TRAVEL DEMAND FORECASTING: ACHIEVEMENTS AND PROBLEMS

ALAN G. WILSON
Department of Geography
University of Leeds
England

This paper represents a personal account of some British and European achievements in travel demand forecasting during the past 10 years in the context of a discussion of ongoing issues. The account is likely to be substantially incomplete, especially in relation to continental European countries because of language and information-availability difficulties. It should also be noted at the outset that the emphases and the judgments about the importance of innovations and of the ongoing issues are personal. Some of the bias will result, again, from lack of information rather than the making of explicit judgments.

The paper is structured into 9 sections that describe the organizational content, with emphasis on features peculiar to the British side of the Atlantic; the main innovations in summary and in more detail, but still only in outline, under the fairly traditional headings of trip generation, distribution, modal split and generalized cost, assignment, urban activity models, and transport and related models; and ongoing issues in research and development.

BRITISH AND EUROPEAN EXPERIENCE: ORGANIZATIONAL CONTENT

The first major transportation studies in Britain were launched in the early 1960s. The first one, the London Study, was authorized in 1960, and the actual survey was carried out in 1962. There were 3 phases of analysis and planning associated with this study (1, 2, 3, 4, 5), and phase 3 reports were published in 1969. Since then, the Greater London Council (GLC) has embarked on a new transportation study, for which the survey was carried out in 1971-72. This brief history of the London developments shows 2 things: that the traditional survey and analysis methods have proved time-consuming, but that, nonetheless, at least in the largest city, model-based transportation planning has taken its place as an ongoing continual activity.

A whole series of conurbation transportation studies was launched and completed during the 1960s. They were usually carried out by consortia of local authorities and partly financed by the Ministry of Transport. In turn, there were studies of the West Midlands (7), Merseyside (8), South East Lancashire and North East Cheshire (9, 10), West Yorkshire (11), Teeside (12), and Glasgow (13). There was considerable development in both objectives and methods between earlier and later studies (or between earlier and later phases in the case of London). In the early days, the models were the American models, usually applied by American consultants. Later, as we shall see in the next section, the objectives were amended to take more account of public transport and to allow for the availability of stronger land use planning controls in Britain. There were corresponding developments in the models; modal split was taken more seriously, and the corresponding submodel was made more sensitive.

During this period, and especially toward its end, more and more local authorities carried out their own model-based transportation studies, some using consultants, some relying on their own staff. It is estimated that more than 60 such studies have now been carried out in Britain.

As noted, this effort built on American experience. However, work at the scale described above has generated much expertise within Britain.

The major local authorities usually have their own staff for continuing studies; the GLC is the most striking example of this. Some continuing work is still being carried out by consortia of local authorities, as in the South East Lancashire and North East Cheshire (SELNEC) region, centered on Manchester. Considerable expertise has been built up in central government also, in both Ministry of Transport headquarters, Department of Environment, and the Transport and Road Research Laboratory. Yet more work is carried out in universities, mostly in departments of transport studies (which are usually associated with civil engineering departments).

The work described so far is in almost all cases specifically concerned with transport (except that in some of the larger studies the transport impacts of alternative land use plans were also examined). In the middle-to-late 1960s and the early 1970s, there have been attempts to integrate this activity with the broader aspects of urban and regional planning. An early straw in the wind was the publication in 1963 of the Buchanan report (77), which spelled out the physical consequences of serving the motor car. In 1968, a new planning act required local authorities to produce new kinds of plans—a structure plan for the broader strategic scale, limited to district and local plans, the latter often for shorter action. Structure plans have much more stringent analytical requirements (14), and urban and regional activity and land use models, in addition to the transport model, can be a considerable help in this context. In parallel with this legislative activity, many planners had begun to use urban activity and land use models following the publication of Lowry's Model of Metropolis in 1964 (17). As Goldner (18) pointed out in a recent paper, more development effort was put into models of this type in the United Kingdom than in the United States. This kind of model-building effort has proceeded on a broad front in Britain and has been reviewed by several authors (19, 20, 21). These urban modeling techniques were used by a number of authorities in a structure planning context.

In 1965, the Regional Economic Planning Councils were created (10 in all), and their staffs have produced plans that have a broad content (i.e., not restricted to economics), have often used models, and usually include sections on regional transport needs (22, 23). Other important studies, which because of the demands of structure planning cross local authority boundaries, have been carried out on a subregional planning basis (24, 25, 26, 27). Further, local government reorganization will begin to take effect from April 1974. The new authorities will be of subregional size, and a further impetus for model-based integrated urban-transport planning can be expected at that time.

It is also perhaps worth mentioning that a number of ad hoc studies utilizing transport models have led to important central government reports. Though their subject matter is not strictly urban, they have considerable urban impacts. In 1966 the Ministry of Transport published a paper (28) on the modeling of flows of goods to ports, and in 1969 the ministry published a green paper (29) on national road planning, particularly with respect to the motorway system, which was also model-based. Another ad hoc model-using study was that of the Roskill Commission (30) on the location of the third London airport. All this again reflects the building up of in-house expertise in government.

For continental Europe, it is much more difficult to give a systematic account. Many cities have carried out transportation studies, some using American or British consultants, some using indigenous ones (such as Seiler and Barbe in Zurich).

MAIN INNOVATIONS: INTRODUCTION AND SUMMARY

The main innovations are summarized here; the typical U.S. model of the early 1960s is taken as a starting point. The types of innovation that have been forced by differences between American and European cities are outlined, a number of important theoretical innovations are noted, and some new ways in which the models have been used in a planning context are noted.

When the various studies were initiated, British and European cities were less highway-car dominated than American cities. This has led to a greater concern with the analysis of modal split and with the explorations of a greater range of public transport options. Car ownership, however, has been and still is increasing rapidly, and this has led to another kind of peculiarly European problem: serious highway congestion and a road-building budget that, from the earliest times, was less able to cope with demands than in the corresponding American situation. This has colored the British view of assignment within the model as well as generated, from another aspect, the need to look at broader sets of public transport plans. This leads to attempts to formulate "balanced" transport plans. Also, at least in Britain, physical planning controls are potentially stronger than in the United States, and that has reinforced the desire to integrate transport planning with the broader aspects of urban planning and to integrate urban models and transport models. The British experience in this field has not been quite so unhappy as some American experiences (31), possibly because of lower expectations.

