WORKING PAPER 441

ON THE DESIGN AND IMPLEMENTATION OF AN INFORMATION SYSTEM FOR URBAN MODELLING AND SPATIAL PLANNING

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1. INTRODUCTION

The initial wave of urban models, stemming from North America in the late 1950s, was founded firmly on the principles of simulation: that is, the objective was seen as the reproduction of urban structure, from which predictions and projections could be made. In relation to this class of models, Batty (1980, p181) observes that they

> "were policy-oriented from the beginning and the need to provide workable computer simulations has meant that such models have always been characterised by rudimentary theory."

This modelling philosophy became the subject of a searching critique in the mid-70s, especially from Lee (1973) and Sayer (1976).

One of Lee's objections is explicitly directed against the role of computers in the modelling process. It is interesting to observe that as long ago as 1973 he was arguing that "bigger computers simply permit bigger mistakes" (p169). In the light of the rapid advances in computational technology in the last decade, such an analysis would imply a truly enormous scale and variety of possible errors in 1985! In spite of the dangers, however, the continued application of these powerful technologies to the field of urban modelling provides a challenge in which the potential rewards are rich. One of the themes of the present paper might therefore be paraphrased 'bigger computers permit better insights'.

The second aspect highlighted by Batty - rudimentary theory - is a less tractable weakness. In Sayer's critique there are essentially three different prongs to the attack on the theoretical naivete of urban models. These are their static nature, the excessive focus on the demand-side at the expense of the supply-side, and a focus on the wrong kinds of actors within the urban system. Of course it is in relation to both dynamics and supply demand interdependence that many of the most exciting theoretical advances have been made in recent years and this provides us with at least a partial response to this type of criticism.

A third type of problem which still needs to be dealt with is the relative paucity of applications of urban models in a planning context. Among the problems here are a lack of human and financial resources for model specification and data collection, and a less tangible scepticism of the utility of modelling procedures in the planning process. This scepticism has undoubtedly been fuelled in the past by the failure of modellers to produce the good results which have been extravagantly promised.

The objective of the present paper is essentially to attempt to harness new computational and modelling power within a framework which is useful for planning. In order to do this we need to ease rather than exacerbate the problem of data collection, and also to elucidate rather than obscure the mode of operation of the underlying models. This may be seen as an attempt to revitalise the concept of the 'Planning Information System', which was seen as a panacea in the late 1960s but foundered in the subsequent backlash (cf. Birkin and G.Clarke, 1985: G.Clarke and Wilson, 1985).

In Section 2 we try to put some flesh on the rather bare bones of the argument of this introduction by outlining the key elements of such an information system. An example is then developed for the city of Leeds to illustrate the potential of the approach in Section 3. We focus throughout Sections 2 and 3 on the case of urban retailing, which has attracted the greatest empirical and theoretical interest in our earlier work (e.g. Harris and Wilson, 1978: M.Clarke and Wilson, 1983: G.Clarke, 1985). The accumulation of further data for both the retail case, and for other urban subsystem models, remains an ongoing research objective in parallel with the type of analysis described in this paper. Section 4 is then an attempt to draw out some theoretical implications in relation to both the partial and comprehensive cases.

2. AN INFORMATION SYSTEM FOR FACILITY LOCATION PLANNING

2.1 Introduction

In the next two sections of the paper we focus on the example of urban retailing. The question to be addressed is how we may develop an appropriate and powerful framework for system evaluation. It is this framework which we refer to as an 'information system', following Nijkamp (amongst others) who defines an "urban information system" as

> "a set of data structured ... so as to increase the insight or level of knowledge regarding the spatial dimensions of urban phenomena, especially from the viewpoint of forecasting and influencing urban structure and processes." (1985, p208).

In particular, we should not confuse this with the concept of a Geographical Information System (GIS), being typically concerned with the efficient organisation of very large amounts of spatial data (e.g. Marble et al, 1984).

In Section 3 of the paper we shall attempt to demonstrate how large amounts of INFORMATION may be extracted from the most primitive of DATA bases. This section is more general in scope. Section 2.2 focusses on the definition of subsystem variables, and the interconnections between them, the latter comprising a set of static, model-based theories. Temporal issues are addressed in Section 2.3, thus providing a basis for projection and prediction. A set of spatial design issues which are also crucial to the modelling approach are discussed in Section 2.4. An information system covering the location of retail facilities in urban areas may then be constructed from the various elements, as in Section 2.5.

2.2 Problem Definition and Sectoral Issues

The organisation of urban retailing may be seen as the outcome of a series of interactions between a set of 'producers' with goods for sale, and a set of 'consumers' purchasing those goods. If we assume that the action takes place on a discrete spatial network then we may let $\{P^m_i\}$ be the population of type m residing in zone i, and $\{W^g_j\}$ be the provision of goods type g in zone j. An individual type m at i may be assumed to demand a quantity $\{e^{mg}_i\}$ of good g, and to have a set of trip costs to facilities given by the array $\{c^m_{ij}\}$. In this situation the interactions between the two sets of actors in space may be given by the relation:

$$S^{mg}_{ij} = A^{mg}_i \, e^{mg}_i \, P^m_i \, (W^m_j)^{\alpha^{mg}} \exp(-\beta^{mg} c^m_{ij}) \tag{1}$$

$$A^{mg}_i = 1 / \sum_k (W^g_k) \exp(-\beta^{mg} c^m_{ik}) \tag{2}$$

– the so-called Huff model of retail trade (Huff, 1964; Lakshmanan and Hansen, 1965), where $\{\alpha^{mg}\}$ and $\{\beta^{mg}\}$ are appropriate parameter sets. In terms of the discussion of Section 1 it is important to regard the model of (1), (2) as a THEORY about the way in which consumers and producers interact, and not just an empirical observation. This theory may be derived in a variety of ways (Bertuglia et al, 1984) the best known of which is statistical averaging (Wilson, 1967, 1970).

Given the interaction model above and the variables defined so far it is possible to define a set of residential PERFORMANCE INDICATORS which describe the equity of the allocation mechanism in relation to the various consumers (e.g. Wilson, 1984; G.Clarke and Wilson, 1985). Some examples of the kind of indicators which might be defined are given in Table 1.

The next step is to ask how we may define a corresponding set of indicators for the suppliers, which could then be taken as measures of efficiency in the system. Obvious supply-side indicators are the revenues generated by particular zones, and the associated costs of provision. If the price of a good g at j is p^g_j then the revenues are:

$$D^g_j = p^g_j \sum_{im} S^{mg}_{ij} \tag{3}$$

while costs might be taken as:

$$C^g_j = W^g_j \sum_r a^{rg}_j k^r_j \tag{4}$$

where $\{k^r_j\}$ is the cost in j of an input to the production process, r; $\{a^{rg}_j\}$ the quantity of r required per unit output of g in j.

It might also be interesting in certain circumstances to define the catchment populations for particular zones by good e.g.

$$\pi^g_j = P^m_i Y^{mg}_{ij} / \sum_{jg} Y^{mg}_{ij} \tag{5}$$

This is the 'proportionate flow method' although many alternatives are possible (e.g. Cottrell, 1983). From these derived variables a set of facility-based indicators might then be constructed, as in Table 2.

Finally, it is possible to aggregate any of these indicators across either the supply or demand-side to produce aggregate system-wide summary measures. Some of the more useful ones are shown in Table 3.

2.3 Dynamics

We observed in Section 1 that one of the most important developments in modelling in the late 1970s was the inclusion of supply-side dynamics. The key step here is to assume that changing activity levels can be built in as a function of supply-side performance. At its simplest, this mechanism can be expressed as a linear function of profitability:

$$\dot{W}^g_j(t) = \varepsilon^g (D^g_j(t) - C^g_j(t)) \tag{6}$$

for an appropriate parameter set $\{\varepsilon^g\}$. In the dynamic model, the system variables are now time-dependent of course.

If the supply-side is allowed to develop freely from structural change in the rest of the system, then an equilibrium will clearly be reached where:

$$D^{g}_{j}(t) = C^{g}_{j}(t) \tag{7}$$

as in Harris and Wilson (1978). As an aside we may observe that the indicator $N^{F10\,g}_{j}$ (see Table 2) now provides a measure of the distance of the system from equilibrium, the structure of which may be evaluated by solving the equations (7) directly in $\{W^{g}_{j}\}$ [through (1), (2), (3) and (4)]. The rate at which the equilibrium is approached depends on the parameters $\{\varepsilon^{g}\}$ in (6). Three potential modes of model operation are now implied, which may be called 'static', 'comparative static' (i.e. equilibrium-seeking) and 'dynamic'. We return to this in Section 2.5.

