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INDICATORS OF URBAN ACCESSIBILITY: THEORY AND APPLICATION

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ABSTRACT

The concept of accessibility and its related indicators have been in use for a long time, with still diverging interpretations of their significance and formulation. In this paper, a review is made of various existing theoretical bases, with special emphasis on recent behavioural approaches. It is suggested that this theoretical framework now allows a better appraisal of accessibility indicators and precise recommendations are proposed for their practical formulation and use. Various examples are given, especially for disaggregate analysis where a calculation "for a given person" is proposed instead of the conventional calculation "by a given mode". Finally, the relations between accessibility and trip rate are examined; from a study made in French cities, it is suggested that accessibility is a powerful determinant of trip rate.

1. Introduction

Accessibility indicators are not really a recent promulgation. The first definitions and mathematical formulations were proposed 20 years ago, for instance by Hansen in 1959. Nevertheless, it seems that there is still no general agreement, among theoreticians or planners, on the exact value and significance of those indicators. They are often appreciated as providing some interesting information; but their apparently subjective and empirical origin and formulation usually confines their practical use to a minor role.

In this general context, this paper would suggest that the role devoted to accessibility indicators in urban planning and transport planning studies should be considerably extended. The views that will be successively examined here may be summarized as follows:

(1) accessibility indicators have now received better and more precise theoretical treatment than is usually assumed;
(2) they provide a sound tool for evaluating transport policies, especially at a disaggregate level;

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(3) precise recommendations can be specified for their practical formulation and use; and
(4) they appear to be a very effective determinant of peoples' behaviour and thus as a key variable to be introduced into traffic or urban development models.

Most of the ideas expressed here, including the justification of accessibility indicators by a behavioural approach to trip decisions taken by individuals, have been expressed in papers published in France in recent years (e.g. Koenig, 1974, 1975a; Poulit, 1974).

2. Theoretical Bases

Accessibility, according to a definition proposed by Dalvi (1978), denotes the ease with which any land-use activity can be reached from a location, using a particular transport system. The most commonly used indicators of accessibility are of two kinds:

(a) Opportunities weighed by an impedance (which is some suitable decreasing function of travel cost or time for reaching these opportunities). For example:

$$A_i = \sum_j O_j \, \mathrm{f}(C_{ij}) \tag{1}$$

where:
A_i = accessibility from zone i to the relevant type of opportunities
O_j = opportunities of that type present in zone j (employment places, shops . . .)
C_{ij} = generalised (or actual) time or cost for a trip from i to j
$\mathrm{f}(C_{ij})$= impedance function – an exponential or power function is generally used.

(b) Isochronic definition (number of opportunities that could be reached within a given travel time "x"). This indicator can be considered as a particular solution of formula (1), with an impedance function equal to 1 (for $C_{ij} < x$) or zero (for $C_{ij} > x$).

Though a general agreement exists on the usual form of accessibility indicators according to eqn. (1), there is a general lack of underlying theory to justify their use in making policy decisions. More exactly, it could be said that most planners and policy decision makers do not really see what these indicators reflect and are not entirely convinced that they would materially assist in evaluating policies. In fact, several theoretical approaches have been proposed during recent years which may help in justifying the use and mathematical expression of accessibility indicators as an aid to decision making.

2.1. COMMON SENSE APPROACH

The notion of accessibility associates two basic aspects of the satisfaction derived from undertaking a trip: achievement of desired opportunities on the one hand and the service provided by available transport on the other. The formulation of eqn. (1) – total number of opportunities, corrected by weighing impedance factors – could be derived from two common sense considerations:

(a) the total number of opportunities may be considered as a crude proxy for the satisfaction provided at the chosen destination: where the wider the range of choice among opportunities, the higher the probability of finding a very good one for fulfilling a given trip purpose or need;

(b) the impedance function $f(C_{ij})$ reflects the obvious feeling that a nearby destination should have a higher weight than a more remote one. An exponential impedance, for instance, seems satisfactory as it counts as one, a destination at zero distance and as zero, a very distant destination.

This approach may seem too naïve and crude to be considered relevant. Nevertheless, its interest should not be neglected since:

(a) more sophisticated behavioural approaches do nothing more than provide a detailed mathematical expression of this initial proxy; and

(b) this simple basis for accessibility indicators can be clearly and readily understood by policy planners and decision makers. Such direct understanding is not provided by mathematical models used in some other approaches leading to the use of accessibility indicators.

2.2. AXIOMATIC DEFINITION OF A SOCIAL WELFARE FUNCTION

This approach was proposed by Weibull (1976). He showed that the quantity A_i in eqn. (1), or any increasing function of this quantity, would adequately fulfill the set of general conditions required for a consistent measure of accessibility.

2.3. CONSUMERS' SURPLUS

Neuburger (1971) has calculated the consumers' surplus in a situation S_1 when compared with a reference situation S_0, assuming that trip distribution is correctly described by a gravity model with a distribution function of the form:

$$g(C_{ij}) = e^{-\frac{C_{ij}}{x_0}} \tag{2}$$

where x_0 is a distribution parameter.
It can be shown that the consumers' surplus is equal to the variation, between situations S_0 and S_1, of:

$$S = x_0 \sum_i G_i \log A_i$$

where G_i = the number of trip origins in zone i and

$$A_i = \sum_j O_j \, e^{-\frac{C_{ij}}{x_0}} \tag{3}$$

A_i can thus be identified with the similar quantity in eqn. (1).

This result, extended by Williams (1976), is in complete accordance with the intuitive approach described above; but it is more precise, as it provides a basis for evaluation in economic terms. It may be wondered why this result seems to have attracted so little attention, at least among practitioners, since it was published. A possible reason is that it received no direct behavioural explanation and, thus, may have been considered as a kind of esoteric mathematical oddity. But this result might also be considered as giving a fairly valuable theoretical basis to the use of accessibility indicators, provided that:

(a) the concept of consumers' surplus is accepted, and
(b) exponential distribution functions are indeed the most suitable to reflect trip distribution, which seems to be the case in most cities of the developed world.

2.4. BEHAVIOURAL UTILITY APPROACH

Behavioural approaches to accessibility usually rest on two prime assumptions:

(a) people associate a cardinal utility with each of the alternatives they are facing (for example: with each available destination, travel mode, route . . .) and take the choice associated with the maximum utility to them as individuals; and

(b) as it is not possible for a planner to evaluate all factors affecting the utility associated with each alternative by a given individual, this utility can be represented as the sum of a non-random component (for the predictable factors) and a random component (for the non-predictable factors).

A behavioural foundation of accessibility can then be derived from this general framework when applied to destination choice. In this case, the utility U^t_{ij} associated by an individual t, living in zone i, with a destination in zone j, can for instance be represented in a simplified way as follows:

$$U^t_{ij} = V^t - C^t_{ij}$$

where:

V^t = gross utility of achieving destination j for individual t (random variable)

C^t_{ij} = generalised travel cost or time from i to j for individual t (considered here as predictable and non random).

This travel time or cost matrix should be calculated specifically for the considered category of individuals; this point will be emphasized again in Section 4.

The problem now is to determine a suitable probability function for the random variable V^t, in order to calculate the expected value of the maximum utility among the utilities U^t_{ij} associated with each of the potential destinations. This expected value represents the average benefit derived from a trip by individual t and it takes into account both the desirability of destinations and the trip cost or time required to reach them.