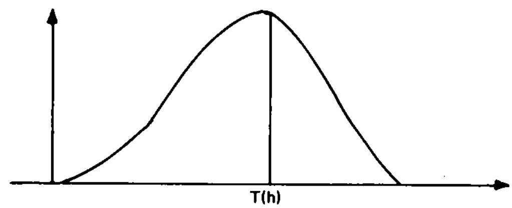
A range of notable theoretical innovations is described below in relation to different model components. For the trip generation submodel, there has been the development of category analysis; for distribution and modal split, there have been the development of entropy-maximizing methods, a set of theorems on balancing factors and connections to mathematical programming, the development of the concept of generalized cost, some innovations with model calibration, and some developments on aggregation issues. These last-named developments could lead to further significant steps forward. Assignment models have been developed to take more account of congestion (and there has been a greater tendency to iterate the full model in conjunction with this) and also to cope effectively with public transport. More generally, there have been interesting work on continuous variable models and a lot of work on urban activity and land use models. The category-analysis form of trip generation has facilitated the connection of these to the transport model. With the transport model as a whole, there has been an emphasis on seeking quick ways of running the model.

In the way the models have been used, there have been attempts to improve evaluation theory and associated techniques such as cost-benefit analysis. This has been associated with attempts to use the model to evaluate a more extensive range of alternative plans. More recently, there have been attempts to examine transportation impacts on particular groups of people and to use the model system to evaluate what now often seem to be more feasible plans that are concerned with traffic management, parking control, pricing, precincts, bus priorities, and so on rather than the building of new facilities.

It is difficult, for the reasons mentioned earlier, to discuss fully other European innovations. Metra/SEMA, for example, developed a different kind of distribution model, which was used in Lisbon and other cities. Much of this work has been reviewed more broadly elsewhere (32, 33, 34). A general description of some Swedish work is given in the report by Bexelius, Nimmerfjord, Nordquist, and Read (35). Other Swedes have produced interesting entropy-maximizing work (36, 37). A different approach altogether to entropy maximizing has been used in Belgium (38). There are French models based on analyses of motivation (39). These innovations are discussed in following sections.

TRIP GENERATION

The basic ideas of category analysis were first reported by Wootton and Pick in 1967 (142) and have been used in many studies since, including London, West Midlands, and SELNEC. The main idea is a simple one: Households are divided into h, and T(h) is defined as the mean number of trips of the same purpose for this category. Suppose the actual frequency distribution of trips for households in this category is as shown in the sketch. Then, the art of category analysis is to define the categories such that the distributions are all as narrow as possible. It is then assumed that T(h) is relatively stable over time, and the forecasting burden becomes that of predicting $a_i(h)$, the number of households of type h in zone i.



The trip generation equation itself can be obtained as follows. We are usually interested in person trips by type n (say car owner/non-car owner). Let H(n) be the set of households containing persons of type n. Then,

$$O_i^n = \sum_{h \in H^{(n)}} a_i(h) T(h) \qquad (1)$$

is the number of trip productions in zone i by persons of type n.

Wootton and Pick used 108 categories made up of 3 car-ownership levels, 6 income levels, and 6 types of household structure (defined in relation to both size and number of workers); many other teams in Britain have used the same categories because they relate well to British census data (40). Thus, if h is the set (n, I, p), where n, I, and p are indexes related to car ownership (n = 0, 1, 2, or more), income group, (I = 1, . . ., 6), and household structure (p = 1, . . ., 6), then (dropping the zone subscript for the present),

$$a(h) = a(n, I, p) = Hf(p) \int_{a_I}^{a_{I+1}} P(n|x)\phi(x)dx \qquad (2)$$

where H is the total number of households, f(p) is the probability of household structure p, (a_I, a_{I+1}) are the limits of the Ith income group, x is income, P(n|x) is the conditional probability of being in the nth car-ownership group given income x, and $\phi(x)$ is the probability of having income x.

Distributions are postulated for f(p), P(n|x), and $\phi(x)$, and then parameters are estimated from current data. Then, forecasts can be made by predicting new means (usually the new mean income distribution suffices) and the new distribution of population, H. Typically, $\phi(x)$ is taken as a gamma distribution, P(n|x) as another form of gamma distribution, and f(p) as a product of distribution relating to mean household size and mean number of workers, which are taken as binomial and Poisson respectively.

Trip attractions can be dealt with by a similar procedure. Wootton and Pick classified urban activities into 8 categories (7 are aggregates of SIC categories, and 1 is population). Then, if $t(\ell)$ is the rate at which trips are attracted to category ℓ, trip attractions D_j are given by

$$D_j = \sum_{1} b_j(\ell)\, t(\ell) \qquad (3)$$

where $b_j(\ell)$ is the number of units (usually employment) of 1 activity in zone j. $b_j(\ell)$ can be obtained directly from the census on corresponding (possibly model-based) forecasting procedures. There is no complicated procedure in this case for postulating individual distribution functions to be combined to make up the same cross classification.

It may well be that category analysis does not have any fundamental theoretical advantage over multiple regression analysis (and, indeed, it has been agreed that category analysis is equivalent to regression analysis with dummy variables, 41, 42), but there are considerable practical advantages. The problem of multicollinearity among independent variables is less overt, if not nonexistent. (The corresponding disadvantage is that, unless the dummy variable regression form can be used, there is no correponding measure of error.)

A second advantage relates to the way in which trip-rate variables are separated from variables representing the distribution of population and economic-activity variables by category. This facilitates separate research work on each and the connection of the transport model to urban-activity models. Further, the method of multiplying together calibrated single-variable or conditional distributions to obtain joint-probability distributions is almost certainly a method that will have to be commonly used to overcome data deficiencies, particularly when large surveys cannot be attempted.

A third advantage is that, because the categories used tend to be common among several studies, interurban comparisons are possible, and results from a large survey in one study area can be used to "support" another study area with a small or nonexistent survey.

Experience with the model in Britain has suggested that the results are encouraging. If there is any doubt, it is in the calculation of trip attractions rather than trip productions, and some interesting work is being carried out on trip attraction by special facilities (44, 45, 46).

DISTRIBUTION, MODAL SPLIT, AND GENERALIZED COST

This bundle of topics can be treated together because in summation they form a unified model. We begin, however, by discussing the distribution model alone. Typically, the model has been used as a doubly constrained model:

$$T_{ij} = A_i B_j O_i D_j f(c_{ij}) \tag{4}$$

where T_{ij} is the number of trips from i to j for some purpose, c_{ij} is interzonal trip cost (or time or distance), f is some decreasing function, O_i is trip production in i, D_j is trip attraction in j, and A_i and B_j are the so-called balancing factors calculated to ensure that

$$\sum_j T_{ij} = O_i \tag{5}$$

$$\sum_i T_{ij} = D_j \tag{6}$$

That is,

$$A_i = 1 \Big/ \sum_j B_j D_j f(c_{ij}) \tag{7}$$

$$B_j = 1 \Big/ \sum_i A_i O_i f(c_{ij}) \tag{8}$$

Equations 7 and 8 are solved iteratively.