The actual dynamic of the system is, however, complicated by the fact that $W^{g}_{j}(t)$ is not the only variable which is subject to temporal adjustment. In reality all the parameters and structural variables in the model may be assumed to be developing over time in response to either endogenous or exogenous impulses. In particular, it is somewhat ironic that in models which were once considered to be excessively demand-dependent, the dynamic focus is now almost always on the supply-side at the expense of the demand-side. We return to this problem in Section 4 below.

2.4 Issues of Spatial Resolution

The issues associated with spatial aggregation are among the thorniest of those facing the model-builder. There are two distinct aspects to this problem concerning the choice of the overall spatial SCALE or the number of zones required for the analysis; and the optimal CONFIGURATION of those zones (cf Batty, 1978). This discussion is itself founded on two prior assumptions. The first of these is that the spatial scale of the overall system of interest has been defined, and this is an exercise which in itself must be undertaken with great care and with regard to the purposes of the analysis. Secondly, we assume that there exists a data set at a FINER spatial scale than that required for the analysis. These zones are usually referred to as basic spatial units (bsu's) e.g. Openshaw (1977a). The problem is then how to aggregate or partition the set of bsu's into a set of model zones (a 'zoning system') in some optimal or satisfactory way.

The problem of spatial scale is usually approached with reference to some kind of external and arbitrary rule of thumb. The most popular of these in relation to interaction models is Broadbent's (1970) rule that intrazonal interactions should be limited to a threshold, usually 10-15% of total trips (e.g. Barras et al, 1971; Masser and Brown, 1975; Masser, Batey and Brown, 1975). In the case of journey to work trips, for example, this kind of rule can be extended to develop arbitrary formulae for the zone size. For a distance deterrence parameter, β, the mean trip length is $1/\beta$ and an average zone radius of $1/10\beta$ will generate 90% interzonal trips (Barras et al, 1971).

Of course one problem with this approach in a comprehensive (multi-subsystem) context is that different submodels may imply different optimal scales of zoning. Thus the residential zoning patterns implied by a journey to work model would probably be in conflict with those implied by a retail model. The same will also be true of disaggregate situations, so that to generate 90% interzonal interactions for low-order goods and services we would expect to require a rather larger number of zones than for higher order goods. These kinds of conflict imply the need for flexibility in zoning i.e. the adoption of different systems for different phenomena even though the basic data units may be identical. Furthermore, this is a strong argument for the inclusion of the zone design procedure within the overall modelling process.

This argument for flexible zoning systems is phrased even more strongly (if implicitly) by Openshaw (1977a,b, 1978), who believes that the theoretical properties of such systems are so little understood that we should adopt the more pragmatic approach of selecting zoning systems to optimise model performance in some respect. Openshaw also demonstrates most clearly the effects of zone design on model performance, this work emphasising most effectively the importance of good zoning systems.

An alternative approach to zone design which may also be thought of as pragmatic is that of Masser, Batey and Brown (1975, 1978). Their idea is essentially an extension of Broadbent's intrazonal trip criterion to the whole zone design problem. Thus the performance of a given set of zones can be assessed in terms of a wide variety of criteria such as equality of population, compactness and intrazonal homogeneity. Bsu's may be juggled into zones so that certain minimum requirements are met on these criteria, and any further improvements may then be regarded as a 'bonus'.

What is lacking in both of the two approaches discussed above is a satisfactory THEORETICAL basis to the zone design problem. Without an understanding of the nature of the problem it is surely impossible to assess any practical solution. In this respect the work of Batty on spatial entropy (e.g. Batty, 1978; Batty and Sikdar, 1982) is crucial since it provides a route into understanding the aggregation problem in terms of a loss of information as bsu's are combined. Once perfected, this method might at last offer an approach to optimal zone design which is both meaningful internally consistent.

2.5 Overall System Design

In Sections 2.2 2.4 we have tried to identify the principal components of a model based 'information system'. It is now necessary to try and synthesise these disparate elements. The first step in the problem is to define the region of interest, perhaps in a hierarchical fashion (e.g. region of major interest, region of secondary interest, external regions). These regions must then be dissected into demand zones and an appropriate set of supply points selected. As we indicated in Section 2.4 above, there are good reasons why such a procedure might be included within the actual modelling process. For present purposes however we have defined this task externally since a full enough database to make the internalisation of the zoning process worthwhile is not yet available.

The problem of spatial system definition is clearly intimately linked to data accumulation since it would be pointless to define systems for which data cannot be extracted or reliably estimated. The variables identified in Section 2.2 are broadly of three types: there are those which must be provided for any kind of model operation, those which need never be provided, and those which may or may not be available in particular circumstances. A typical set of assumptions about these variables is given in Table 4. We assume that the minimum information available is the zonal populations and their expenditure, a trip cost matrix and the suppliers' cost structure. An observed interaction matrix $\{S^{mg}_{ij}\}$ may or may not be known - if it is, then $\{\alpha^{mg}\}$ and $\{\beta^{mg}\}$ may be calibrated: otherwise known or estimated values of alpha and beta may be used to compute the interactions endogenously. Similarly if floorspace distributions are not known then comparative static and dynamic analyses (in the style of M.Clarke and Wilson, 1983, for example) may still be conducted. If $\{W^{g}_{j}\}$ is known for some base year t_0 then static analysis may be carried out and projections based on assumed ε^{g}. Finally, if a time series is available, then ε^{g} itself may be calibrated. The price of goods is also an optional variable which may be defined exogenously or allowed to vary spatially in response to changes in profitability.

We assume here that the balancing factors $\{A^{mg}_{i}\}$, catchment populations $\{\pi^{g}_{j}\}$, revenues $\{D^{g}_{j}\}$, and costs $\{C^{g}_{j}\}$ are always calculated endogenously. In principle, however, even some of these restrictions could be relaxed - for example if we knew turnover and cost figures, these could be used to generate estimates of the input costs internally.

The availability of data and hence the determination of exogenous, optional and endogenous variables determines a process of MODEL DEFINITION. Within the model so defined there exists a variety of MODES OF OPERATION. There are two types of distinction here. The first is temporal, that is the model may be run in static, comparative static or dynamic modes as described in Section 2.3. Static options would be used to calibrate a model for an existing situation, or to calculate the 'performance' of the existing system state in terms of the indicators discussed in Section 2.2. Comparative static modes comprise an attempt to assess the underlying logic of the existing distribution. This then provides an aid in interpreting system dynamics, as changing states are evaluated incrementally.

The second type of distinction is between CURRENT and BASE modes. Base mode usually represents an existing pattern/ dynamic/ plan. A current procedure then represents an attempt tp monitor the effect of changing parameters or structure variables on the system's performance e.g. to assess the impact of new centres or to test the stability of equilibria with respect to key agencies.

Once the mode of operation has been selected, the various modelling operations are conducted: interaction measures are calculated and, if necessary, the appropriate structure variables (conventionally floorspace, but potentially involving items such as rents and prices too - see Birkin and Wilson, 1985). The outcomes of the modelling process must then be evaluated, again using the performance indicator framework.

The types of indicator considered range from straightforward activity measures such as total floorspace or per capita demand through to more complex indices of accessibility and consumers'/ producers' surplus. Measures such as total floorspace, or changes in total floorspace, reflect more traditional uses of these kinds of models, especially in terms of facility location planning and consequent impact analysis. On the other hand, indices of accessibility or welfare lead us more formally into the realm of social geography and questions of equity versus efficiency.

Whatever indicators are chosen, the objective is to provide large amounts of information which must be collated and assessed by the planner himself. We therefore see the kinds of modelling which we are advocating as a TOOL for analysis. In relation to 'expert systems', we see decision-making as the function of the ANALYST, and it is important to force an understanding of the way in which models operate and, more importantly, of the way in which they represent real world processes.

As an aid to evaluation, the issue of REPRESENTATION is crucial. Thus it is necessary to provide clear and intelligible summaries of model outputs which are easy to interpret. This is one of the ways in which modern computational developments (high resolution graphics, spreadsheeting etc) are of some importance, although simple enhancements in processing speed are also crucial in the development of both interactive and batch systems.

The whole procedure is summarised in Figure 1.