Two particular methods are proposed here (if we exclude the Probit model, which does not lead to a closed form solution).

(a) The Hivex model

This model, introduced by Koenig (1974, 1975a) could be called "Hivex" (exponential in the area of higher values of utility) as it assumes that the probability density function of V^t is, in the area of the higher values of utility, an exponential of the following form:

$$p\,(x) = k\,e^{-\frac{x}{x_0}} \qquad (4)$$

From this basic assumption, four important results can be derived (Koenig, 1974):

(i) The maximum net utility, which can be shown as independent of the shape of the probability density in the area of the lower values of utility, has the following mean value for one trip:

$$U_i = x_0 \log A_i + \text{constant} \tag{5}$$

where A_i is the accessibility indicator of eqn. (3).

The additive constant in eqn. (5) depends only on the category of people being considered (parameters k and x_0). It is equal to: x_0 [log $(k\, x_0) + C$], where C is Eulers constant ($C \simeq 0.577\ldots$). In fact, this additive constant is usually not explicitly calculated (see Section 3.4). The variance of the maximum net utility is equal to $^1/_6\ \pi^2\ x_0^2$.

(ii) Furthermore, it can be shown that the trip distribution derived from these assumptions is identical to a gravity model with an exponential distribution function of the same form as eqn. (2). This is in accordance with experimental results: for example, various impedance functions for gravity trip-distribution models have been tested and compared for 10 French cities, where home interview surveys had been made. Exponential impedance functions were, in nearly all cases, found to be the best and the results obtained were not improved by using more complex functions with 2 calibration parameters.

(iii) Conversely, it might be conjectured (but this is not yet proved) that, if trip distribution should be identified with a gravity model with exponential impedance, the probability function of gross utility should necessarily be of the Hivex type (or any particular case of it, like the Weibull distribution).

Thus, provided the concept of individual utility is accepted and if exponential gravity models are the best for trip distribution, it might be concluded that the utility of trip-making is adequately measured by eqn. (5).

This result is fully consistent with the approaches quoted earlier and provides a behavioural foundation to the use of accessibility indicators A_i.

(iv) Finally, it is possible to take into account, for work trips, effects of competition at the destination. It can be shown that effects of competition between applicants (e.g. changes in wages, or changes in the probability of an applicant for a job being accepted), may be expressed by using the attraction correction coefficients calculated in doubly-constrained gravity models. A similar economic interpretation of dual variables in these models was also given by Williams and Senior (1978), and extended to the "location rents" of the employer's landlords.

It should be mentioned here that an identical model has also been proposed by Cochrane (1975).

(b) The Logit model

In the well known Logit model (C.R.A., 1972) the V^t are assumed as independent (as in the "Hivex") with Weibull's cumulative distribution function (CDF):

$$P(V \leqslant x) = e^{-ke^{-\frac{x}{x_0}}}$$

where x_0 and k are constants.

The expected value of maximum net utility was calculated by various authors, for example, by Domencich and McFadden (1975); the result was found identical to that obtained with the Hivex model.

This could have been predicted, since Weibull's distribution may be considered as a particular case of a "Hivex" distribution: it is easy to verify that the probability density of Weibull's distribution (derivative of the CDF) is asymptotically equivalent, in the area of higher values of utility, to an exponential. In conclusion, therefore, to these four approaches to accessibility, it might be said that some reasonably good theoretical bases exist to justify the use of accessibility indicators.

2.5. DISCUSSION

It seems that, despite the various theoretical justifications described above, planners are usually still somewhat hesitant about the real value of the concept and indicators of urban accessibility. One reason for this attitude could be insufficient information. Valuable theoretical foundations have been provided only recently and very often, unfortunately, in a form that can be completely understood only by a minority of specialists. Another reproach is directed towards the more or less arbitrary assumptions in theoretical approaches: for instance, the assumption of a Hivex or Weibull distribution of the random part of utility was originally justified more by the convenience it affords to calculation, than by a verification with people's real behaviour and attitudes. Nevertheless, these assumptions, as well as Neuburger's result for consumers' surplus, do find empirical support in the experimental fact that trip-distribution seems correctly described by gravity models using an exponential impedance function.

Finally, some aspects of user-benefits are not correctly reflected in actual theories of accessibility. For instance:

- several attributes of transport supply cannot be easily converted and expressed in cost or time units (e.g. cost of a trip as passenger in a car, which implies "finding" a driver).
- benefits derived from non-home-based trips are frequently ignored (Ben Akiva and Lerman, 1978). It could be possible here to diversify the set of travel alternatives and introduce these non-home-based trips in behavioural models; but this would destroy the essential simplicity of accessibility indicators.

Despite these shortcomings, it seems possible to conclude that the value of the concept of indicators of accessibility is considerably higher than is usually appreciated by policy planners.

3. Accessibility and the Evaluation of Planning Alternatives

A comprehensive policy evaluation should consider various aspects: including costs and benefits derived by users, as well as externalities like environmental effects, accidents or indirect effects on land use. In this paper, only benefits derived by users will be considered; of course, this does not mean that the others should be in any way neglected in the planning process.

These benefits may be in reality shared with other groups (land and real estate owners, employers, retailers . . .), through successive transfers. Such social mechanisms resulting in direct and indirect transfers, changes in rents and locational patterns could over a long period, considerably modify the benefits calculated for users; but they are not well known and will not be considered in this paper. They certainly deserve a thorough study and offer an interesting field for further research.

In this section, it will be examined how accessibility may be used for evaluation of planning alternatives (which may differ by the transport supply and/or by the urban structure). Two levels of evaluation will be considered:

(a) evaluation at a disaggregate level, i.e. comparing various alternatives for a given individual; and

(b) evaluation at an aggregate level, i.e. comparing alternatives for the whole population, or for a non-homogeneous segment of this population.

3.1. "EMPIRICAL VERSUS MICROECONOMIC" CONCEPTION OF ACCESSIBILITY

In order to select a relevant, specific formulation of accessibility indicators, a first step consists in determining which of the various approaches quoted earlier should be preferentially followed. As a matter of fact, these approaches lead to formulations which are similar but not necessarily identical and which might be interpreted in different ways.

According to the author's experience, it seems that the main source of such conflicting conceptions of accessibility can be found in the opposition between empirical approaches (similar to the "common sense approach" mentioned earlier) and microeconomic approaches (like the behavioural utility approach or consumers' surplus).

From the empirical point of view, accessibility is basically an intuitive and qualitative concept, which may be expressed in a number of ways, usually in political or urbanistic terms (i.e. range of choice offered to the inhabitant, potential for spatial interaction or exchanges with other zones . . .) Formulating accessibility indicators would here merely consist in finding some direct empirical transcription of the basic qualitative concept. This would usually result in Hansen-type indicators like A_i in eqns. (1) and (3), or in an isochronic indicator N_i, or in other and sometimes strange formulations.

From the microeconomic point of view, these intuitive derivations of accessibility indicators are lacking any sound basis and cannot offer sufficient guarantee of their validity. The only indicator offering a strong underlying theory would be U_i, which is justified both as a disaggregate expression of consumers' surplus and as the result of a consistent behavioural approach.