This model is usually viewed as a gravity model based on the hypotheses

$$\left.\begin{array}{l} T_{ij} \propto O_i \\ T_{ij} \propto D_j \\ T_{ij} \propto f(c_{ij}) \end{array}\right\} \tag{9}$$

with A_i and B_j added to achieve internal consistency. O_i and D_j are interpreted as "masses," and a Newtonian-law-of-gravity analogy is invoked.

Entropy-Maximizing Method

The entropy-maximizing method changes the basis of the analogy. Essentially, it is a statistical average of the behavior of individuals making trips (47). The entropy of a distribution is defined as

$$S = \frac{T!}{\prod_{ij} T_{ij}!} \tag{10}$$

where T is the total number of trips, and if S is maximized subject to Eqs. 5 and 6 and a constraint on total travel cost

$$\sum_i \sum_j T_{ij} c_{ij} = C \tag{11}$$

then we get

$$T_{ij} = A_i B_j O_i D_j e^{-\beta c_{ij}} \tag{12}$$

with

$$A_i = 1 \Big/ \sum_j B_j D_j e^{-\beta c_{ij}} \tag{13}$$

and

$$B_j = 1 \Big/ \sum_i A_i O_i e^{-\beta c_{ij}} \tag{14}$$

This is the gravity model mentioned earlier with $e^{-\beta c_{ij}}$ replacing $f(c_{ij})$. However, even this is not too restrictive; for example, replacing c_{ij} by log c_{ij} transforms $e^{-\beta c_{ij}}$ into $c_{ij}^{-\beta}$.

The entropy-maximizing method can be viewed in at least 4 ways (44, 45, 46).

1. S can be interpreted as the probability that the distribution T_{ij} will occur, and so the model maximizes probability subject to known constraining information. This makes entropy maximizing a useful theoretical tool because a basic research task is to improve the constraining information, and that leads to new models.

2. T_{ij}/T can be taken as p_{ij}, the probability that an individual is assigned to the (i-j) state, and then S can be identified with the information-theory measure of entropy,

$$S = -\sum_i \sum_j p_{ij} \log p_{ij} \tag{15}$$

and the procedure then produces a best estimate, again constrained by known information. Jaynes (48) has developed this argument in relation to the use of entropy in statistical mechanics, and Tribus (49), among others, has developed it more generally.

3. S in Eq. 15 can be identified with the negative of the log-likelihood function for a statistical analysis of our problem. Thus, when we choose the form of the probability function that maximizes entropy, we minimize the likelihood function. This is another way of stating that the probability distribution that maximizes entropy makes the weakest assumption consistent with what is known.

4. If we take S in Eq. 10 as $W\{T_{ij}\}$, the probability that T_{ij} occurs, then an alternative to maximizing probability is to average, to find $\overline{T_{ij}}$ as

$$\overline{T_{ij}} = \frac{\sum W\{T_{ij}\} \cdot T_{ij}}{\sum W\{T_{ij}\}} \tag{16}$$

The mathematical procedure for making the calculation is the Darwin-Fowler method, and, again, the same answer is obtained.

These 4 views of entropy maximizing are, of course, all mutually consistent. It is nice to consider them as a statistical averaging procedure for the population making trips for a particular purpose, for that does preserve the connection with individuals and, as we shall see later, helps with a discussion of aggregation issues.

Perhaps the most important advantage of the entropy-maximizing method is that it generates models that are internally consistent with respect to the constraining information so that, as long as that is consistent, the model is consistent. It facilitates model building in a wide variety of situations. In the transport field, it facilitated the construction of a model that recognized differential availability of modes among person types (in particular, car owner/non-car owner). This led to a model of the form

$$T_{ij}^{*n} = A_i^n B_j O_i^n D_j e^{-\beta^n c_{ij}^n} \tag{17}$$

$$\frac{T_{ij}^{kn}}{T_{ij}^{*n}} = \frac{e^{-\lambda^n c_{ij}^k}}{\sum_{k \epsilon \gamma(n)} e^{-\lambda^n c_{ij}^k}} \tag{18}$$

T_{ij}^{kn} is the number of trips from zone i to zone j by persons of type n by mode k; the asterisk denotes summation over the index it replaces; $\gamma(n)$ is the subset of modes available to persons of type n. Note also that in this model trip productions were characterized by person type while trip attractions were not, which seems realistic. A_i^n and B_j are sets of balancing factors that ensure

$$\sum_j T_{ij}^{*n} = O_i^n \tag{19}$$

$$\sum_i \sum_n T_{ij}^{*n} = D_j \tag{20}$$

so that

$$A_i^n = 1 \Big/ \sum_j B_j D_j e^{-\beta^n c_{ij}^n} \tag{21}$$

and

$$B_j = 1 \Big/ \sum_i \sum_n A_i^n O_i^n e^{-\beta^n c_{ij}^n} \tag{22}$$

c_{ij}^n is interpreted as a composite of modal-interchange costs, c_{ij}^k, which represents the i-j impedance as perceived by type n people. The suggested aggregation is

$$e^{-\beta^n c_{ij}^n} = \sum_{k \epsilon \gamma(n)} e^{-\beta^n c_{ij}^n} \tag{23}$$

We shall later see that this is a first-principles method for producing an internally consistent model, which is one of the set defined by Manheim (50). Other aggregation methods are possible, however (47). β^n and λ^n are parameters that relate to the average behavior of type n people with respect to trip length and sensitivity to modal costs respectively. This was essentially the form of model used in the SELNEC study (51). The model was found to fit reasonably well and to be policy sensitive.