3. AN EXAMPLE APPLICATION

3.1 Data-base Construction

For illustrative purposes, we have decided to concentrate on a single composite good (all retail sales) and a single population group for the base year 1981. Data was available for 33 shopping centres in the area of the pre-1974 Leeds C.B. (G.Clarke, 1985): this area is effectively embraced by 24 of the 33 wards of the 1981 Metropolitan District. This 24 X 33 zone spatial system is illustrated in Figure 2. While clearly rather coarse, it is rather convenient for representation and interpretation of model outputs. We discuss a more disaggregate case in Section 3.6.

In order to correctly represent income and expenditure distributions across the origin zones, it is necessary to construct average expenditures from disaggregate data. Expenditure patterns are available for Yorkshire and Humberside from the Family Expenditure Survey of 1981 for the weekly outlay in four expenditure categories by 8 social groups; and for the percentage of spending on 6 types of good. On the assumption that the regional figures may be applied to the Leeds area, it is easy to derive the expenditure of each social group by type of good. These multipliers may be applied to disaggregate population measures derived from the 1981 census to obtain the average expenditure patterns, while a simple summation across social groups provides the population inputs.

Total floorspace estimates were available for the 33 shopping centres from a survey by one of the authors (G.Clarke, 1985). To generate a crude measure of average costs, we assumed here a single input for which $a_j = 1 \; \forall \; j$, and invoked two further assumptions: that average costs are equal across zones; and that there is a whole system equilibrium between revenue and costs i.e.

$$\sum_j D_j = k \sum_j W_j \quad \Rightarrow \quad k = \sum_j D_j \Big/ \sum_j W_j \tag{8}$$

Finally, for the cost matrix we will use the euclidean distance between ward centroids and shopping centres.

While many of these assumptions may be seen as excessively arbitrary, the objectives of this section are primarily illustrative. Only in sub-section 3.6 and then Section 4 will we attempt to summarise the kinds of addition which will greatly enhance the scope of the empirical application.

3.2 Static Analyses

Since data on interactions is presently unavailable, the first thing we need to do is to generate some plausible values for alpha and beta. In the case of alpha, this is relatively easy: the power function, which relates floorspace to net attractiveness (equation (1)), is independent of the scaling of W_j and experience suggests a value around 1.1[1] to be quite reasonable. Beta is more problematic, since the negative exponential function induces a dependence on the relative dimensions of the cost matrix. We can study the effect of beta by focussing on one of our whole system performance indicators, the total expenditure on trip-making in the system (see Table 3). Some results are shown in Table 5 where we can clearly see that values of beta around 2.0 imply a very low degree of dispersion relative to the nearest centre case. In the examples below we concentrate on beta values of 1.0 and 0.5, with beta=0.1 as a limiting case, with dispersion becoming very high.

It is within the field of static model analysis that system description and problem identification can begin, using a variety of performance indicators such as those discussed in Section 2.2 and listed in Table 1. Having articulated particular problem areas,

1. Under this assumption, the largest centre - the CBD - is 25 times the size of the smallest (Selby Road) and 35 times more attractive.

alternative policy options can then be explored. Here we focus on residential indicators, in particular accessibility and consumers' surplus measures, in order to identify 'resource deficient regions'. Davies (1984) stresses that

> "an improvement in people's accessibility to shops and shopping centres is one of the main goals of retail and commercial planning"

and generally notes the importance of looking more closely at 'social' facets of retailing: not only the identification of areas lacking facilities but also in terms of improving accessibility patterns to existing facility distributions. This latter issue is pursued in more detail in Section 4.

It is also interesting to note that recent studies by certain local authorities have been concerned with identifying 'shopping deficiency areas', such as Islington Borough Council (1980) and Leeds City Council (1984). The Leeds City study, for example, compared the relationship between the number of shops and total floorspace, for a variety of goods, to the number of households in each area to find 'low' levels of shopping provision (priority areas)[2].

For now, let us briefly look at two simple indicators of consumers' welfare. First, Figure 3a picks up the basic elements of the residential pattern, highlighting the greater expenditure of the more affluent northern and peripheral wards at the expense of the centre and south. It is interesting to compare this pattern with the two simple measures of consumers' welfare given in Figures 3b and 3c. The Hansen (1959) accessibility statistic relates the ease of travel (β) to the distribution of centres (see Table 1). In this case, the central zones appear to fare relatively well, reflecting greater clustering of centres in the central and north-western areas of the

2. The areas were 23 large scale and ARBITRARILY defined catchment areas and it would be interesting in future research to look more closely at the definition of suitable catchment areas (cf. equation (5) above).

city (see Figure 3d).

Clearly a feature of this measure, however, is that no account is taken of the effect of the consumer scale economies parameter, alpha. The trade-off between trip costs and scale economies is accounted for explicitly in the consumers' surplus indicator ($N_i^{R5\ km}$ in Table 1). Here we see the north-eastern zones faring much better (Figure 3c), reflecting the fact that the centres which are available are quite large (recall from Table 5 that the dispersion effect is not very large here, hence consumers are quite likely to end up at their nearest available centre). The same conclusions may be inferred from Table 6, where the information is presented in tabular rather than cartographic form for Figures 3b and 3c.

3.3 Comparative Statics

The determination of the equilibrium distribution of facilities is a very important theoretical problem, which has attracted much of the research interest in supply-side modelling (e.g. Wilson and M.Clarke, 1979; M.Clarke and Wilson, 1983; M.Clarke, 1984; G.Clarke, 1985). The analysis of equilibria is also of interest for real systems, however, since it is highly suggestive of the logic which underpins existing distributions. Figure 4 provides examples of this kind of analysis.

Figure 4a is unsurprising, showing that for a very low beta value, activities will concentrate at a single location in response to consumer scale economies. What is most interesting in this case is that the concentration comes not at the city centre, but in Hyde Park, around 1½ miles to the north. This illustrates the importance of the historical dynamic to current structure. The city centre would have developed as the most accessible point in an earlier city, much smaller in size. Once established, however, it would continue to develop an advantage as the focus of major routes, and thus retain its dominant position, while population has fanned out towards the north. These effects are usually picked up by factoring the cost of trips to the city centre (e.g. M.Clarke, 1985). Reducing the cost of all such trips by 5% allows the city centre to become dominant under this scenario - see Figure 4b.

Figure 4c shows an equilibrium plot based on a value of beta (1.0) which is perhaps rather higher than we would expect to be now operating. This is interesting as only 17 of the 33 centres are picked out at equilibrium. A similar result applies even when we allow beta to become very close to its limiting value at 3.0 (Figure 4d) where we still have only 19 centres. This suggests two things. First, the existing pattern is in part the outcome of an historical process in which there are little or no consumer scale economies for certain types of good, which in turn implies a need to disaggregate by good-type. This situation still exists for certain types of convenience goods, hence the persistence of the cornershop as an institution, albeit at a relatively small scale (e.g. Wilson and Oulton, 1983). Secondly, many of the smaller centres may have particular advantages in terms of attractiveness and especially costs, since rents in the city centre wil clearly bear little comparison with those of the decaying inner-city ring.

3.4 System Dynamics

The comparative static explorations of Figure 4 provide a useful background for dynamic analyses in which the objective is to try and project the future development of the system. For the experiments of this section, we have assumed $W_j(t)$ to be the only variable subject to structural adjustment, the remainder of the backcloth being fixed. The exercise has been undertaken over ten time periods for three different beta values (0.1, 0.5 and 1.0) and two rates of adjustment (epsilon=0.001 and 0.005, using the procedure of equation (6)) with results shown in Figure 5.

These rates of change are deceptively fast. We are operating with a unit cost of k=95,[3] so even a value of 0.001 implies a 10% shift towards equilibrium at each time period (equation (6)). This ensures that the pattern of development is crucially dependent on variation in beta, as in Figure 4. For high beta we have a gradual dispersion of centres with the development of quite a number of centres of significant sizes. Low beta, on the other hand, gives rise to a more concentrated pattern, while the intermediate case of beta=0.5 is arguably the most realistic.

The effect of slower adjustment rates is only marked with respect to the beta=0.1 case, but here a relatively complex dynamic is in evidence. With slow growth (Figure 5f) we see that the city centre retains a dominant position but there is some expansion of other centres, especially those within the inner ring. With a faster dynamic, which might equally be viewed as a temporal extension of the previous case (Figure 5c), the inner ring centres have captured the trade of the CBD, especially Headingley and Bramley to the north-west.