The problem is that, for a large majority of the parties involved in the planning process, the natural way of reasoning would be much closer to an empirical conception of accessibility than to sophisticated approaches. It is clear that, if accessibility indicators are to be used widely in the planning process, they should have a simple structure supporting an empirical justification and making them readily understandable by non-specialists. Thus, it seems unjustified to try to enforce an exclusive use of the relatively complex indicator U_i. Such an attempt seems also unjustified for two other reasons:

- for many applications, the use of more simple indicators than U_i would provide quite correct or equivalent results; and
- the theories of consumers' surplus or behavioural utility, as valuable as they might be, are not above criticism.

Rather than banning all simple empirical formulations of accessibility, the microeconomic approaches should be used for controlling the acceptability of these formulations, assessing their field of validity and avoiding formulations which would lead to major inconsistencies.

In practice, it seems to the author that the main recommendations which can be derived from this control by theoretical approaches would be the following:

(a) "Cost-like" indicators, even when incorrectly depicted as accessibility indicators, should be in all cases avoided. An example of such a cost-like indicator is the following:

$$C_i = \frac{1}{\sum_j O_j} \sum_j O_j C_{ij} \; e^{-\alpha C_{ij}}$$

As a matter of fact, such indicators would be exposed to the well known errors made when considering changes in travel time for evaluation purposes.

(b) Indicators U_i, A_i or even N_i can be used indifferently for comparing (on an ordinal scale) various alternatives for a given individual; only U_i should be used for aggregating individual preferences.

(c) Theoretical validity and immediate intelligibility can often be associated by representing the indicator A_i on a logarithmic scale. This presentation, used for several figures in this paper, may lend itself to a qualitative reasoning in simple terms for non-specialists, as well as to more precise economic considerations. Similarly, comparisons between two values of A_i should be made by calculating their ratio rather than their difference.

Points (a) and (b) seem important and will be now emphasized.

3.2. ACCESSIBILITY, UTILITY AND TRAVEL TIME

The pathological properties of travel time (or cost) as an indicator of welfare change have been recognized for a long time (Neuburger, 1971; Poulit, 1974; Koenig, 1974; Williams, 1976). It is easy to find cases where an obvious improvement of transport conditions might paradoxically be associated with an increase of the mean or total travel time. As an example, improving transport conditions (by reducing travel time) between a city centre and a suburban centre may lead some inhabitants of that suburban centre to give up a nearby shopping destination in their suburb, and prefer shopping in the more attractive city centre, even with a higher travel time.

It can be easily verified in this example that the apparent inconsistency observed with travel time indicators would be suppressed by considering, for the inhabitants of the suburb, accessibility indicators of the A_i or U_i type; the same conclusion would be reached by considering consumers' surplus.

This advantage of accessibility indicators is more than a mere coincidence. It is clear, from the above example, that a correct appreciation of benefits derived from improvements of transport conditions should consider not only changes in travel time (i.e. the resistance factor of tripmaking) but also changes in the benefits afforded by the chosen destination (i.e. the motivation factor of tripmaking); in our example, travel time indicators would ignore the higher satisfaction provided by the possibility of shopping in the city centre.

This calculation of the difference between the motivation factor and the resistance factor of tripmaking is made implicitly when using consumers' surplus; but it could also be made explicitly, by introducing these two factors in a behavioural model of destination choice. In this latter approach while the resistance factor (travel time or cost) could be obtained from traffic models for all potential destinations, such a precise determination is obviously not possible for the motivation factor or gross utility, and a probabilistic approach would be needed.

Clearly this attempt to overcome the inconsistencies of travel time indicators would directly and logically lead to the behavioural approach described previously, and thus to the use of accessibility indicators.

It is suggested therefore, that:

(a) the basic assumptions of such behavioural models are not purely arbitrary and correspond with a logical need; and

(b) the accessibility indicators U_i and A_i as derived from these behavioural models are intrinsically able to take into account both the motivation and resistance factors of trip making; and this explains why they escape the important contradictions encountered when using, for economic evaluation purposes, indicators of mean or total travel time.

3.3. ACCESSIBILITY, UTILITY AND AGGREGATION OF INDIVIDUAL PREFERENCES

It was previously shown that the indicators A_i may reflect adequately the preferences of a single given individual on an ordinal scale. It will be suggested here that these indicators A_i, which have been shown adequate in the previous problem, may lead to unsatisfactory conclusions when used without sufficient care – as is sometimes done – to aggregate the preferences of several individuals.

This important point could be illustrated in the following example, where a choice is to be made between two alternatives (I and II) concerning two individuals (a and b). Accessibility indicators A_i to employment places are assumed to take the values shown in Table I.

It appears that individuals "a" and "b" are in conflict. This problem of optimal decision in conflicting situations is a difficult one, as theoreticians of the economy of collective goods have shown. The usual method consists in choosing an indicator which seems adequate (e.g. consumers' surplus, accessibility . . .) and calculating an average or total value over the population considered.

TABLE I

Individual	Alternative	
	I (e.g. developing individual transport)	II (e.g. priority to public transport)
a (e.g. non car owner)	1,000	2,000
b (e.g. car owner)	22,000	20,000

In our example, a comparison could be made between the two alternatives by using the mean or total value of the A_i indicator over the whole population. It would conclude that alternative I (with an average indicator equal to 11 500) is better than alternative II (average indicator equal to 11 000). With the indicator U_i instead of A_i, a quite opposite conclusion would have been reached: it is easy to verify that the total value of alternative I (i.e. $x_0 \log (1000/A_0) + x_0 \log (22\,000/A_0)$) is lower than the value of alternative II (i.e. $x_0 \log (2000/A_0) + x_0 \log (20\,000/A_0)$).

The conclusion reached with U_i can be shown here as obviously more acceptable than that suggested by A_i. The use of U_i – which corresponds, as Neuburger (1971) has shown, with a maximization of consumers' surplus – results in more social equity than the use of A_i; as a matter of fact, it would suggest that it is better to increase, by 1000 units, the accessibility of the poorly-served individual a than to increase by 2000 units the accessibility of the well-served individual b. It is generally admitted that equity among inhabitants is an important social value in urban planning, which would sometimes justify a preference for alternatives with less consumers' surplus, but more social equity. Thus, the use of A_i should be avoided, as it results here not only in less economic surplus, but also in less social equity than the mere maximization of consumers' surplus.

In this problem of aggregation of individual preferences, it can be concluded that the utility indicator U_i (identified here with the concept of consumers' surplus) is more acceptable than the accessibility indicator A_i, and of course than ordinary travel time indicators.

3.4. PRACTICAL CALCULATION OF ACCESSIBILITY

The calculation of accessibility indicators A_i and U_i, as derived in formulae (3) and (5), is usually easy and does not introduce any new difficulty in comparison with previous methods of evaluation. The coefficient x_0 can be determined from survey data; it can be shown (Koenig, 1974), by using the behavioural "Hivex" model described in Section 2.4, that the same coefficient x_0 will be found in the exponential trip distribution function given by eqn. (2). Such trip distribution functions can easily be calibrated from home interview surveys. Tests in French cities (CETUR, 1976) have concluded that, if utility and travel costs C_{ij} are measured in terms of generalized travel time like in formula (7), the value of x_0 is close to 12 mins of generalized travel time per trip (values ranging between 10 and 15 mins).