Generalized Cost

It is useful to digress at this point to the concept of generalized cost by mode, c^k_{ij}, which has been implicitly introduced above. British work in the development of this concept was initiated in the work of Quarmby (52) reported in 1967. It is of interest that the modal-split function in Eq. 18 turns up in a variety of approaches to modal split, including the discriminant-analysis approach of Quarmby. In effect, he took c^k_{ij} as a discriminant function and estimated the weights of the components of his linear function, which gave maximum discrimination. This work can be connected to other work on the value of time (55), which usually expresses value of time as a proportion of income. The way in which such concepts have been used in British studies is again illustrated by the SELNEC study. The initial weights used were essentially Quarmby's, but adjusted slightly as part of the model-calibration procedure. The model, for example, predicts car-owner/non-car-owner mix at destination zones, and terminal costs were adjusted to get this as nearly correct as possible. Further calibration adjustments produced one particularly interesting result: Different weightings were appropriate for the distribution and modal-choice parts of the model. These can be written $c^k_{ij}(d)$—which is then used in Eq. 23 to give c^n_{ij}—and $c^k_{ij}(m)$ respectively. The forms used were

$$c^k_{ij}(d) = a_1 t^k_{ij} + a_2 e^k_{ij} + a_3 d^k_{ij} \tag{24}$$

and

$$c^k_{ij}(m) = a_1 t^k_{ij} + a_2 e^k_{ij} + a_3 d^k_{ij} + p^k_j + \delta^k \tag{25}$$

The detailed definition and results are given in the paper already cited (51); t^k_{ij} is travel time, e^k_{ij} is excess time, and d^k_{ij} is distance, used for estimating operating costs. p^k_j is the terminal cost, essentially car-parking time and cost, and δ^k is a term used to represent "intrinsic" preference for car. Thus, the result mentioned earlier was that parking costs, p^k_j, and the public transport handicap, δ^k, were not relevant in distribution to the decision as to where to go, but were relevant in modal choice. The model as a whole was appropriately sensitive, but it is interesting to recall that, when Eq. 23 was used with travel time only, the fit was bad, but, when used with generalized cost, it was quite good.

Intervening-Opportunities Model

It is perhaps worth mentioning briefly that the entropy-maximizing method offers an interesting insight into the intervening-opportunities model (47), which seems to have been relatively little used in Britain. This model can be derived if the following assumption is made: Intervening opportunities between i and j provide a proxy for travel cost, but are counted again each time an opportunity is passed. That is, if $j_\mu(i)$ is the nth zone in rank order away from i and $D_{j_\mu(i)}$ is the number of opportunities at $j_\mu(i)$, then the "equivalent" cost function is

$$c_{ij_\mu(i)} = (\mu - 1)\, D_{j_1(i)} + (\mu - 2)\, D_{j_2(i)} + D_{j_{\mu-1}(i)} \tag{26}$$

and this seems a rather odd function.

Balancing Factors and Connection to Transportation Problem of Linear Programming

Particular attention has been paid in Britain to the properties of the balancing factors, A_i, B_j (in Eqs. 4, 7, and 8, say). Murchland (57) used a maximization foundation of the problem, following Samuelson (58), and some theorems in mathematical programming to establish the uniqueness and existence of the balancing factors. Evans (59) has shown that the iteration procedure that is usually used to calculate A_i and B_j does indeed converge to the desired unique solution. An interesting corollary of his analysis is that, if a matrix F_{ij} is being adjusted by balancing factors A_iB_j to give

$$\hat{F}_{ij} = A_iB_jF_{ij} \tag{27}$$

such that, say,

$$\sum_j \hat{F}_{ij} = O_i \tag{28}$$

and

$$\sum_i \hat{F}_{ij} = D_j \tag{29}$$

then, if F_{ij} is replaced by any matrix of the form $a_ib_jF_{ij}$ (i.e., with multiplicative terms with i-dependence and j-dependence only) and the new matrix is balanced in relation to constraints in Eqs. 28 and 29 to give $\hat{\hat{F}}_{ij}$, $\hat{\hat{F}}_{ij} = \hat{F}_{ij}$. Thus, if we are balancing to given trip end totals, only terms in the model that depend on i and j simultaneously will affect the answer!

It is interesting also to note that these kinds of matrix-adjustment procedures are used in some methods of estimating input-output matrices (60), and similar theorems to those of Evans have been proved in this context, independently, by Bacharach (61), who reported that Denning and Stephan (62) made the first investigation of biproportional matrices. He calls F_{ij} proportional matrices.

More recently, Evans (63) has proved formally a result that has been believed at the level of conjecture for some time. In a model of the form given by Eqs. 12, 13, and 14, for example, as $\beta \rightarrow \infty$, T_{ij} tends to the solution of the corresponding linear programming problem.

Model Calibration

One of the inherent problems in trip-distribution models of the doubly constrained type is that they can eat up computer time because of the iterative calibration for A_i and B_j. Two pieces of work can be mentioned that attempt to alleviate this problem. Kirby (64) has defined an approximate noniterative formula for the balancing factors, and in the calibration procedures for the SELNEC model (65), which involve a large number of runs of the model, one doubly constrained run was carried out, and the value of B_jD_j thus obtained substituted for D_j in singly (noniterative) constrained runs for other parameter values. Final results are checked with other doubly constrained runs.

This is a convenient point to mention other recent work on calibration methods. Hyman (66) has explored distribution-model calibration by constructing an evidence test (based on Bayes' theorem), which also connects closely, as might be expected, to the entropy-maximizing view of the model, and he gives an iterative method for parameter estimation that has since been used by other authors. One consequence of this analysis is that, if a power function is used as an impedance function instead of the experimental function, then the mean of log c_{ij} is the best goodness-of-fit statistic for β rather than the mean of c_{ij}. Hyman's method and other search methods of calibration have been tested by Batty and associates (67, 68, 69). The mathematical processes involved have been further explored by Evans (70), and the statistical processes by Kirby (71).

Continuous-Variable Models

Another theoretical task in the development of distribution and modal-split models that may prove useful in the longer run is the development of continuous-variable models, mainly represented in Britain by the work of Angel and Hyman. Their work will be mentioned only briefly here, and the reader is referred to the original papers for the details.

There are 2 ways in which we might seek to introduce continuous variables into the distribution model: First, take a subscript, such as the type of person index n in Eq. 17, and make a continuous variable such as income or, second, make the spatial variables continuous. The introduction of a continuous-income variable was explored by Hyman (72). One possible development of such models is to try to introduce a hypothesized, known income distribution explicitly into the model so that the parameters of such a distribution become part of the set of parameters of the trip-distribution model. Continuous spatial variables were first used by Angel and Hyman (73) in their analysis of urban velocity fields and associated geodesics—minimum time paths in these fields. They then formulated a continuous distribution model and calibrated it by using SELNEC data (74). It is interesting to note that "assignment" in such a model is the calculation of flow densities along geodesics. The network is not, of course, explicitly represented.

