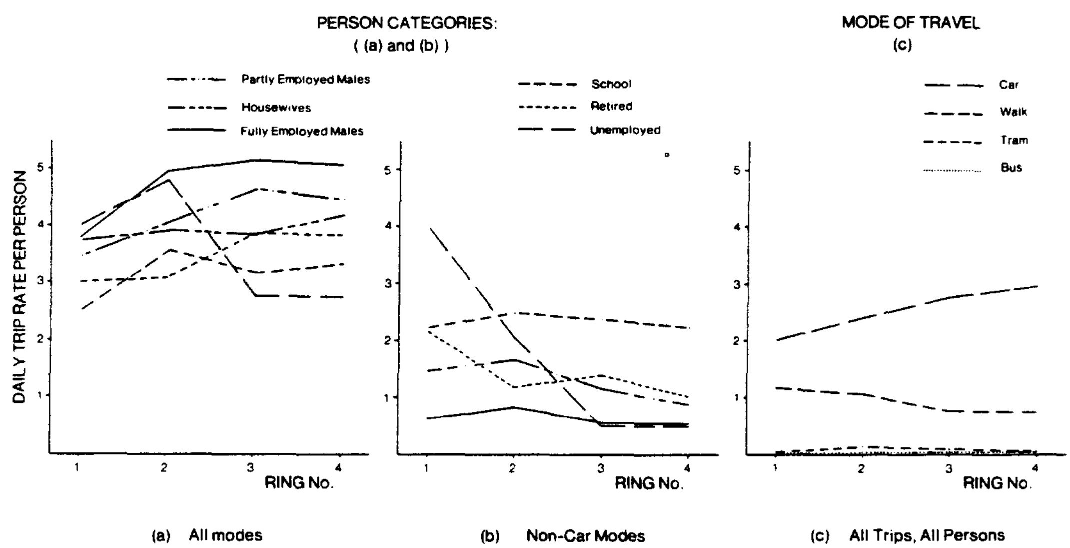


Fig. 6. The effect of accessibility on trip rates in Ballarat.

An attempt was made to overcome the effect of car ownership on the overall trip generation rate by dividing the population into licence holding and non-licence holding groups. This step approximated the range of person types used by Koenig. Thus Koenig's person category of:

"non-working, non-car owning and over 60 years old"

is approximated by our person category:

"retired and non-licence holding".

Figure 7 shows that once again our analysis does not unequivocally support the hypothesis; again the result is inconclusive. However, also plotted in Fig. 7 are the results for the person category:

"housewife, without driving licence"

which indicates a slight but significant decrease in trip generation with a decrease in the level of accessibility. The category:

"housewives licensed to drive"

is also shown. Socio-economic factors are again likely to explain the increase in trip generation rate with the decrease in level of accessibility. However, housewives with driving licences at all levels of accessibility make significantly more trips than those without, indicating that the former group is far more "mobile" in the sense discussed earlier in this paper. The same conclusion can be drawn for all employment status groups although the results are not presented here.

Fundamental assumptions underlying Koenig's approach

There are some practical considerations and theoretical assumptions in Koenig's formulation which may limit

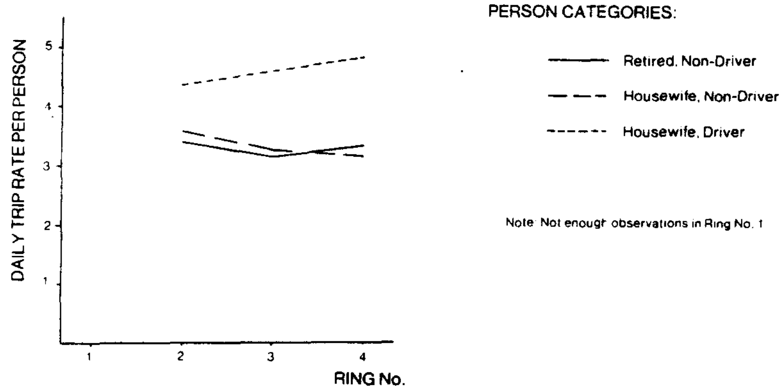


Fig. 7. Further effects of accessibility on trip rates in Ballarat.

the effectiveness of the whole approach when attempting to incorporate it into a working trip generation sub-model.

One practical consideration is that of the zoning system. According to micro-economic consumer choice theory the individual perceives that a set of alternatives is open to him (Henderson and Quandt 1971) and that each alternative possesses a certain level of utility.† In a working model the alternative destinations are typically aggregated within a zonal framework. For the model to be behaviourally sound 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 zoning system used (Dalvi and Martin 1976). Ben Akiva and Lerman (1978) further suggest that unless the zoning system is carefully designed "the measure of accessibility will in general be biased".