The additive constant in formula (5) and the parameter k in formula (4) do not need to be specified if it is only required to compare two situations (in which case the constant would be eliminated by subtraction) or may, if required, be fixed by a suitable convention. For instance, a net utility U_i equal to zero can be attributed to people having an accessibility index A_i to potential destinations equal to a given reference value A_0. This can be achieved with an appropriate convention defining the level zero of gross utility.

The exact value of the parameter k corresponding to that convention can be determined if desired but does not need to be calculated explicitly in this case, as the utility U_i will obviously be given by:

$$U_i = x_0 \log \frac{A_i}{A_0} \tag{6}$$

This is the formulation of utility which seems the most simple and suitable for practical use.

Finally, it should be mentioned that practical formulations of accessibility have to be adapted by the decision makers and professional planners involved in the planning process. Three formulations of accessibility can be considered here:

(a) Indicator A_i

This indicator – as given for example by eqn. (3) – has the advantage of being rather easily explainable. It corresponds clearly with a simple concept that most non-specialists would probably accept; as a matter of fact, it denotes the "range of choice" offered by the city and its transport facilities, in the form of a sum of potential destinations.

Its formulation supports the fundamental idea in the concept of accessibility, which can be expressed by the common sense statement that travel conditions and availability of opportunities cannot be separated when considering the benefits derived from trip making. An increase of the index A_i will indicate that the individual considered will probably find, in the new situation, a destination which will be either more attractive, or at a shorter travel time, or both, than previously.

Nevertheless, this indicator is not expressed in economic terms and heavy errors can be made (and have been made in the past) when using it without sufficient care for aggregate evaluations of alternatives, as was shown in the previous section.

(b) Utility U_i

The indicator U_i has the important advantage of being expressed in economic terms, thus associating an economic value with the range of choice A_i offered to an individual (Poulit, 1974). But its formulation (as a logarithm of A_i) cannot be easily explained without reference to relatively complex theories (behavioural models of destination choice, or consumers' surplus) of which most political decision makers, and even some professional planners, cannot have a complete understanding.

Despite this difficulty, the utility indicator has important advantages related to its comparatively strong theoretical bases. As the value, and also the weak points, of these bases can be fully analysed, the field of valid application of the indicator U_i can be assessed with a better precision than for other formulations of accessibility.

(c) Isochronic indicator N_i

This indicator denotes the number of potential destinations within a given limit of time or cost. It can be derived from the general formula (1), by assuming an impedance function equal to one within the time limit, and equal to zero beyond, instead of the exponential function used in A_i.

The index N_i, although distorted in relation to A_i because of this manipulation, has the advantage of being very readily understood (e.g. 50 000 jobs within less than 15 mins); and as it still reflects the concept of range of choice associating both urban structure and travel time, it remains intrinsically sound.

3.5. AN EXAMPLE: COMPARISON BETWEEN TWO ROAD INVESTMENTS IN LE MANS, FRANCE

The example proposed in this section will illustrate how the use of accessibility indicators may help in providing a better understanding and interpretation of results obtained during conventional transportation studies.

Accessibility indicators have been used in a study in 1971 for the city of Le Mans (200 000 inhabitants), in order to compare at a zonal disaggregate level two road investment programmes. Conventional results of traffic assignment tests (travel time, speed and congestion on each link) did not provide very clear or precise conclusions.

The problem in Le Mans was to determine whether it was better to begin by extending westwards the existing southern ring road, or by first building the northern radial road.

Figures 1 and 2 show, for each alternative, the maps of net utility or accessibility offered by the jobs accessible by car in peak hour conditions. Although the core of the city is the area where traffic is most congested, it does offer at the same time the best utility, the density of employment being very high. Figure 3 shows the difference between the utilities offered by these two alternatives, and suggests some unexpected conclusions.

For instance, the city centre is paradoxically better served by the ring road which does not pass through it, than by the radial road which does. This arises because the ring road relieves congestion in the core of the city by removing large volumes of the traffic flowing between outlying districts, which would otherwise have to cross the city centre. Thus, the large advantages of the ring road over the radial road in the present case are clear.

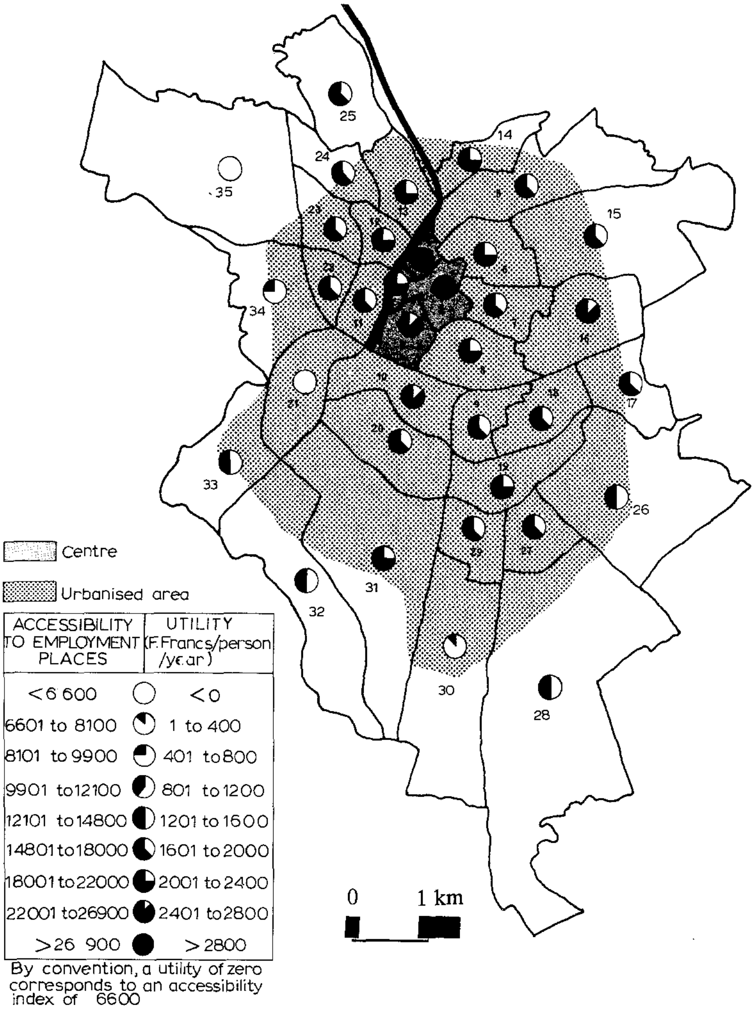

Fig. 1. Le Mans, 1977. Radial road alternative. Accessibility and net utility offered by employment places (by car).

Likewise, it may seem surprising that the only areas where the northern radial road is competitive in relation to the ring road are in the south. This arises because the extension of the ring road attracts a lot of new traffic to its existing southern part, thus increasing congestion and acting as a barrier between the south and the city centre.