Aggregation, Utility, Elastic Trip Generation, Dynamics, and Other Current Issues

The model whose principal equations are Eqs. 17 and 18 can be taken as a reasonable example of the current state of the art in Britain. The equations are repeated here for convenience.

$$T^{*n}_{ij} = A^n_i B_j O^n_i D_j e^{-\beta^n c^n_{ij}} \tag{17}$$

$$\frac{T^{kn}_{ij}}{T^{*n}_{ij}} = \frac{C^{-\lambda^n c^k_{ij}}}{\sum_{k\epsilon\gamma(n)} e^{-\lambda^n c^k_{ij}}} \tag{18}$$

A^n_i and B_j are balancing factors calculated in the usual way. O^n_i and D_j are obtained from category analysis. C^n_{ij} is related to c^k_{ij} by an equation of the form of Eq. 23, and c^k_{ij} is given by equations of the form of Eqs. 24 and 25 for use in the distribution and modal-split equations respectively. Such a model was used in the most recently published report of the SELNEC study (9).

A number of criticisms can be made of models of this form: They are insufficiently connected to, and perhaps even inconsistent with, microeconomic theory; trip generation is inelastic; it does not respond to accessibility levels; the model is essentially static; and so on. As a response to these criticisms, a number of new approaches have been suggested from both sides of the Atlantic. In this section, we attempt to confront the criticisms of the model in its present form and to compare the resulting suggestions with those made by others. The argument presented summarizes one that is given in more detail in another paper (75).

It is essential to begin with a discussion of the aggregation problems involved in proceeding from a microtheory of individual or household travel demand to a model of aggregate travel demand between zones. An adequate connection between the models at the (useful) level of aggregation we use and microeconomic models can only be made if this problem is solved.

In such a discussion, we must first characterize transport as a good. Usually, we can speak of quantity x_i of good i purchased at price p_i. But for transport, 2 variables are needed to describe quantity: frequency of trips in the same time period and length of trip (perhaps measured as expenditure). Then, for an individual resident r in zone i, say, we can describe his trip-making at different levels of aggregation as follows:

1. Amount of travel consumed — C^r_i, O^r_i
2. Distribution among trip purposes — C^{pr}_i, O^{pr}_i

3. Distribution among destinations for each purpose c_{ij}^{pr}, T_{ij}^{pr}

4. Distribution among modes c_{ij}^{pkr}, T_{ij}^{pkr}

C_i^r and O_i^r represent total expenditure on travel and number of trips made. C_i^{pr} and O_i^{pr} are similar quantities split by purpose. T_{ij}^{pr} is O_i^{pr} split by destination, and c_{ij}^{pr}—in accord with our usual convention—is the cost of a single trip from i to j. When these quantities are split by mode, they become c_{ij}^{pkr} and T_{ij}^{pkr} for mode k. These variables provide descriptions of the individual's travel behavior at the 4 levels shown.

The usual entropy-maximizing model is obtained by aggregating individuals r into groups of type n, denoted by $r \epsilon R(n)$, say, and assuming that

$$\sum_i \sum_{r \epsilon R(n)} C_i^{pr}$$

and

$$\sum_{r \epsilon R(n)} O_i^{pr}$$

are given. We usually also assume that totals of trip destinations, D_j, are given.

The usual utility-maximizing model is obtained by taking variables at level 4 for individual r and finding their values by maximizing his individual utility function, probably subject to a budget constraint (76). The problem is then the usual one of how to obtain aggregate demand. For a population with arbitrary utility functions, aggregation is virtually impossible. Beckmann and Golob have indicated the range-of-utility function that makes aggregation feasible (76). There is a further difficulty: At level 4, each utility function is a function of a large number of variables. The suggestion made is that it may be much more reasonable to define individual utility function at a higher aggregation level for the individual, say, level 2, and then, having determined values of C_i^{pr} and O_i^{pr} and aggregated these over r, to use something like an entropy-maximizing method to obtain T_{ij}^{pkn} for persons of type n. The paper cited earlier (75) outlines a model based on such a scheme. At first sight, this may simply appear to defend the status quo for the entropy maximizer, but in fact a number of radical changes are suggested for the model given by Eqs. 17 and 18. They are summarized below; full details are available in the paper cited earlier (75).

1. In the aggregation scheme, we never wish to aggregate to groups larger than individuals within a zone and then to assume that we can have a model to estimate C_i^{pn} and O_i^{pn} for a person of type n. This means that the distribution-model parameter β^n should be replaced by β_i^n and calculated for each zone i.

2. C_i^{pn} can be modeled in the same way as O_i^{pn}. We have suggested that, ideally, a full economic model could be developed. However, in the way in which various techniques that are familiar to us are used to estimate O_i^{pn}, similar techniques could be used to estimate C_i^{pn}, for example, category analysis. If this is done, then β_i^n (or β_i^{pn} if we distinguish purpose explicitly) ceases to be a parameters; it is directly calculable as a function of C_i^{pn}. Further, we have now shifted the problem of predicting the change in β_i^{pn} over time to that of predicting C_i^{pn}, which task, although hard, is more feasible.

3. In aggregating to the resident's zones only, we no longer feel it necessary to use fixed-attraction constraints unless capacity constraints are definitely known to exist. Otherwise, attractiveness factors should be used, as in the shopping model (78).

4. In such a scheme, there is no reason why O_i^{pn} should not be a function of accessibility and the availability of opportunities. Thus, it seems that the best way to introduce elastic trip generation is to seek to make the estimating equation for O_i^{pn}—whether regression analysis or category analysis—elastic. The variation of C_i^{pn} over time, and the corresponding variation in β_i^{pn}, could be said to produce an elastic trip-length model.

5. One of the weakest parts of the entropy-maximizing derivation of Eqs. 17 and 18 has been that which produces the modal split. In the new scheme, this derivation is

improved. Alternatively, it could be replaced by a utility-maximizing derivation of a "market-share" type.

6. If C_i^{pn}, c_{ij}^k, and O_i^{pn} can be modeled as functions of variables whose time behavior can be predicted, then we have the basis for a fully dynamic model.