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). Figure 7 indicates the strength of this effect assuming that licence/non-licence holding is a proxy for car availability. Approximating assumptions can also be employed if one wishes to avoid the adoption of mode-specific trip generation values.

One other important, yet tacitly accepted assumption in Koenig's formulation (though shared with current travel demand modelling practice) is that all travel is of a simple nature. That is, travel is assumed to be composed solely of two-stage journeys:‡ starting at home, going to a single destination for a single purpose and then returning home. As a large proportion of travel is accounted for by multi-stage journeys, this assumption is incorrect.

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 accessibility 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 that:

$$T_i = f(\bar{E}_i, U_i) = g(\bar{E}_i, \log_e A_i) \tag{5}$$

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 eqn (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 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):

$$\frac{\partial U_i}{\partial T_i} > 0 \text{ and } \frac{\partial^2 U_i}{\partial T_i^2} < 0. \tag{6}$$

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 (1966) adopt the approach of maximising the utility of individuals with respect to their travel requirements subject to the constraints of the total amounts of time and money that individuals are willing

†It is only necessary that the individual be able to rank all the perceived alternatives open to him (Henderson and Quandt 1971, Samuelson 1971).

‡A journey is defined as a trip sequence starting and ending at the home base. A multi-stage journey involves more than one intermediate destination.

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 j, T_{ij}, and the potential for interaction at each destination. Thus

$$U_i = a\sum A_j f(T_{ij}) \tag{7}$$

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):

maximise

$$U_i = a\sum A_j f(T_{ij}) \tag{8}$$

subject to

$$H_i \geq \sum t_{ij} T_{ij} \tag{9}$$

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:

$$U_i = \log_e T_i \tag{10}$$

where T_i is the sum of all trips produced at i by the individual.†

This obeys the first and second order requirements:

$$\frac{\partial U_i}{\partial T_i} > 0 \text{ and } \frac{\partial^2 U_i}{\partial T_i^2} < 0. \tag{6}$$

The logarithmic assumption leads to the result

$$T_{ij} = \frac{H}{\bar{t}_i}\frac{A_j}{\Sigma A_j} \tag{11}$$

where $\bar{t}_i$ is the average travel time for trips taken by an individual at i. If one then assumes that an individual's perception of the attractiveness of j for interaction (A_j) is the accessibility of j with respect to i as defined by Koenig, i.e. $S_j\,\mathrm{e}^{-\lambda t_{ij}}$, then

$$T_{ij} = \frac{H_i}{\bar{t}_i}\frac{S_j\,\mathrm{e}^{-\lambda t_{ij}}}{\Sigma S_j\,\mathrm{e}^{-\lambda_{ij}}} \tag{12}$$

which is composed of two terms

(1) a trip generation term, $(H/\bar{t}_i)$; and

(2) a trip destribution term, $\frac{S_j\,\mathrm{e}^{-\lambda t_{ij}}}{\Sigma S_j\,\mathrm{e}^{-\lambda t_{ij}}}$,

which is simply the gravity model as formulated by Koenig (amongst others) but with travel time rather than generalised travel cost as the impedance measure.

Equation (12) can be rewritten as eqn (16) by substituting for $\bar{t}_i$, as follows:

$$\bar{t}_i = \sum t_{ij} T_{ij} / \sum T_{ij} \tag{13}$$

and

$$\sum T_{ij} = T_i = H_i \bar{t}_i$$

$$\therefore \quad \bar{t}_i = T_i \frac{\sum t_{ij} S_j\,\mathrm{e}^{-\lambda t_{ij}}}{\sum S_j\,\mathrm{e}^{-\lambda t_{ij}}} \Big/ T_i \tag{14}$$

$$\bar{t}_i = \frac{\sum t_{ij} S_{ij}\,\mathrm{e}^{-\lambda t_{ij}}}{\sum S_j\,\mathrm{e}^{-\lambda t_{ij}}} \tag{15}$$

$$\therefore \quad T_{ij} = H_i \frac{S_j\,\mathrm{e}^{-\lambda t_{ij}}}{\sum t_{ij} S_j\,\mathrm{e}^{-\lambda_{ij}}}. \tag{16}$$

Summing over all destinations (i.e. over all j) gives the total trip generation rate for an individual in zone i

$$T_i = H_i \frac{\sum S_j\,\mathrm{e}^{-\lambda t_{ij}}}{\sum t_{ij} S_j\,\mathrm{e}^{-\lambda t_{ij}}} \tag{17a}$$

or

$$T_i = \frac{H_i \cdot A_i}{\sum t_{ij} S_j\,\mathrm{e}^{-\lambda t_{ij}}}. \tag{17b}$$

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 eqn (17b).