4. Accessibility at a Disaggregate Level: An Example of Social Segmentation

Ten years ago, the main emphasis in economic evaluation of transport

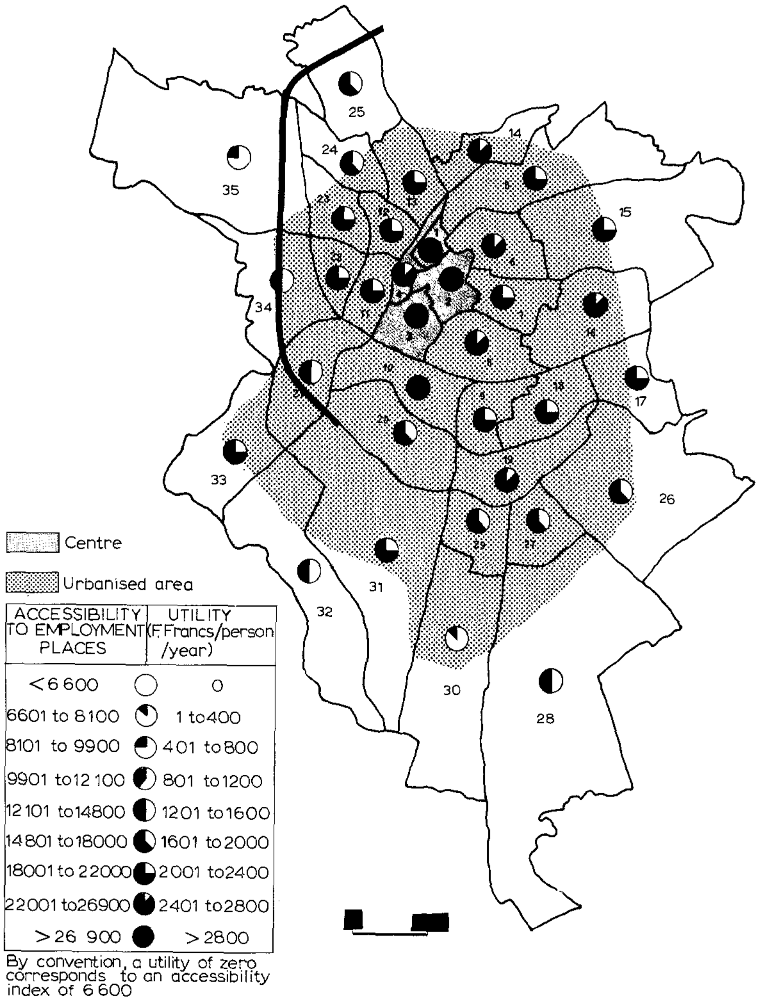

Fig. 2. Le Mans, 1977. Ring road alternative. Accessibility and net utility offered by employment places (by car).

plans was often given to aggregate concepts like total consumers' surplus. But it appeared that important difficulties were raised by the principle of aggregation itself, which does not consider properly social distributional effects, especially for relatively disadvantaged people. In recent years, attention has been transferred to the evaluation of distributional effects of transport policies for various segments of the population. As behavioural theories of accessibility produce accessibility indicators at an individual level, they are particularly suitable for such distributional studies.

A difficulty should be mentioned here, in relation to the frequent calculation of accessibility indicators by a given mode, instead of for a given

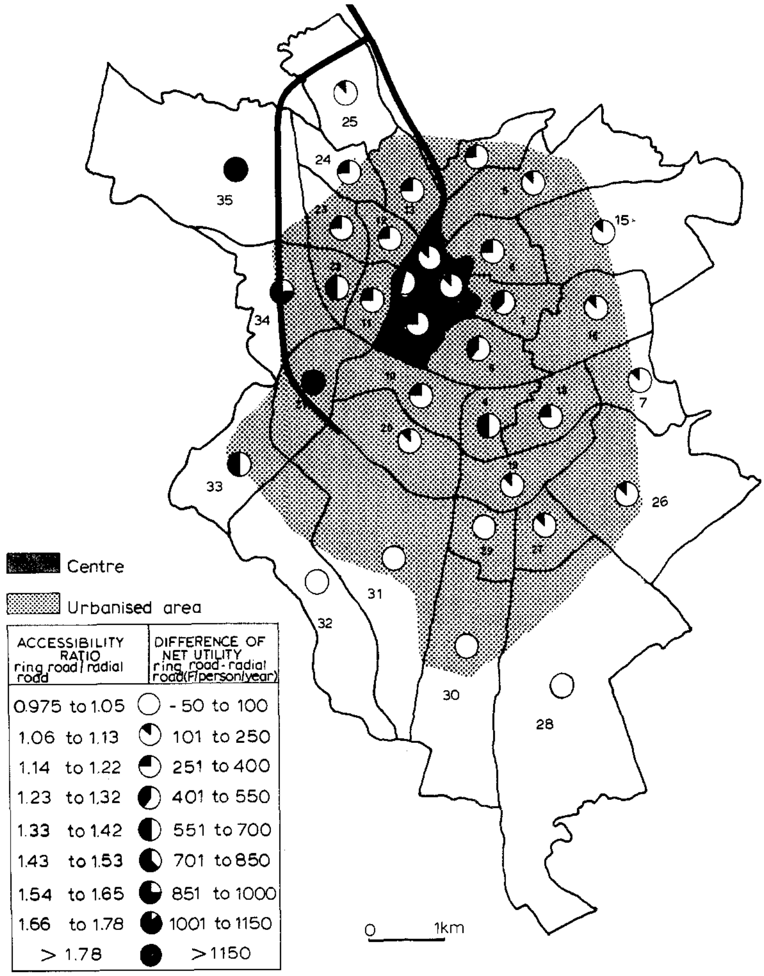

Fig. 3. Le Mans, 1977. Comparison between ring road and radial road alternatives.

person. This calculation by a given mode (for example, by introducing in eqn. (3) the travel time C_{ij} of the mode considered) has the advantage of simplicity; but it does not really reflect the situation of individuals, who usually have a potential choice among various modes (e.g. walking, public transport, two-wheeled vehicle, car . . .). Thus if the matrix of travel time or costs C_{ij} is to be adapted to the situation of each category of persons considered, it should reflect, for each destination, the cost perceived by the mode that the individuals considered would use.

A method to achieve this was proposed by the author (Koenig, 1975b) and will now be described.

4.1. CATEGORIES OF PEOPLE CONSIDERED

To calculate travel time matrices (C_{ij}) with a behavioural meaning, the urban population has to be split into several categories: people within each of those categories should, as far as possible, have a similar perception of the travel costs or times. Two factors have been considered as influencing heavily the perceived cost or time C_{ij} between a zone i of residence and a zone j of destination:

- the age of the person considered (and thus the perceived discomfort of modes like walking, public transport, two-wheeled vehicles); and
- the possession of or access to a car.

More precisely, six categories of persons have been considered, by crossing two levels of access to car (yes or no) with three categories of age (less than 30, 30 to 60, more than 60).

4.2. CALCULATION OF TRAVEL COST BY EACH MODE FOR A GIVEN CATEGORY OF INHABITANTS

For people of a given category, the generalised travel time C_{ij} from i to j by mode m was formulated as follows:

$$C_{ij}^{m} = k^{m}\ \theta_{ij}^{m} + \frac{1}{T}\ \gamma_{ij}^{m} \tag{7}$$

where:

γ_{ij}^{m} = monetary cost from i to j by mode m;
θ_{ij}^{m} = travel time from i to j by mode m;
k^{m} = discomfort coefficient associated with mode m by the persons considered;
T = value of time for the persons considered.
Parameters T and k^{m} may change from one category of persons to another.