The model that results from applying these recommendations can be summarized as follows (75):

1. Calculate the spatial distribution of activities that generate transport flows, capacity constraints at destination trip ends, and modal and person-perceived interzonal travel costs. All these quantities are inputs to the travel demand forecasting model, but some of them, such as the interzonal costs, can only be finally obtained within an iterative scheme that involves running the travel model with preliminary estimates of their values.
2. Calculate C_i^{pn} and O_i^{pn} as functions of the variables listed above.
3. Divide destination zones into sets Z_1 and Z_2, where Z_1 is the set of zones in which destination capacity constraints "bite," and Z_2 is the set in which they do not. [This technique of building a hybrid model by dividing zones into sets of different characteristics was first introduced in a residential location context by Wilson (79).] Then, for trips from i to j by person of type n for person p,

$$T_{ij}^{pn} = A_i^{pn} B_j^p O_i^{pn} D_j^p e^{-\beta_i^{pn} c_{ij}^{pn}} \tag{30}$$

for $j \epsilon Z_1$ and

$$T_{ij}^{pn} = A_i^{pn} O_i^{pn} X_j^p e^{-\beta_i^{pn} c_{ij}^{pn}} \tag{31}$$

for $j \epsilon Z_2$, where D_j^p is the destination capacity, and X_j^p is the destination attractiveness when a constraint is inoperative. (The makeup of the sets Z_1 and Z_2 can only be discovered after a preliminary run through the model.) The balancing factors A_i^{pn} and B_j^p are determined in the usual way (though the resulting equations are slightly unusual because of the sets Z_1 and Z_2), and β_i^{pn} is directly calculable from C_i^{pn}.

4. Modal split is given by

$$M_{ij}^{pkn} = \frac{e^{-\lambda_i^{pn} c_{ij}^k}}{\sum_{k \epsilon \gamma(n)} e^{-\lambda_i^{pn} c_{ij}^k}} \tag{32}$$

so that

$$T_{ij}^{pkn} = M_{ij}^{pkn} T_{ij}^{pn} \tag{33}$$

λ_i^{pn} may well be taken as independent of i.

5. Assignment can then take place in the usual way as part of an outer interative loop.

It is argued, then, that the revised model presented here represents a framework within which many of the outstanding problems in travel demand forecasting can be solved. The research needed to implement such a scheme is clear from the above description, and much of it can be carried out with data and methods that are already available or well known.

We can now explore how this approach relates to others that have been suggested, beginning with utility-maximizing approaches. It should be clear that a utility-maximizing approach can only be adopted if the aggregation problem is solved. It will not do to call the entropy function utility. [Beckmann and Golob (76) come quite close to this at times, but do also attack the more general problem that was first explored by Neidercorn and Bechdolt (80).] What has been suggested here is that there is an aggregation level at which economic theory and utility maximizing should be helpful (and best) and another, finer level at which entropy maximizing remains the most useful procedure.

Another new approach is represented by Manheim's class of general share models (50). We need only remark here that the model presented above is one such model. Manheim's approach is an alternative to entropy maximizing for the task of producing internally consistent models. The proposals in this paper attempt to add a certain amount of flesh to the bones.

One word of caution should be added about another alternative approach, entropy-maximizing models based on a certain kind of market share variable (81), that uses

$$x_{ij} = T_{ij} c_{ij} \tag{34}$$

or

$$x_{ij} = \frac{T_{ij} c_{ij}}{C} \tag{35}$$

where C is total expenditure. It is argued in an appendix to the earlier paper (75) that there are fundamental reasons why such models are unrealistic.

The whole range of alternative models is reviewed by Brand (82). It is a useful exercise to relate the conclusions of this paper to the issues raised by Brand in relation to the general classes of models that he discusses.

The classifications of models used in Brand's paper are based on his interpretation of the assumptions that are made about an individual traveler's choice within different kinds of models. Thus, the traditional model, in the sequence of trip generation, distribution, modal split, and assignment, connects to notions of the traveler making a sequence of choices about frequency, destination, mode, and route. Such models are called indirect demand models in contrast to direct demand models, which connect to multiple and simultaneous choice notions. The rather loose words "connect to" have been used above because the nature of the connections cannot be made clear unless the aggregation problem (how to get from a micromodel of individual choice behavior to an aggregative model) is solved for the particular models under discussion.

There is one general issue that is useful to tackle at the outset: Some aggregative models (which are used and are useful) do not necessarily imply the microassumptions that have been assigned to them by commentators. Thus, the traditional model does not necessarily imply a certain sequence of decisions on the part of the individual traveler, but only a certain conceptualization of the model-building process that leads to some final model that then stands or falls on its own. Further, it is often considered a difficulty in such models that "late-stage" information, e.g., on link flows and speeds, is needed at an earlier stage and that, therefore, an iterative solution to the model equations is the only possible one. There is sometimes a confusion between this kind of iteration or a mathematical technique for solving equations (which is all it is in this case) and microinterpretations of what the model represents.

In summary, then, 2 main issues run through Brand's review: multiple choice (direct demand) versus sequential choice, with or without iteration (indirect demand), on the one hand and degree of disaggregation with respect to individuals on the other.

It is clearly useful (and has been attempted in a different way in the main discussion of this subsection) to investigate the nature of rational choice at an individual level, and Brand's discussion of such topics as rational choice behavior and utility maximization is most useful. However, again, care must be taken because it is possible for microassumptions to be unnecessarily and even unreasonably attached to aggregative models that are then criticized because of these assumptions. There is little doubt that large-scale empirical investigation (if this were possible) of individual behavior would reveal behavior that could be explained by using either decision theory or utility theory. The likeliest outcome of such research, however, would be that the population as a whole exhibited a wide variety of choice mechanisms or a wide variety of utility functions. It could then be argued that a procedure such as entropy maximizing could be taken as a statistical average across this wide variety of individual behavior. Further, the aggregation explorations in the main part of this paper simply examine alternative levels of resolution (83) at which different kinds of analysis can be carried out, e.g., the $\{O_i^{pn}, C_i^{pn}\}$ level for utility maximizing and the $\{T_{ij}^{pkn}\}$ level for entropy maximizing. It does not make any assumption about choice-ordering on the part of the individual traveler.

Thus, the main point to be made here is that, although it is most interesting to explore the possibility of building new models by finding ways of aggregating alternative micromodels of choice behavior or utility maximization, other aggregative models should not necessarily be criticized for microassumptions that their builders do not subscribe to! Further, because of the difficulties of solving the aggregation problem (84), we should note that the models that can be built are likely to have very restrictive assumptions built into them that certainly do not reflect the hybrid-varied nature of the real-world situation.

It seems that many of the criticisms of the traditional model are, in effect, directed at the BPR form of the model, largely because of (a) its internal inconsistency and (b) its inadequate connection with microtheory. What we have tried to show in this section is that a model of this type can be made internally consistent and is compatible with a wider range of microassumptions than most alternative models. By making an appropriate judgment about the level of resolution at which to apply microeconomic theory, the model can be extended and the advantages of a utility-maximizing model of transport consumption incorporated.