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 weight, 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 a maximum amount of time (and/or money), which he is willing to devote to travel. The individual will use his maximum time, except in the unlikely event that he is able to make all the interactions he desires in less time. Therefore an improvement in the transport system will generally not cause an individual to spend more or less time travelling. Thus each individual's travel time budget is simply obtained by observing his travel behaviour, i.e. the

†The full derivation is not reproduced here: the reader is referred to the original article (Niedercorn and Bechdolt 1969). Slight differences have been introduced here to conform with Koenig's terminology.

amount of time he wishes to spend travelling equals the amount he actually travelled.

The average time spent travelling daily by Ballarat residents was analysed for different categories of individuals. 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.

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 min (43% above the average), while another group (males, less than 10 years) exhibited a daily travel time budget of only 39 min (40% below average). Figure 8 shows the results for all sex/age groups. Included on Fig. 8, for interest mainly, are the daily travel times allocated to car driving and walking by residents in 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 years is observable in both Ballarat and NTS results. The most obvious difference between the two analyses is the relatively low average amount of time spent walking in Ballarat; 10.5 min 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 apparent in Fig. 8. For instance, the tendency of men, at all age levels, to spend more time 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 40–55 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† 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 to be 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 eqns (1)–(5), 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‡ the following expressions for T_{ij} and T_i:

$$T_{ij} = G_i(1 - e^{-KA_i})\frac{S_j\, e^{-\lambda C_{ij}}}{A_i} \tag{18}$$

and

$$T_i = G_i(1 - e^{-KA_i}) \tag{19}$$

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

†That is eqns (17a) and (17b) can be disaggregated by person type (incorporating both personal and household attributes), mode and purpose (although it could be stretching credibility too far to suggest that individuals have travel time budgets for each travel purpose).

‡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 which differ from ours.

Table 1. Mean daily travelling time† per person in Ballarat (1970)

Primary mode	Time (Min)	Destination purpose	Time (Min)
Car Driver	29.3	Home	28.9
Car Passenger	13.2	Work	11.3
Tram	13.6	Employer's Business	1.5
Bus	2.4	Social/Recreational	9.0
Taxi	0.5	Eat Meal	0.5
Truck Passenger	0.2	Medical/Dental	0.7
Walk	10.5	Personal Business	1.7
School Bus	0.2	Shopping-Convenience	4.2
Other (Bicycle)	5.0	-Comparison	1.5
		School	5.5
TOTAL	65	TOTAL	65

†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.