The values of the discomfort coefficients k^{m} can be estimated, for each of the six categories, from home interview surveys. This can be achieved by calibrating the modal split model obtained when assuming that each individual would use, towards a given destination, the mode with the lowest generalised cost to him.

This calibration could more precisely consist in:

(i) associating each surveyed individual with one of the six previous categories of persons (by using data collected during the survey);

(ii) for each trip made by people belonging to a given category, determining the mode with the lowest generalised cost, by using a predetermined set of values of the k^m; this mode is the predicted mode for the trip considered; and
(iii) modifying the set of values of k^m for the considered category in order to maximise the number of correct modal choice predictions.

For example, such calibrations of k^m have been made from the home interview surveys carried out in Nice, Grenoble and Rouen in 1973 (CETUR, 1976).

For the sake of simplicity, the value of time T for these calibrations was assumed to be the same for the six categories of people (T = 10 FF/hour); this parameter was not calibrated, as the generalised travel time of formula (7) is not very sensitive to its value.

The results in the three cities were found close to the values shown in Table II.

TABLE II

Discomfort Coefficient for 6 Categories of People (Average Values) Calibrated from Home Interview Surveys in Nice, Grenoble, and Rouen, France)

Category of person	Estimated part of urban population (over 5 years old) in Rouen (1973) (%)	Discomfort coefficient			
		Car	Public transport	Two-wheeler	Walk
(1) Less than 30 years old, with car	8	1	1.1	2.2	1.2
(2) Less than 30 years old, without car	39	∞	1.1	1.8	1.2
(3) Between 30 and 60 years old, with car	19	1	1.3	2.6	1.7
(4) Between 30 and 60 years old, without car	18	∞	1.3	2.6	1.7
(5) Over 60 years old, with car	4	1.5	1.9	∞	2.2
(6) Over 60 years old, without car	12	∞	1.9	∞	2.2

4.3. INTERMODAL TRAVEL TIME MATRIX FOR A GIVEN CATEGORY OF INDIVIDUALS

Among all modes available to him, it is assumed that the individual considered would use, on each link $i \to j$, the mode with the lowest generalised cost. Thus: $C_{ij} = \min\limits_{m} \; C_{ij}^{m}$. With this method, specific cost matrices and accessibility indicators can be obtained for each given category of person instead of the conventional calculation by mode.

Other methods have been proposed to determine an adequate value of the perceived cost when several modes are offered. The method used here can be considered as asymptotical limit of the "composite cost" proposed by Williams (1976), when the parameter in this composite cost tends to infinity.

4.4. DISAGGREGATE CALCULATION OF ACCESSIBILITY IN MARSEILLES, FRANCE (1966)

As an example of results found with the previous method, Fig. 4 illustrates the values of accessibility obtained in Marseilles for the reference year 1966. It will be seen that possessing a car gives a marked improvement in accessibility for an elderly person (A_i almost doubles between curves 5 and 6). On the other hand, accessibility is improved to a lesser extent for a middle-aged car owner (by about 40 per cent, if curves 3 and 4 are compared) and the advantage is even more reduced for a young person (curves 1 and 2 are almost indistinguishable). Lastly, it emerges that the relative improvement

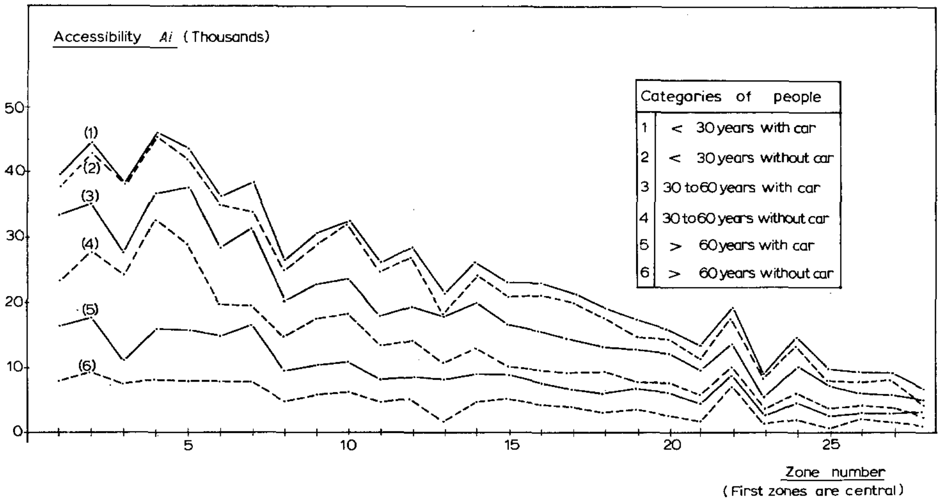

Fig. 4. Accessibility to tertiary employment places for different categories of people in Marseilles, 1966.

in accessibility derived from car ownership is greater in outlying districts than in the city centre. Viewed from this angle, increased car ownership promotes urban sprawl (and vice versa).

4.5. GEOGRAPHICAL ANALYSIS OF ACCESSIBILITY FOR A CATEGORY OF DISADVANTAGED PERSONS IN ROUEN, FRANCE

Among the six categories of persons in the previous example, the most disadvantaged is that of elderly people without car (about 16% of the population over 5 years old in Marseilles). Figure 5 illustrates the accessibility for this group to tertiary employment places in Rouen.

In central areas, accessibility is not too bad for these people, who benefit:

(a) from the high density of opportunities in central areas, allowing some trips to be made by walking to a nearby destination (despite the high discomfort coefficient);
(b) from the large number of bus lines in central areas, providing acceptable conditions to suburban destinations.

In suburban areas, the availability of suitable destinations within walking distance decreases rapidly, and these elderly persons have to rely almost completely upon public transport. Thus accessibility becomes very bad in some zones with no or poor public transport.

Such maps may help in detecting areas with very bad transport conditions for people without car, and suggesting priorities for public transport improvements.

5. Accessibility and Trip Rate

One of the main fields of application for disaggregate calculations of accessibility might be found in behavioural models of individual decisions related to travel (trip rate, car ownership, land use . . .). In this section, only application to trip rate prediction will be considered, and some results obtained in France will be presented.

Many current models of traffic generation are based solely upon socio-economic characteristics of the different zones (population, employment, income, car ownership . . .).

However, it is obvious that the number of trips made by people will also depend on the quality of transport and on the availability of attractive destinations. While some trips (such as going to work) have to be made anyway, other trips (shopping, leisure) can be postponed or not made at all if transport conditions are too bad or potential destinations too remote.

As far as accessibility indicators reflect these factors of tripmaking, their introduction into traffic generation models could be expected to improve the value of these models and bring them closer to equilibrium models.