This is a convenient place to raise 2 additional points that arise in relation to topics discussed in Brand's paper. First, one of the elements of choice is the time of day at which the trip is made. Although this has not been modeled explicitly in British studies, it is perhaps worth commenting that it has been more often the case in British studies that peak-hour trips have been modeled explicitly rather than 24-hour trips. The second and final point is a somewhat disconnected one and relates to the work of Lancaster (85). Brand points out how this work has been used, for example, by Quandt and Baumol (141) and by Blackburn (87) to produce certain kinds of direct demand models. Mathur (88) and Allen (89) have also discussed the possibility of applying Lancaster's theory to spatial interaction models in the context of Neidercorn and Bechdolt's work. In Britain, Lancaster's ideas have been used in a different way by Evans (90) to investigate the time constraints that relate the consumption of different bundles of characterization and, hence, to say something about the value of time that results from the relaxation of these constraints. This has an obvious relevance to issues of importance in transport studies. Following Evans, this author has explored other ideas, particularly the notion of opportunity gaps. An alternative and interesting approach to time-constraint problems is through-time budget analysis, following partly from Swedish work, and investigated in Britain by groups in London and Cambridge, the latter using entropy-maximizing methods (92, 93, 94).

ASSIGNMENT

It is clear from the length of the preceding discussion that distribution and modal split are considered in this paper to be at the heart of the travel demand forecasting process. Assignment is seen then as having 2 main roles: First, network loadings are useful for engineering purposes; second, the assignment procedure must constrain interzonal travel costs to be related to link loadings and link travel times. There is always the problem that this can only be accomplished in an outer iterative loop in the model because c_{ij} is needed in the distribution and modal-split model, which must precede assignment. This outer iteration is now an accepted part of most British assignment procedures, for example, in London and SELNEC. In essence, this balancing of travel cost against link loads is the so-called capacity-restraint procedure. A variety of such procedures have been used in British studies.

A particular problem mentioned earlier that has occurred in the British context is that no amount of capacity-restraining adjustment will remove link congestion. A special linear programming procedure was developed in phase 3 of the London Transportation Study (5, 143) to overcome this. The problem is that the method has no behavioral basis: What is really necessary is an elastic-trip-generation model.

Assignment takes place on separate modal networks, and most experience, of course, is with highway networks. One British contribution to the public transport side is the Freeman, Fox, Wilbur Smith TRANSITNET assignment program, which calculates minimum paths for a network on which public transport routes and service levels are specified (144). Another approach to assignment by a team at the Transport and Road Research Laboratory has relevance to this (and other) problems. Wigan and Bamford use an iterative perturbation method for assignment to congested and overloaded networks, and the same model has also been used to study the impact of road pricing schemes (95, 96).

Finally, a theoretical comment: It is tempting as computer capacity expands to think of assigning on multimodal networks—in effect, possibly directly to routes on an abstract modal basis. It has been shown that, except under rather special conditions, such a procedure would lead to a model that has unrealistic features: That is, inconsistencies arise because the axiom of independence of irrelevant alternatives (as discussed by Brand) is not satisfied. This is another example of a class of mathematical aggregation problems (47, 84).

Finally, we note that relatively little empirical work has been carried out on route choice, though there is one recent European contribution (97).

URBAN-ACTIVITY MODELS

Predictions of travel demand using the kinds of models that have been discussed can only be as good as the inputs to those models. In particular, travel demand in a city region is a function of the spatial distribution and intensities of population and organizational activities. Predictions of such quantities are, of course, needed for general planning purposes that extend far beyond transport planning. If such predictions are to be at least informed by models, if not completely made by models, then at least the following models are required: demographic models for the study area as a whole and probably operating for a multiregion system; economic models for the study area as a whole; models of the location of population activities—residential and workplace location and the utilization of a whole range of services; and models of the location of economic activities. Travel demand models can then be connected to such a model system. The future pattern of travel demand will be determined more by the spatial distribution and intensity of these activities, and associated parameters such as car ownership and overall income levels, than by specifically transport-system parameters.

Because each of the urban subsystems interacts more or less with one another, this model set should be combined into a general urban model in which these interactions, and the relative time rates in which the different processes involved take place, are explicit. First, however, we comment on British and European work on each of the 4 models listed above and then discuss the task of building a general model. So as not to overload the paper (for this section could be much larger than the rest of the paper put together), the discussion will be inadequately brief, but reference will be made to other review papers and to the appropriate literature where particular innovations are cited.

Demographic Models

The population forecasts associated with transportation studies are usually particularly simple (98), perhaps dangerously so. The set of models developed by Rogers (99, 100) can be used for this purpose, but there has been some reluctance to do so in Britain, possibly because it is relatively difficult to match the data requirements of the model. Recent work in Leeds (101, 102) has aimed at simultaneously improving the model's base and confronting the data problems, and the results appear to be very promising.

Economic Models

More intensive theoretical work has been carried out on the task of building input-output models for urban areas, but again the difficulty is one of finding data that will enable an input-output table to be constructed. Thus, effort has been concentrated on a small number of studies for which such data are directly collected (103, 104) and a larger number (105) that attempt to construct small area tables from national tables plus, say, local row and column information.

It is appropriate under this heading to add a note on car ownership, which is likely to be very much a function of the level of economic development. Much work has been carried out on building submodels of this (106, 107), and this determines the population in the main subdivisions of person types required for the transport model. The next stage of this kind of work is to estimate the car availability for different types of people, but relatively little progress has been made with this as yet (108).

Population-Location Models

Considerable progress has been made on both sides of the Atlantic with models of the utilization of the more obvious services, such as retail services (109, 110). The use of such models is relatively commonplace, and little more need be said [though there are needs for obvious refinements such as making the models mode sensitive (111)].

A much more complicated problem is that of building models of residential and workplace choice. The traditional models are simple gravity models. These have been extensively used, but, although they can give some useful guidance (79, 112), they obviously underrepresent the richness of the real-world situation—different types of people who have different incomes and jobs and live in different types of housing that vary in price. Models are now being built that attempt to reflect this richness (113, 114, 115) and there is some indication of success. As with transport models themselves, this particular model-building problem can be tackled from the viewpoint of microeconomic theory, and, although relatively little operational work in this field has been achieved on the British side of the Atlantic, more can be expected in the future. Some attempts have been made, which again give indications of success, to integrate the 2 styles of approach (117, 118, 119, 120).