The fortunes of smaller centres are also strongly dependent on the beta value and on their interdependence with the larger centres. Consider, for instance, the case of Roundhay, which exists as a medium-sized centre for beta=1.0, disappears when beta=0.5 but recovers to be a small centre when beta=0.1. The interpretation for beta=1 is fairly clear-cut. Roundhay is a fairly isolated centre in a high expenditure zone and can thus maintain a healthy level of activity. With falling beta, however, there are other nearby centres which have potentially bigger catchment areas and can exploit the greater scale economies now available. Thus centres like Harehills and

3. This is rather large because k is also operating here as a scaling parameter between revenue and cost, as explained in relation to equation (8) above.

Harehills Lane have expanded, and Roundhay has disappeared. At extreme values of beta the Harehills centres have themselves been eclipsed by more distant locations, especially Headingley. However Roundhay is sufficiently distant from these new, highly attractive centres, to once again be able to maintain a rather small level of activity. This kind of analysis has potential policy implications, to which we now turn.

3.5 Current Modes and Policy Applications

At the end of the last section we focussed on the interesting case of the Roundhay shopping centre, whose fortunes were dependent on changing parameter values in a way which is intuitively difficult to predict. This difficulty lies at the heart of the modelling philosophy i.e. that models allow us to pick up changes that are not otherwise obvious. Another interesting case from the point of view of policy is the Middleton centre. Throughout the 1970s, planners in Leeds have been trying to encourage the development of a new superstore here, in an area that was perceived as being under-provided. There are at least two kinds of question which we might attempt to shed light on using the framework which has been developed here. The first is really an impact analysis - what kind of effect would such a development have, and might the investment perhaps not be better channelled elsewhere? Secondly, are these developments stable, or will the new store be unable to generate sufficient revenue to maintain long-term viability?[4] Other types of question could also be addressed e.g. to see the implications for neighbouring centres, but we do not attempt this explicitly here.

For the purpose of these experiments, we assumed a value of

4. The latter attitude clearly prevailed among the entrepreneurs who resolutely refused to build in this period.

beta=0.5, which we argued above is probably quite realistic. Table 7 shows the results for the three residential performance indicators discussed in section 3.2 above. It can be seen that both Middleton and Hunslet perform particularly badly on all three measures, while consumers' surplus in neighbouring Beeston is also very low, although this ward fares rather better on the accessibility measures. In relation to the discussion of sub-section 2.5, this forms our 'base' model. A series of 'current' operations may now be defined as modifications to the base scenario. Two possibilities are shown in Table 8. First, we can see that if an extra 20000 square feet of floorspace (the approximate size of a small new superstore development) is added to Middleton then there is a significant improvement (over 10%) in the performance of Middleton ward on the consumers' surplus indicator, and a dramatic improvement in the Hansen accessibility. The Schneider-Symons accessibility measure shows least change, but this is also the least significant indicator, as we argued in section 3.2. Notice that there is little feed through effect to the neighbouring zones of Hunslet and Beeston since consumers in these zones are strongly attracted either to local centres or the CBD.

An obvious alternative strategy is to create extra facilities in Hunslet, since this ward apparently rivals Middleton as the worst performer of all. As Table 8 shows, however, such a strategy is of relatively little value, presumably reflecting the proximity of other local centres and the CBD once again.

The stability of the two strategies can be assessed by applying the appropriate dynamic model to a modified initial distribution. Table 9 shows what happens for the case of ε=0.001 over 10 iterations. The base situation is the one shown in Figure 5e, with Middleton showing strong growth and Hunslet a steady decline. It is not surprising, therefore, that expansion of the existing facility at Middleton results in a similar growth pattern, but investment in

Hunslet is unable to arrest the decline of that centre.

These patterns are fairly clear, and could have been predicted from Figure 5, where Middleton can be seen as a growing centre for beta=1.0 and 0.5 (but not 0.1). Hunslet, on the other hand, is a growing centre for beta=1.0, but declining when beta=0.5. It is, however, one of those interesting centres (like Roundhay) which fares better for beta=0.1.

The important principle which is illustrated here is that of devlopment possible (DP) - no development possible (NDP) states, introduced by Harris and Wilson (1978). Clearly for beta=0.5, Middleton is a DP zone and it is safe to invest there, while Hunslet is NDP, hence extra development is useless. For either the beta=1.0 or 0.1 cases, however, the situation would be much less clear.

3.6 An Alternative Spatial Framework

In a study of the city of Leeds, the definition of 33 shopping centres is probably a reasonable one, notwithstanding our comments in relation to dynamics in sub-section 3.4. However the adoption of 24 demand zones is somewhat coarse. In this section we adopt a much finer level of spatial resolution on the demand-side, replacing these 24 zones with a 729 zone spatial grid of 27 X 27 square zones. The extent of this grid is shown in Figure 6. Expenditure and population data were estimated using the same methods as in section 3.1, but with an enumeration district rather than a ward base (see G.Clarke, 1985).

The adoption of a finer scale on the demand-side clearly permits a greater level of detail in the interpretation of residence-based indicators. For the present, however, we wish to focus on two kinds of issue which arise from section 2.4, relating to the compatibility of parameter values, and the similarity of spatial structure.

In attempting to determine the effect of the new spatial system on the distance deterrence parameter beta, we can again focus on the total trip cost indicator (${}^{S2\,g}N$), and recall that in optimisatio theory beta is the Lagrangian multiplier associated with the tota trip cost as a constraint (e.g. Evans, 1973). The gross trip length associated with the two zoning systems over sampled beta values ar given in Table 10. Unfortunately, because the two zoning systems ar not spatially coterminous, it is not possible to compare these gros lengths directly. However if we derive the limiting value for th gross length as beta tends to zero, then we have a measure c dispersion around the centre which acts as a reasonable datum agains which to compare other beta values. The variation in the two paramete sets appears to be very similar, reflecting the fact that both sets c demand zones are randomly distributed with respect to the suppl centres. Most importantly, this implies that parameter values ar roughly comparable across the two data sets, which would not be th case if the origin and destination zones were correlated in some wa e.g. if the shopping centres were also ward centroids.

This property is exploited in Figure 7, where we have attempt to compare the structural outcomes of the two spatial systems for th alpha=1.1, beta=1.0 case. Figures 7a and 7b focus on the profitabili indicator ${}^{F10\,g}N_j$, and in general the results are quite encouraging wi a very similar looking pair of distributions. The major anomaly is t Moortown centre, clearly implying a boundary problem, since th centre falls right on the edge of the 24 zone system, but is well in the interior of the 729 zone grid. Moreover, since there is no outsi competition for this new catchment area, profitability becomes ve high here.

The differences which do exist in the static case are magnifi in terms of the spatial structure if dynamics are introduced, as sho in Figures 7c and 7d. Here we see that the size distribution centres is again very similar but there are many significant loc variations. For example, in the 729 zone case Crossgates grows to a very large centre, while with 24 zones its position is usurped by Seacroft and Selby Road. The obvious implication is that we need to be quite sure about the implications for system performance of the particular zoning system we adopt. Greater stability could in principle be induced, however, by a more careful consideration of the non-locational factors which give individual centres dominance over their neighbours, and we return to this in the next Section.

4. CONCLUSIONS AND RESEARCH TASKS

The concern of this paper has been to construct and begin implement a model-based information for urban planning. Our examp throughout has been the case of urban retailing and clearly one of t most obvious research tasks is to extend this framework to cater for variety of other kinds of subsystems. As Wilson (1984) explains, the is a need to develop the whole set of subsystem models and to le how to use each as design tools. Clearly this will demand ma investments of time and energy but it seems a vital step forwa Progress with the set of sub-models should then enable us to wo towards the articulation of more COMPREHENSIVE systems where many the sub-models are more formally linked (see Birkin, M.Clarke a Wilson, 1984; Birkin and M.Clarke, 1985).

It is hoped that work on other subsystems will also perm extensions to the range of performance indicators we are current working with. The concept of system performance may be due a ma comeback in geographical analysis (see G.Clarke and Wilson, 1985, f an extended discussion).

A considerable emphasis in the paper has been focussed on zon systems and in section 3.6 a very fine-scale demand-s representation was introduced. In terms of measures such accessibility, it seems there are great advantages in using such f systems where deficient or priority areas can be more accurat pinpointed. This then helps to reduce many of the well-known probl of area-based studies (see G.Clarke and Wilson, 1985 for a br review). Such a fine-scale specification of demand should also help to explore the ways in which we can improve levels of accessibil through the provision of extra facilities. This then suggests look at the improvement of transport links or even the introduction centralised computer-based facilities for various members of t population (see Davies and Edyvean, 1984, who describe t computerised shopping and information system run for the elderly and disabled from libraries and community centres in Gateshead). Much fruitful research is possible then in the area of accessibility and consumers' welfare.