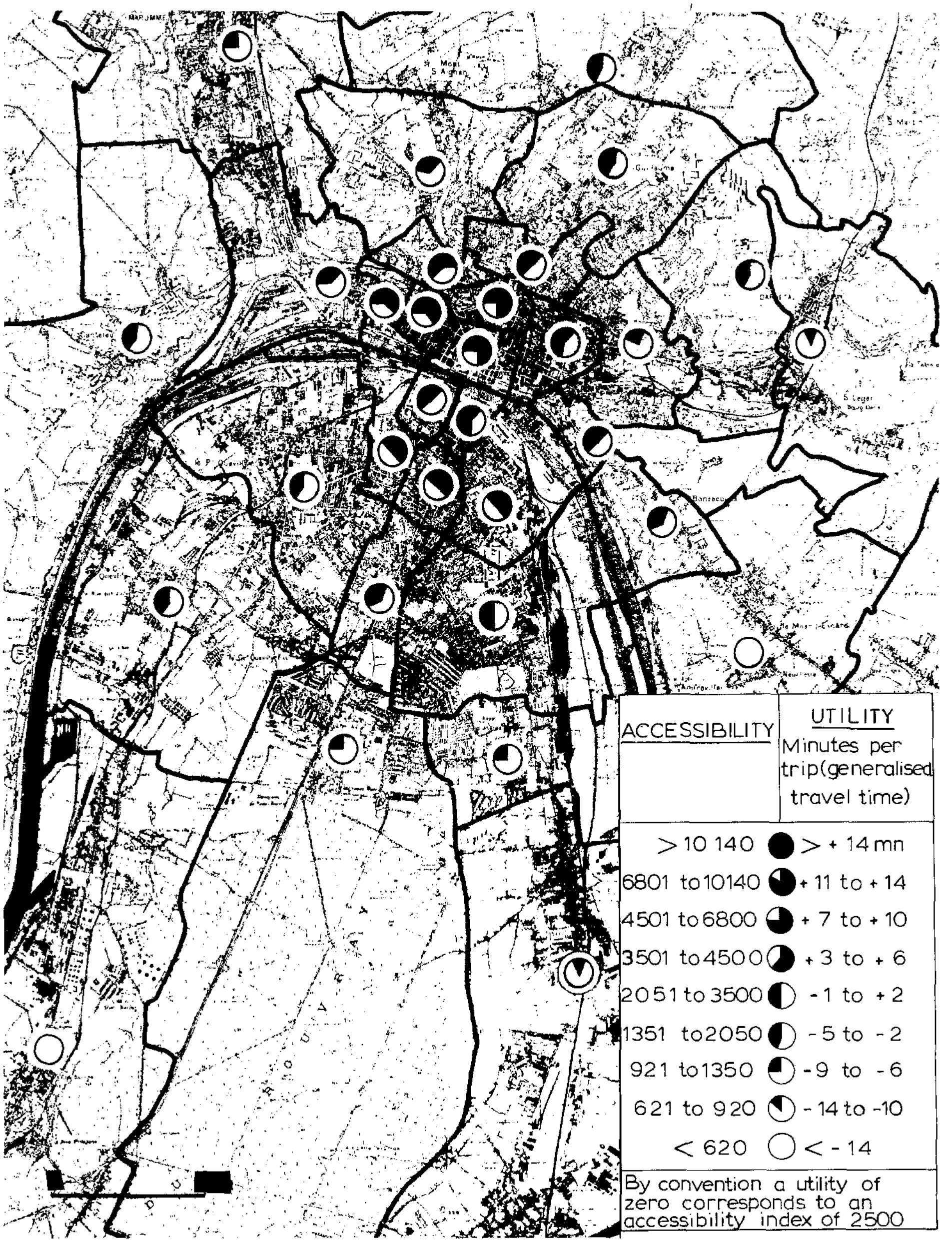

Fig. 5. Accessibility to tertiary employment places in Rouen (old people without car).

Many attempts have been made to detect a significant relation between mobility and accessibility; some of them – for instance by Dalvi and Martin (1976) in Great Britain – found accessibility rather ineffective as a means of explaining trip generation. A possible explanation of this failure could be that accessibility was calculated by mode, instead of by category of person and also that trip generation excluded walking trips.

A similar study has been undertaken in five French cities (CETUR, 1976) for the same six categories of inhabitants as in Section 4.1 (defined by crossing two levels of car ownership with three levels of age). Trip generation included walking trips and accessibility was calculated separately for each category, with the same method as described previously. Under these conditions, accessibility was found to be a very good determinant of trip generation for non working people; moreover, the empirical relation between these two variables appeared approximately constant over the five cities.

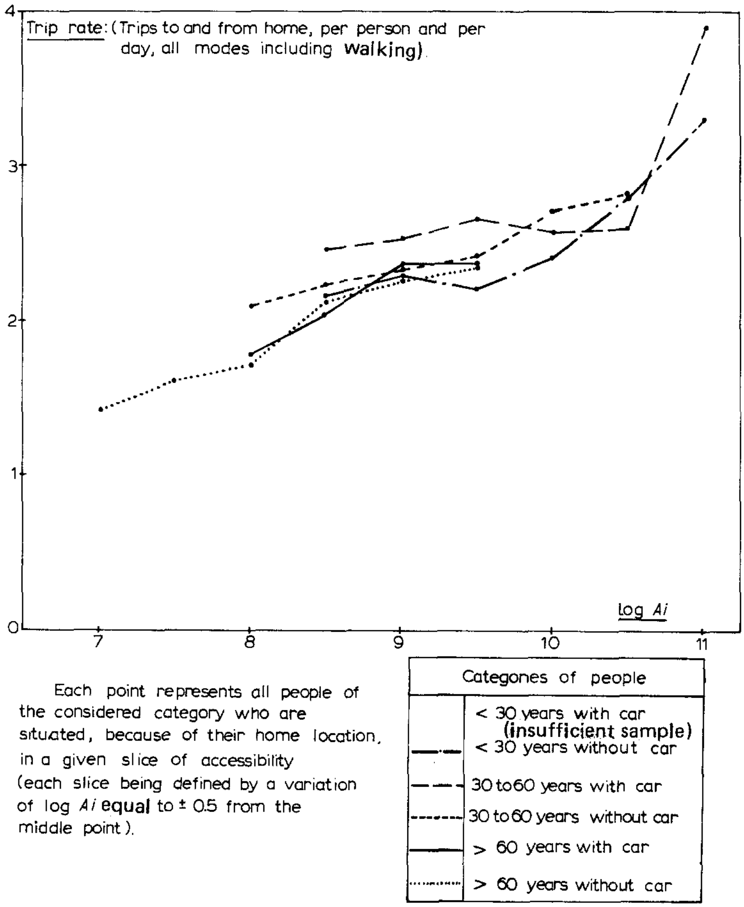

Fig. 6. Relation between accessibility and trip rate for five categories of non-working people in Marseilles, 1966.

Some of the results of this study are illustrated in Figs. 6–8. Figure 6 suggests that a very clear empirical relation exists between accessibility and mobility (in the sense of trip rate per person) and that this relation may be considered as identical for the five categories of people considered. Figures 7 and 8 show that this relation is also very similar from one city to another, whatever the category of persons considered (car owners and non car owners in Fig. 7, elderly people without car in Fig. 8). Thus this relation may be considered, in a first rough approximation, as universal.

These figures point out accessibility indicators as a very powerful determinant of mobility; within a group of people with homogeneous characteristics, the average trip rate may double or triple from a zone with poor accessibility to a zone with good accessibility.