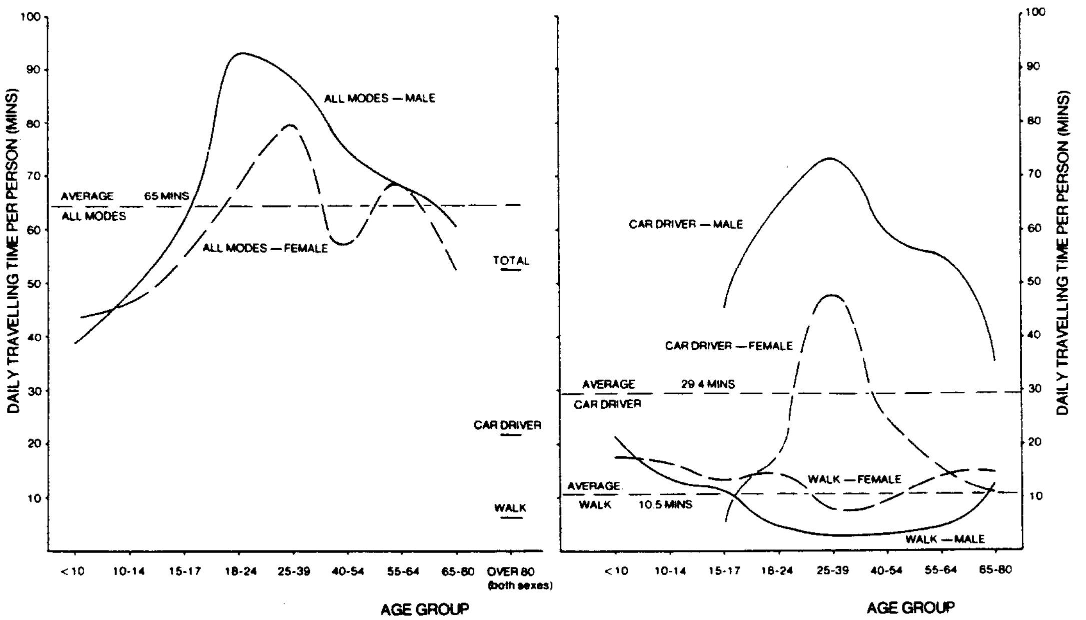


Fig. 8. Daily travelling time per person in Ballarat.

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_i and K. Rough estimates of G_i and K were made for the results depicted in Fig. 5 for the City of Nice (1966):

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

and

$$K = 0.068.$$

Cochrane's model is perhaps the most useful from an operational standpoint. The model also has the theoretical nicety 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 of the others discussed.

LINKAGE OF TRIPS AND ACTIVITIES

The Ballarat data were examined to check on the proportion of multi-stage journeys. Figure 9 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 complicated by the inclusion of linked trips. There are two distinct 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 ignored. 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 undue aggregation of purpose codings can result in significant loss of detail within a trip sequence. Nevertheless information is retrievable by going back to the basic survey data.

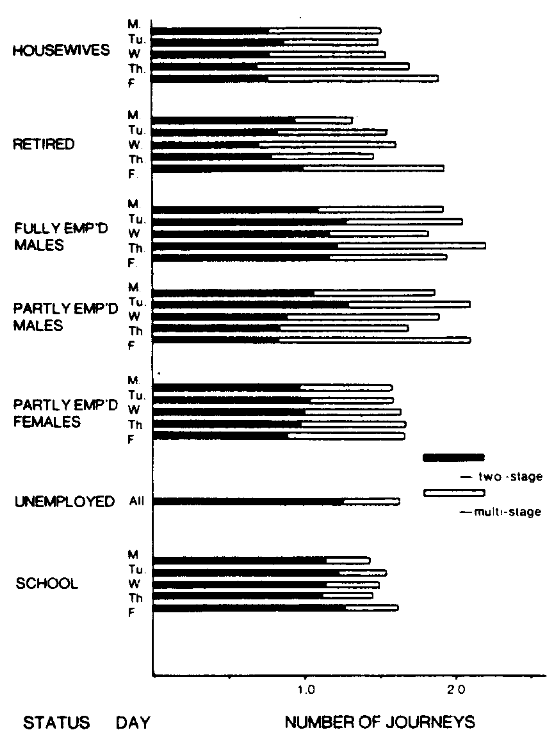


Fig. 9. The incidence of journey making in Ballarat.

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 with hypotheses of destination choice (and in a similar manner, modal choice). This link is made the more difficult to handle by 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, preceived, and resource (actual) determinants of travel utility and is treated in detail by McIntosh and Quarmby (1972) and 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.

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 of 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 must place 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 and 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 (Daor 1975, Dalvi and Martin 1976), where the link is drawn at the evaluation stage when the resultant functions in the models of elastic travel demand 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 the 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 multi-stage in nature.

The following questions may now be posed. Is accessibility to be attributed to: (1) the *home base* of a trip sequence? or (2) 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 to 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 visted in the sequence. Hanson (1978), however reports the empirical results of one study which demonstrates that "95% of all stops are planned before the individual leaves home".

If a simultaneous decision model is adopted, then all these choices collapse to a cumulative accessibility value allocated only to 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 journey 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 journey stages. Descriptive models of the multi-stage journey and the chained activity structure involved have been built using Markov and transition matrix formats (e.g. Wigan and Richards 1978). 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 journeys 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 household members, individually and co-operatively; and (c) the management of travel within the household—details are not usually recorded on decisions regarding, say, the allocation of cars between licenced drivers in the household, or who will undertake the travel necessary for the collective well-being of the household.

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 in which they desire to participate—the activity linkage view of travel (Jones 1976, 1978, Bentley *et al.* 1977, Hanson 1978). 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 institutional 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. A starting point is provided by consumer choice models of activity demand which address the problem of the value to be placed on travel time savings (Becker 1965, De Serpa 1971, de Donnea 1971). 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. It is therefore suggested that research proceed on two fronts:

First, attempting to improve our understanding of travel behaviour by undertaking simple descriptive analyses of journey making and behaviour and, if the data can be obtained, of activity patterns pursued by persons and households.

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.

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