The explicit dynamic focus of this paper has been on the supply-side. It was argued that there has been crucial progress here, allowing us to examine concepts of discrete change and bifurcations. Providing there is sufficient knowledge on some changing system of interest, it is now possible to model 'revolutionary' change rather than simply evolutionary development (a pertinent critique of Dawson, 1980). However concern with these supply-side dynamics has been at the expense of the demand-side. At least two possible extensions may be considered.

At a rather coarse level of analysis, it is possible to generate information on population change from a knowledge of changes in the housing market. That is, given knowledge about the pattern of housing construction (or demolition) in a given area it is possible to speculate on resultant population change, and of course for particular time periods these estimates can be ratified with respect to the decennial census of population.

Ultimately, however, we need to build in formal models of population change. In one respect this is a subsystem issue, and clearly a population and housing sector would occupy a key place in any comprehensive model. It has been argued in a recent paper (Birkin and M.Clarke, 1985), however, that the treatment of the demand-side through micro-simulation is an appealing alternative treatment, at least in the interim. We would envisage an eventual fusion of these two approaches, with the population sector being treated through micro-simulation in a comprehensive model (e.g. M.Clarke and Wilson, 1985).

Finally, possible improvements in the production-based performance indicators can be considered. So far we have typical: used indicators such as total floorspace and revenue generate. Clearly we need far greater efforts in looking at prices and costs a their disaggregation both spatially and sectorally. Similarly t attractiveness of particular kinds of facility or location may have t be more carefully specified. Work on the spatial costs a attractiveness of centres for retailing is underway (G.Clarke, 1985) while theoretical extensions have been undertaken by Birkin and Wils (1985).

In this paper, we have tried to develop a powerful framework f the identification and solution of problems in urban planning. Havi identified a large number of research areas, it is clear that we nee to continue to work more closely with 'real' data for empiric applications, to complement the theoretical advances being made - i effect, focussing on the 'data accumulation' box of Figure 1. If on could only involve the planner, in particular within the domain o policy evaluation, then we would truly be working with an 'interacti planning information system'.

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FIGURE 1: ELEMENTS OF A MODEL-BASED INFORMATION SYSTEM

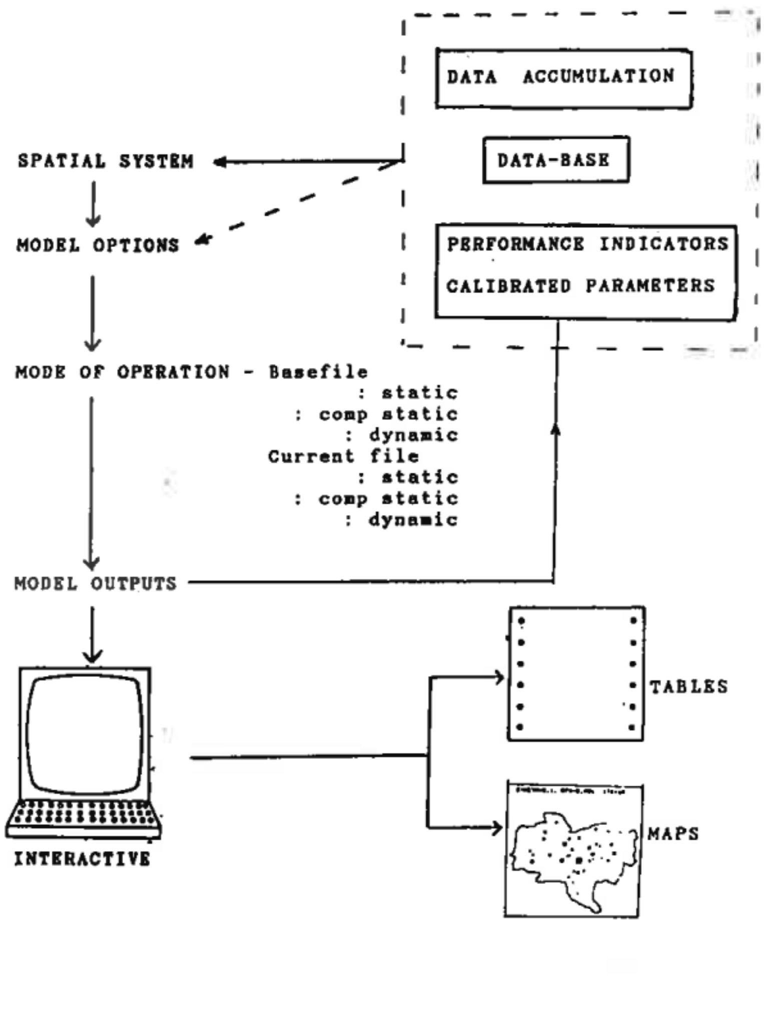

FIGURE 2a: 24 WARDS IN LEEDS, 1981

1	ARMLEY	9	HAREHILLS	17	PUDSEY S.
2	BEESTON	10	HEADINGLEY	18	RICHMOND H
3	BRAMLEY	11	HORSFORTH	19	ROUNDHAY
4	BURMANTFTS	12	HUNSLET	20	SEACROFT
5	CHAPEL ALL	13	KIRKSTALL	21	UNIVERSITY
6	CITY + HOL	14	MIDDLETON	22	WEETWOOD
7	COOKRIDGE	15	MOORTOWN	23	WHINMOOR
8	HALTON	16	PUDSEY N.	24	WORTLEY

FIGURE 2b: 33 SHOPPING CENTRES

1	CITY CENTR	12	HEADINGLEY	23	SHAFTSBURY
2	HOLT PARK	13	HAREHILLS	24	YORK ROAD
3	SEACROFT	14	FARSLEY	25	HALTON
4	ROUNDHAY	15	HYDE PARK	26	PUDSEY
5	MOORTOWN	16	BRAMLEY	27	ARMLEY
6	HFTH TN ST	17	HHILLS LA	28	HUNSLET
7	MEANWOOD	18	CROSSGATES	29	BEESTON HL
8	CHAPEL ALL	19	STANNINGLY	30	DEWSBRY RD
9	HSFTH N RD	20	WOODSLY RD	31	BEESTON RD
10	OAKWOOD	21	KKSTALL RD	32	BEESTON PK
11	HOLLIN PK	22	SELBY ROAD	33	MIDDLETON

FIGURE 3. STATIC MODEL, 1981 BASE. BETA=1.0, ALPHA=1.1.