This result is not necessarily inconsistent with the assumption which is sometimes expressed of an approximately constant travel time budget, as it was observed that the average travel time is inversely related to trip-rate. The

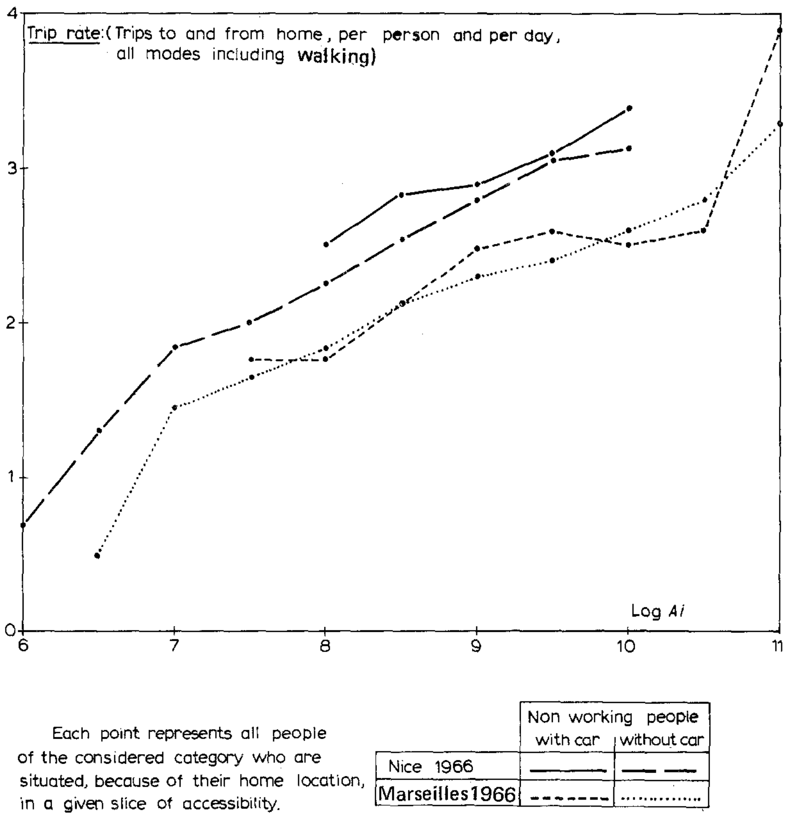

Fig. 7. Relation between accessibility and trip rate for non-working people, with and without car (surveys in Marseilles and Nice).

apparently positive results obtained here suggest also that the disaggregate method used to calculate accessibility for various categories of persons corresponds in some way with reality.

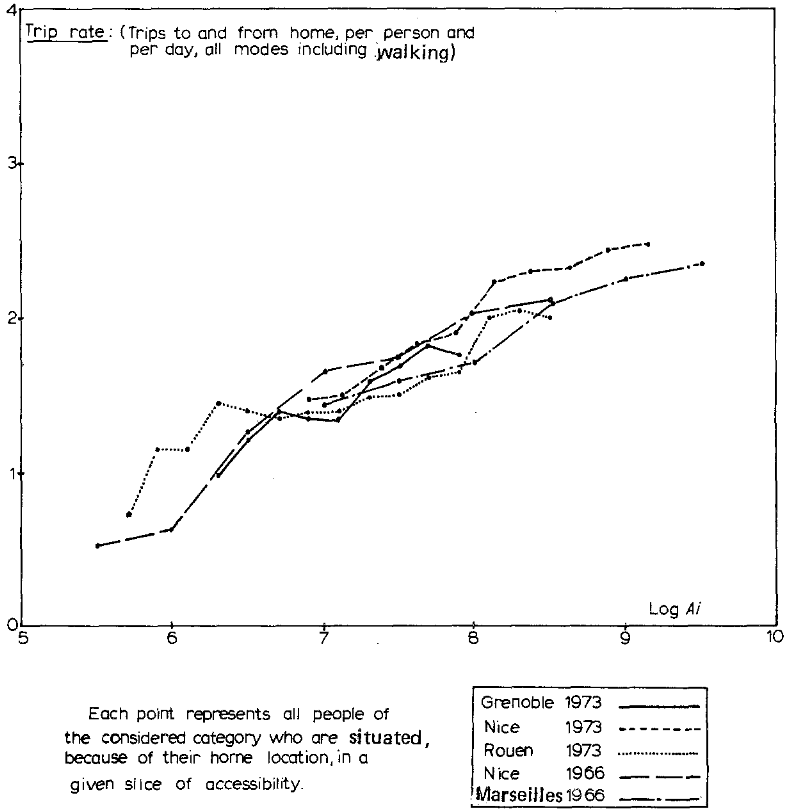

Fig. 8. Relation between accessibility and trip rate; comparison between five cities (non-working people, over 60 years, without car).

6. Conclusion

Accessibility appears more and more as a key concept in urban and transport planning. It expresses what is possibly the major function of cities: i.e. providing opportunities for easy interaction or exchange.

The first quantified formulations of this concept in terms of opportunities weighed by a cost dependent proximity factor, were based on purely intuitive and common sense approaches; thus accessibility indicators have up to now often been considered with suspicion, because of this apparent lack of theoretical support.

In recent years, it was shown that these indicators could also be derived from more elaborate approaches like consumers' surplus or behavioural models. This remarkable convergence between logically compatible but quite different common sense or microeconomic approaches does not appear as a mere coincidence, but as further evidence of the polyvalence and central position of the concept of accessibility with its related indicators.

This theoretical background provides a new respectability to accessibility indicators. It allows a precise understanding and assessment of their significance, limits of validity and desirable mathematical expression. It explains why they would escape the well-known inconsistencies encountered by travel cost indicators. It finally points to their use as a preferential tool for evaluating policies, especially at a disaggregate level, and also as an important determinant of people's behaviour in traffic prediction models. Practical experience, though still limited, tends to confirm this positive judgement.

When used for evaluation purposes, accessibility indicators have proved very effective. At a disaggregate level, and provided an adequate segmentation of the population is made, distributional effects of policies can be clearly detected and appreciated. Furthermore, accessibility indicators may be expressed in simple mathematical terms, which can be easily explained to non specialists but are still compatible with more elaborate concepts like consumers' surplus; thus, they may provide a useful basis, during the planning process, for a dialogue with political authorities and the public.

Applications in the field of behavioural modelling (trip generation, car ownership, urban development . . .) are still under research; but very encouraging results have already been obtained, at least for trip generation. Thus accessibility indicators can rank among the more powerful planning tools available today. It can be hoped that their use in the future will increase so as to realise their remarkable potentialities.

List of Symbols

A_i = accessibility indicator from zone i to the type of opportunities considered.
C_{ij} = generalised travel time from zone i to zone j.
$f(C_{ij})$ = impedance function.
$g(C_{ij})$ = trip distribution function in gravity models.
G_i = number of trip origins in zone i.
k = parameter in the "Hivex" probability density function of gross utility.
k^m = discomfort coefficient of mode m.
N_i = isochronic accessibility indicator from zone i.
O_j = opportunities of type considered in zone j.
$p(x)$ = probability density function of gross utility at a destination.
S = consumers' surplus.

T = value of travel time.
U_i = utility of tripmaking for a resident of zone i.
V^t = gross utility of a randomly selected destination for individual t.
x_0 = parameter in the "Hivex" probability function of gross utility, also intervening in the related trip distribution function.

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