Economic-Activity-Location Models

It has proved even more difficult to build models of economic-activity location. This can also be seen as a 2-stage operation: first, to model the distribution of economic activities by sector and, second, to collect where necessary what may be called the population-perceived distributions of housing, jobs, and services. One of the main reasons why these sectors have proved more difficult to model is that a relatively small number of decision-makers (relative, say, to the population as a whole vis-à-vis population activities) may be involved in the determination of a spatial pattern, especially when government is involved. In the latter case especially, this can be a saving grace for the modeler because he can take a range of possible decisions as input to other (e.g., population activity) submodels rather than model them directly. The relatively modest achievements in this field will, in fact, be reported in the next section because they were made in a "general" model context.

General Models

Perhaps the most obvious way to build a general model is to take the best available submodels from the wide range of work described above, to investigate the submodel interactions in some detail, and then to build the appropriate general model. However, this is harder then it sounds, if only because the best submodel work probably involves people whose main expertise is in relation to the corresponding subsystem, and it is difficult to assemble the best subsystem expertise plus corresponding general model-building expertise in one team. At present, however, some progress has been made theoretically with this strategy (121).

It is more tempting for people who wish to build a general model to start from some such existing model and to try to apply and to improve it. In Britain, the favorite starting point has been the Lowry model. Much interesting work has been carried out in this way, and the results are well documented (18, 21, 122, 123, 124, 125). Of course, the point could be reached, and perhaps has been reached, where the final improved model looks very unlike the original. Another approach has been to use econometric models based on EMPIRIC (121, 126, 127), and it is in this context that some models of the location of economic activities have been developed. It is particularly important to build explicitly dynamic models, and a start has been made on this (128, 129, 130).

USE OF TRAVEL DEMAND FORECASTING MODELS

It has been argued, in more or less similar terms by several authors (19), that planning processes contain 3 kinds of activity concerned with analysis (understanding, tracing impacts, problem diagnosis), design (generation of alternative plans in relation to the full range of possible policy instruments, including land use and spatial organization), and policy (methods and criteria for choice among alternatives). Travel demand and associated models offer different kinds of aid to these different aspects of planning processes. This is not the place to spell them out in detail or to give case histories, but a number of general comments are appropriate.

Perhaps the most important development in the past 20 years has been our changing view of the transport problem. In the beginning, the transport planner's task was conceived of as building highway facilities that would carry the traffic loads generated at saturation car-ownership levels 20 or 30 years hence. Now, and especially in a European context, we see that such simple objectives are not compatible with the structure of our cities, or we cannot afford the facilities—they are simply infeasible. So we now look at many modes, at impacts on different groups of people in different parts of the city (because we are more socially conscious), and at several time horizons (short, medium, and long term); and then we try to set the plans in the context of the structure of the city as a whole (19). In Alexander's (131) terms, we are becoming more fully self-conscious with respect to all aspects of our planning options.

In Britain, some progress has been made along this line: The full variety of modes is now taken seriously in the model; a greater range of network alternatives is examined; some disaggregation has been achieved in the evaluation indicators, whether in a cost-benefit analysis framework or structure; some progress has been made in testing the transport impacts of alternative land use plans. These trends have affected the travel demand models in the manner described in earlier sections, and they raise ongoing issues to be discussed in the next one.

ONGOING ISSUES IN RESEARCH AND DEVELOPMENT

Comments about ongoing issues can be made in relation to 3 statements:

1. In relation to the travel demand model itself, we must be getting very near to the point of diminishing returns in attempting to improve the model as we know it (though we should leave open the possibility of new kinds of models emerging).

2. The main variables that determine the changing patterns of transport demand, and the associated planning problems, probably mostly lie outside the travel demand model—in particular, economic development and car ownership, population growth, and urban spatial organization. Thus, the travel demand model should be connected to a more general urban model.

3. The model system that is developed must be able to play its part in a responsive, adaptive overall planning system. There will be new issues and problems to be faced on a continuing basis.

The consequences of these statements are explored in turn.

Travel Demand Model

For given inputs, the travel demand forecasting model as we know it is a reasonably good tool. It is unlikely that a refined assignment technique, for example, will fundamentally change its character and its present degree of fit. However, in terms of possible future research projects, a number of points can be made.

1. A formal "drawing-together" operation may be useful, repeated every 5 to 10 years, to make the "best possible" model—or more realistically a range of such models—generally available.
2. A modest program of funded research on the model as we know it will remain worthwhile (earlier sections raise a number of good research problems).
3. It will always be worthwhile to investigate new kinds of models, such as utility-based models, general share models, and so on, though the practical need is not so great that more than modest funds should be associated with such projects. (Some of the problems in such fields involve fundamental theoretical problems of the mathematics of aggregation, which have not yet been fully understood as problems, and caution should be exercised before new approaches are accepted as much better than, or even very different from, older ones.)
4. Another modest research program that systematically compares different types of models, with respect to their prediction of elasticities, for example, might be useful.
5. It would be valuable, for reasons that have been partly discussed and that rise again below, to investigate ways of making the travel demand model quick and cheap to run, for example, by using census data so that special surveys are not required.

Connecting Travel Demand Model to General Urban Model

We argued in earlier sections that work on general model building continued in Britain long after it slowed down in the United States. The British work has been less ambitious, in the first instance, and so has generated fewer traumata than corresponding American work. It has been modestly useful to planners. In Britain, we are perhaps now poised to become significantly more ambitious and, in the end, to be correspondingly more useful to planners. The conclusion seems inescapable that there should be considerable research investment in this field, whether it be called research on general model building or, more simply, on urban structure and dynamics.

Response to New Planning Problems

Planning problems can arise at very general levels or in relation to very specific issues. At the general level, given the models discussed in the sections immediately above, we need an exploration of the range of possible futures as we could now visualize them. This is rarely, if ever, attempted in a whole system kind of way. We have to decide whether to go on accepting low densities and processes of decentralization or, if we find aspects of these that we dislike, whether there are feasible alternatives. We have to match an exploration of alternative future transport systems against broad investigations of that kind.

At more specialized levels, as we saw earlier, we have to confront new issues. We seem to be moving into an era, at least for British cities, in which large highway building programs are recognized as infeasible. The alternatives before us are more likely to be stated in terms of public transport options (in relation to urban structure and densities), pedestrianization of city centers, the scale of out-of-town shopping facilities, traffic management, road pricing, parking control and bus-priority schemes, new schemes of compensation for those affected by development, and so on.

Relatively little research has been carried out on the methods of generating alternatives for testing and optimizing the program of implementation (133, 134, 135, 136, 138, 145). The short-run objective is perhaps simply to ensure that a wide range of possible futures are explored. In the longer run, we should investigate ways of being more systematic (139, 140).

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