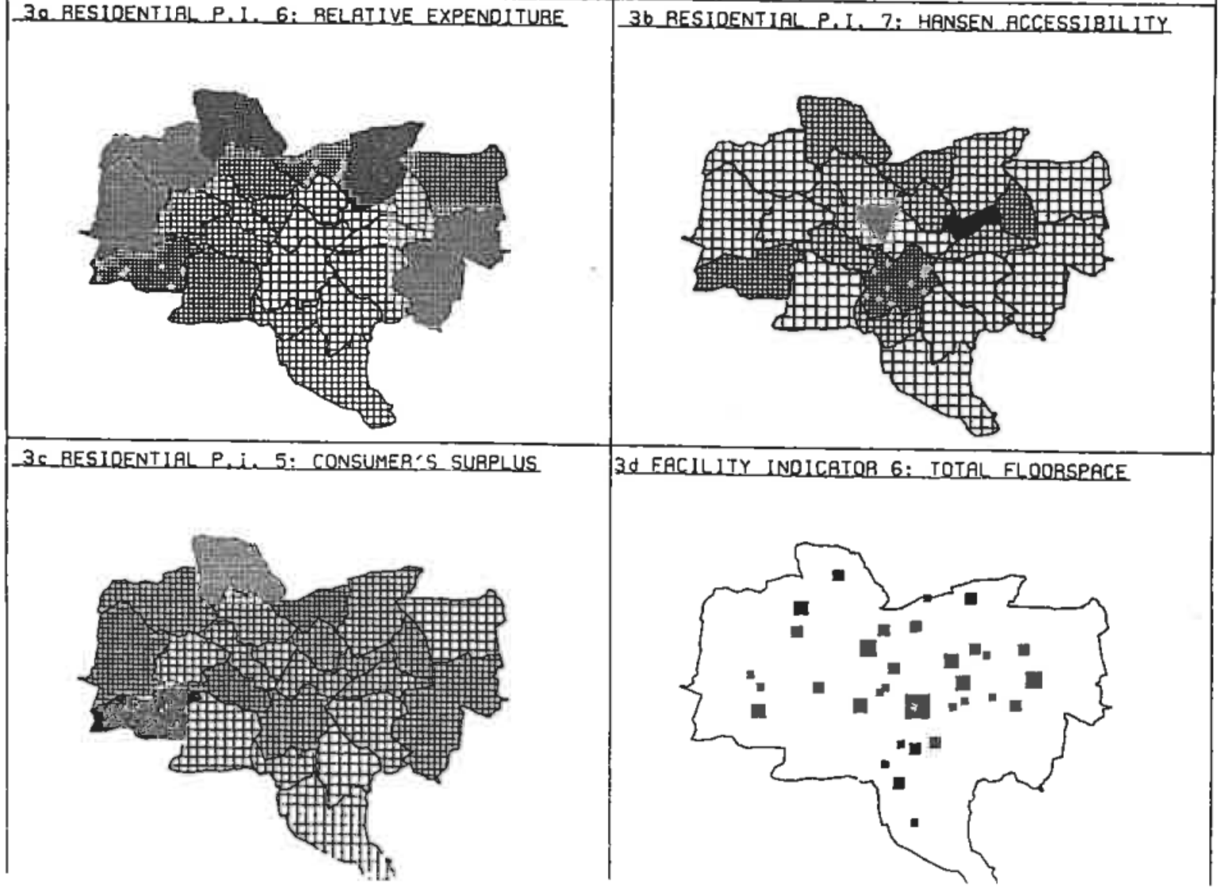

FIGURE 4. EQUILIBRIUM MODEL: VARYING BETA

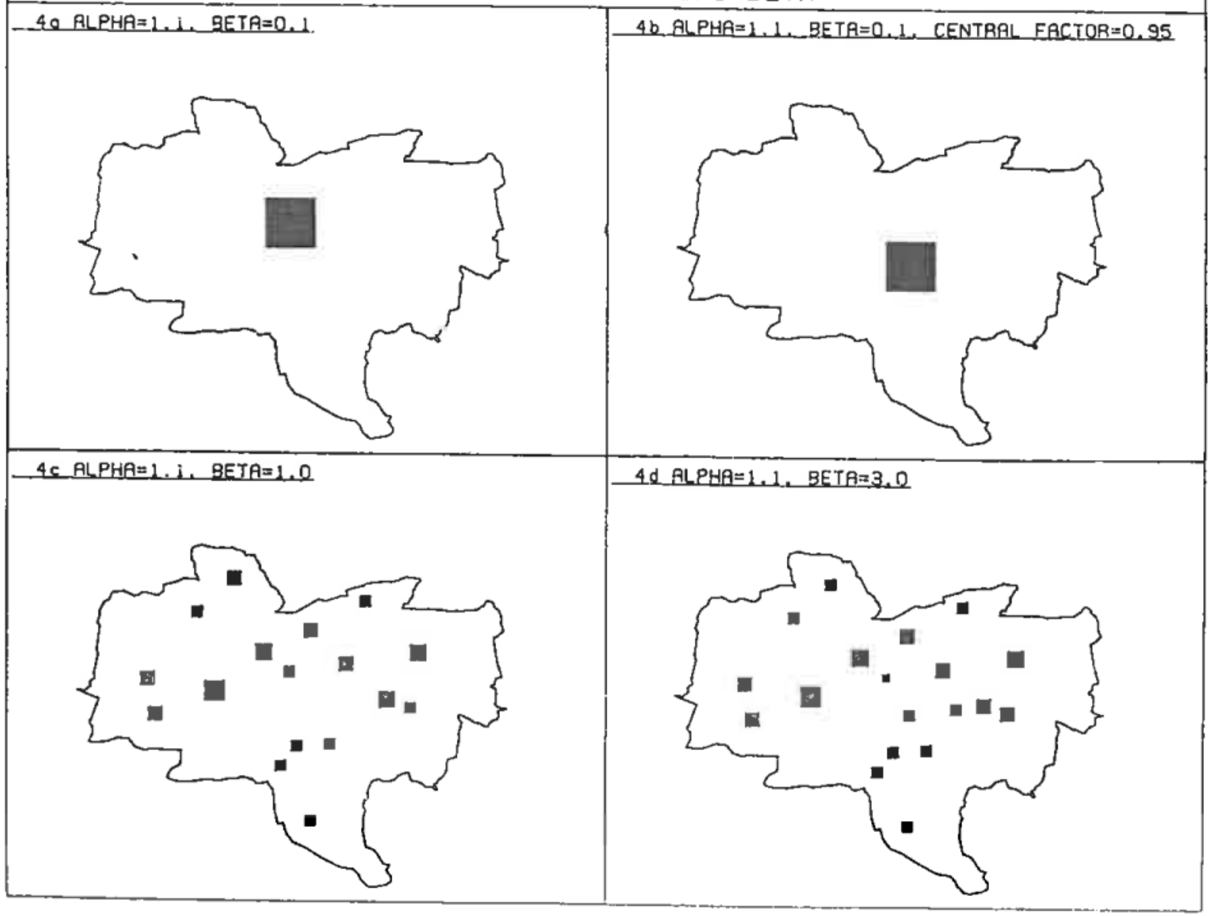

FIGURE 5. DYNAMIC MODEL: VARYING BETA AND EPS; ALPHA=1.1

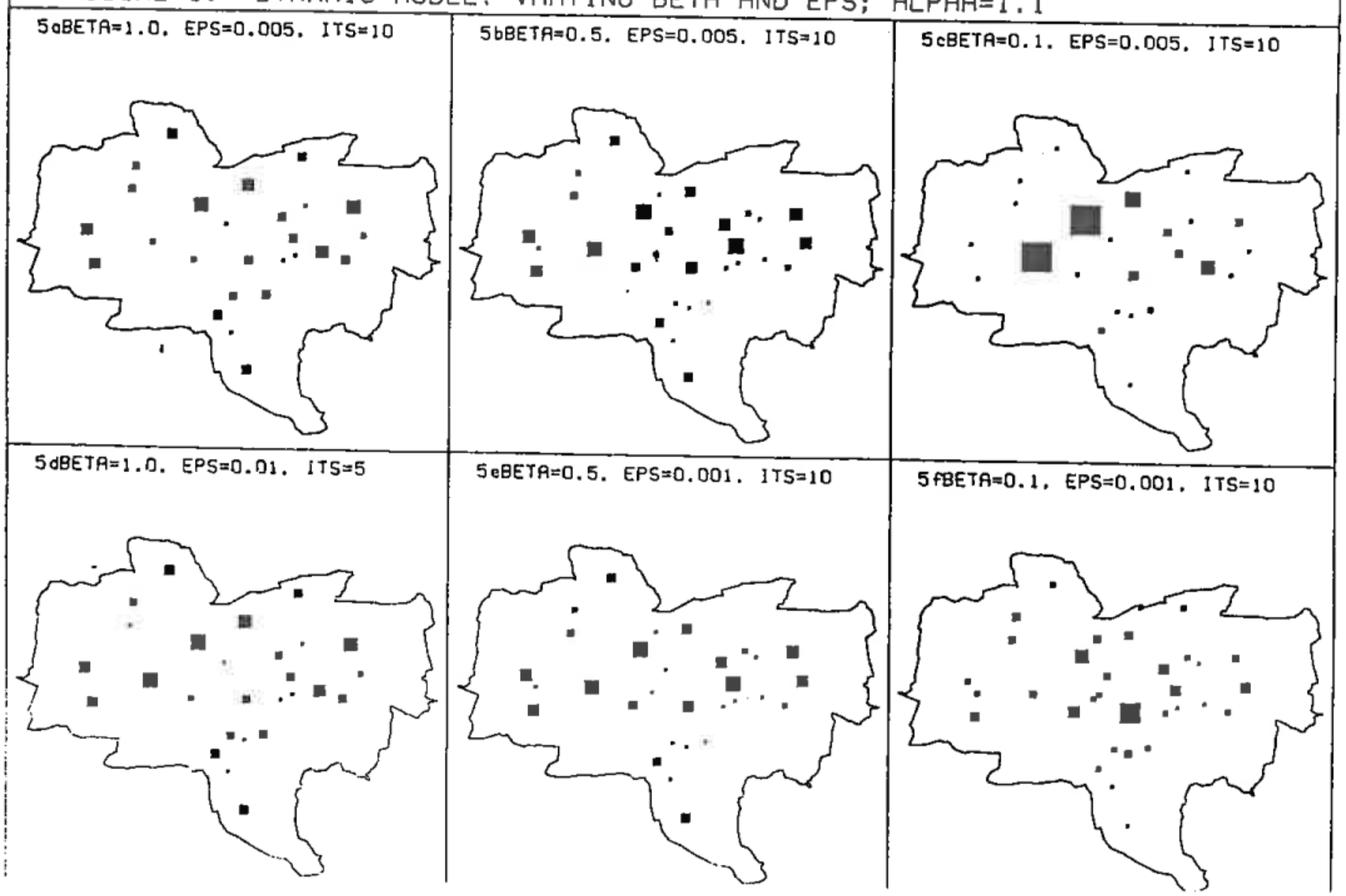

FIGURE 6: RELATIONSHIP OF 24 WARDS TO 729 DEMAND ZONES

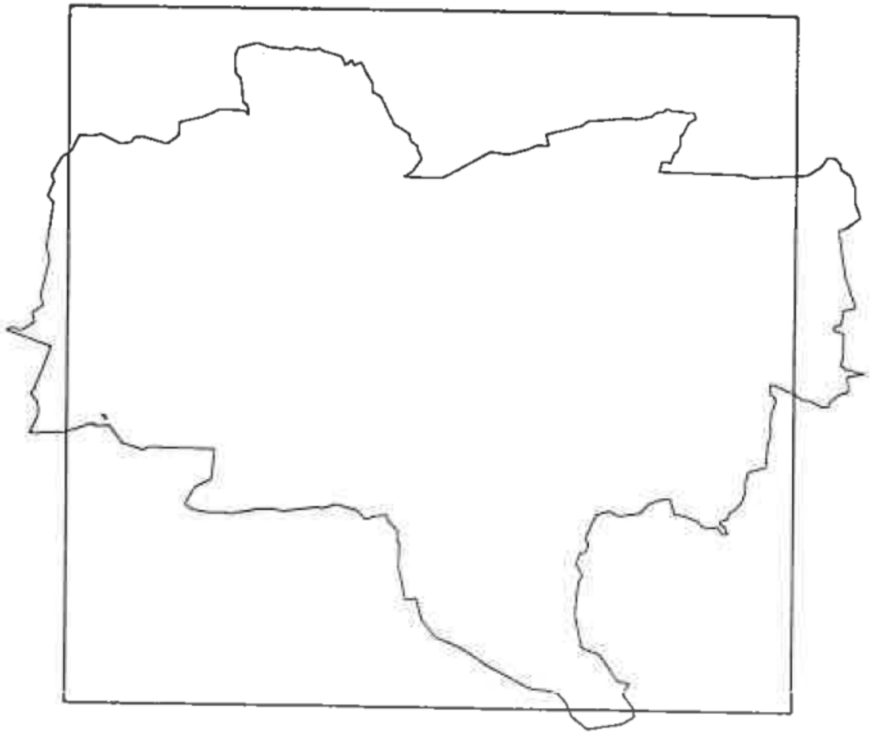

FIGURE 7. A COMPARISON OF THE TWO SPATIAL DEMAND SYSTEMS

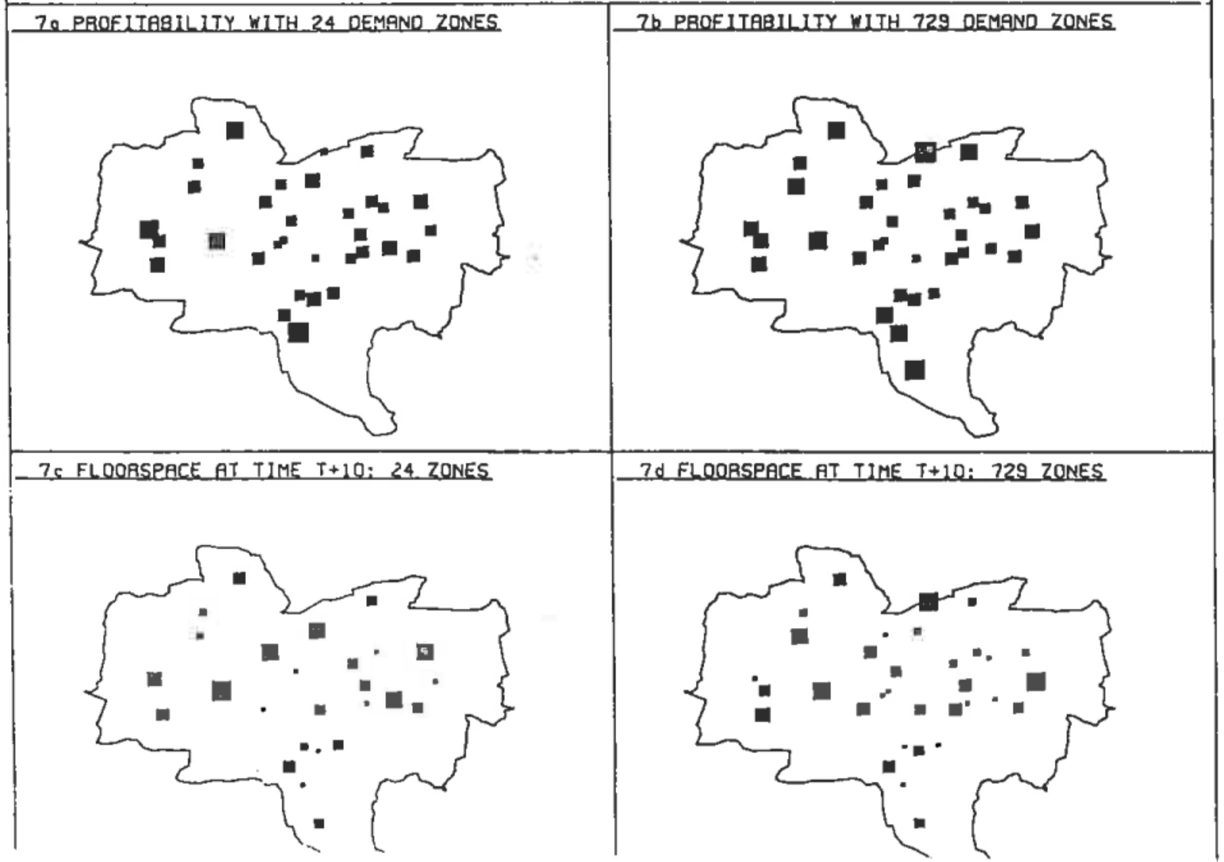

TABLE 1: A SUITE OF RESIDENTIAL PERFORMANCE INDICATORS

1.	$N_i^{R1\,mg} = \sum_j [W_j^g Y_{ij}^{mg} / \sum_i Y_{ij}^{mg}]$	Output of good g allocated to residents type m in i.
2.	$N_i^{R2\,mg} = N_i^{mg} / P_j^m$	Per capita expenditure on m-type residents of zone i for n
3.	$N_i^{R3\,mg} = \sum_j Y_{ij}^{mg} P_j^m$	Transport expenditure of residents type m in i to obtain g
4.	$N_i^{R4\,mg} = e_i^{mg} P_i^m / \sum_i e_i^{mg} P_i^m$	Relative expenditure on g by m at i
5.	$N_i^{R5\,mg} = \sum_j Y_{ij}^{mg} [(\alpha/\beta) \log W_j^g - c_{ij}^m]$	Consumers' surplus for m-type residents in i for g
6.	$N_i^{R6\,mg} = \sum_j [W_j^g / c_{ij}^m]$	Schneider- Symons accessibility
7.	$N_i^{R7\,mg} = \sum_j W_j^g \exp(-\beta^{mg} c_{ij}^m)$	Hansen accessibility

TABLE 2: A SUITE OF FACILITY-BASED PERFORMANCE INDICATORS

1.	$^{F1}N^{g}_{j} = W^{g}_{j}$	Level of output (floorspace) for goods type g at j.
2.	$^{F2}N^{g}_{j} = D^{g}_{j}$	Revenue accruing through the sale of g at j.
3.	$^{F3}N^{g}_{j} = C^{g}_{j}$	Cost of provision.
4.	$^{F4}N^{g}_{j} = \pi^{g}_{j}$	Catchment population of facilities at j in g.
5.	$^{F5}N^{g}_{j} = W^{g}_{j} / \pi^{g}_{j}$	Production per head of catchment population.
6.	$^{F6}N^{g}_{j} = D^{g}_{j} / \pi^{g}_{j}$	Revenue per head of catchment population.
7.	$^{F7}N^{g}_{j} = C^{g}_{j} / \pi^{g}_{j}$	Cost per head of catchment population.
8.	$^{F5}N^{g}_{j} = D^{g}_{j} / W^{g}_{j}$	Average revenue.
9.	$^{F9}N^{g}_{j} = C^{g}_{j} / W^{g}_{j}$	Average cost.
10.	$^{F10}N^{g}_{j} = D^{g}_{j} / C^{g}_{j}$	Profitability.

TABLE 3: POTENTIAL SYSTEM-WIDE PERFORMANCE INDICATORS

1.	$N^{S1\,g} = \sum_{j} C_{j}^{g}$	Total cost of producing g.
2.	$N^{S2\,g} = \sum_{ijm} Y_{ij}^{mg} c_{ij}^{m}$	Total transport expenditure on obtaining g.
3.	$N^{S3\,g} = \sum_{im} \left[N_{i}^{R6\,mg} P_{i}^{m} / \sum_{im} P_{i}^{m} \right]$	' Smith efficiency' (weighted Schneider-Symons accessibility)

TABLE 4: TYPICAL VARIABLE ASSIGNMENT SCENARIO

EXOGENOUS	P_{i}^{m} e_{i}^{mg} c_{ij}^{m} k_{j}^{r} a_{j}^{rg}
OPTIONAL	S_{ij}^{mg} α^{mg} β^{mg} p_{j}^{g} W_{j}^{g} ε^{g}
ENDOGENOUS	A_{i}^{mg} D_{j}^{g} C_{j}^{g} π_{j}^{g}

TABLE 5: EFFECT OF VARYING BETA ON TRIP COSTS; ALPHA=1.1

beta	0.	0.1	0.2	0.3	0.5	1.0	2.0	LIMIT
gross trip length	173.4	165.9	132.7	107.9	77.9	51.6	42.3	38.1
relative trip length	4.551	4.357	3.482	2.832	2.045	1.360	1.110	1.000

TABLE 6: RESIDENTIAL PERFORMANCE FOR BETA=1.0, ALPHA=1.1

RESIDENTIAL INDICATOR NUMBER 5
DEFINITION: CONSUMERS SURPLUS OF M-TYPE RESIDS IN I FOR G

ZONE	GOOD	GROUP	PI SCORE	ZONE	GOOD	GROUP	PI SCORE
ARMLEY	TOTAL	AGGREG	6900021.00	BEESTON	TOTAL	AGGREG	5037704.0
BRAMLEY	TOTAL	AGGREG	5172714.00	BURMANTFTS	TOTAL	AGGREG	5721010.0
CHAPEL ALL	TOTAL	AGGREG	6248971.00	CITY + HOL	TOTAL	AGGREG	6492037.0
COOKRIDGE	TOTAL	AGGREG	8122225.00	HALTON	TOTAL	AGGREG	6439872.0
HAREHILLS	TOTAL	AGGREG	6550398.00	HEADINGLEY	TOTAL	AGGREG	5267031.0
HORSFORTH	TOTAL	AGGREG	6551727.00	HUNSLET	TOTAL	AGGREG	3628328.0
KIRKSTALL	TOTAL	AGGREG	5705587.00	MIDDLETON	TOTAL	AGGREG	4677419.0
MOORTOWN	TOTAL	AGGREG	6868704.00	PUDSEY N.	TOTAL	AGGREG	7173786.0
PUDSEY S.	TOTAL	AGGREG	8840379.00	RICHMOND H	TOTAL	AGGREG	4797646.0
ROUNDHAY	TOTAL	AGGREG	5819294.00	SEACROFT	TOTAL	AGGREG	6447597.0
UNIVERSITY	TOTAL	AGGREG	5838558.00	WEETWOOD	TOTAL	AGGREG	5949006.0
WHINMOOR	TOTAL	AGGREG	4687512.00	WORTLEY	TOTAL	AGGREG	4704675.0

RESIDENTIAL INDICATOR NUMBER 7
DEFINITION: HANSEN-ACCESSIBILITY BY RESIDS TYPE M IN I FOR G

ZONE	GOOD	GROUP	PI SCORE	ZONE	GOOD	GROUP	PI SCORE
ARMLEY	TOTAL	AGGREG	2838.82	BEESTON	TOTAL	AGGREG	3011.6
BRAMLEY	TOTAL	AGGREG	1167.60	BURMANTFTS	TOTAL	AGGREG	3390.4
CHAPEL ALL	TOTAL	AGGREG	2939.72	CITY + HOL	TOTAL	AGGREG	4924.9
COOKRIDGE	TOTAL	AGGREG	3505.86	HALTON	TOTAL	AGGREG	964.6
HAREHILLS	TOTAL	AGGREG	6301.98	HEADINGLEY	TOTAL	AGGREG	5598.6
HORSFORTH	TOTAL	AGGREG	1080.98	HUNSLET	TOTAL	AGGREG	798.7
KIRKSTALL	TOTAL	AGGREG	2209.50	MIDDLETON	TOTAL	AGGREG	332.9
MOORTOWN	TOTAL	AGGREG	3969.77	PUDSEY N.	TOTAL	AGGREG	1005.8
PUDSEY S.	TOTAL	AGGREG	4797.20	RICHMOND H	TOTAL	AGGREG	999.6
ROUNDHAY	TOTAL	AGGREG	1403.93	SEACROFT	TOTAL	AGGREG	4563.1
UNIVERSITY	TOTAL	AGGREG	6866.14	WEETWOOD	TOTAL	AGGREG	2698.4
WHINMOOR	TOTAL	AGGREG	409.33	WORTLEY	TOTAL	AGGREG	250.4

TABLE 7: RESIDENTIAL PERFORMANCE FOR BETA=0.5, ALPHA=1.1

RESIDENTIAL INDICATOR NUMBER 5
DEFINITION: CONSUMERS SURPLUS OF M-TYPE RESIDS IN I FOR G

ZONE	GOOD	GROUP	PI SCORE	ZONE	GOOD	GROUP	PI SCORE
ARMLEY	TOTAL	AGGREG	14710556.00	BEESTON	TOTAL	AGGREG	10547576.00
BRAMLEY	TOTAL	AGGREG	12509044.00	BURMANTFTS	TOTAL	AGGREG	13223665.00
CHAPEL ALL	TOTAL	AGGREG	14622807.00	CITY + HOL	TOTAL	AGGREG	14419538.00
COOKRIDGE	TOTAL	AGGREG	15142692.00	HALTON	TOTAL	AGGREG	14921962.00
HAREHILLS	TOTAL	AGGREG	13760169.00	HEADINGLEY	TOTAL	AGGREG	11347788.00
HORSFORTH	TOTAL	AGGREG	14549719.00	HUNSLET	TOTAL	AGGREG	9050426.00
KIRKSTALL	TOTAL	AGGREG	12756490.00	MIDDLETON	TOTAL	AGGREG	9759214.00
MOORTOWN	TOTAL	AGGREG	13642934.00	PUDSEY N.	TOTAL	AGGREG	16145366.00
PUDSEY S.	TOTAL	AGGREG	17667392.00	RICHMOND H	TOTAL	AGGREG	12916678.00
ROUNDHAY	TOTAL	AGGREG	13236211.00	SEACROFT	TOTAL	AGGREG	13445748.00
UNIVERSITY	TOTAL	AGGREG	12215055.00	WEETWOOD	TOTAL	AGGREG	12537663.00
WHINMOOR	TOTAL	AGGREG	11723760.00	WORTLEY	TOTAL	AGGREG	13283947.00

RESIDENTIAL INDICATOR NUMBER 7
DEFINITION: HANSEN-ACCESSIBILITY BY RESIDS TYPE M IN I FOR G

ZONE	GOOD	GROUP	PI SCORE	ZONE	GOOD	GROUP	PI SCORE
ARMLEY	TOTAL	AGGREG	12046.36	BEESTON	TOTAL	AGGREG	9279.73
BRAMLEY	TOTAL	AGGREG	7595.44	BURMANTFTS	TOTAL	AGGREG	14948.80
CHAPEL ALL	TOTAL	AGGREG	16443.40	CITY + HOL	TOTAL	AGGREG	19611.79
COOKRIDGE	TOTAL	AGGREG	6798.94	HALTON	TOTAL	AGGREG	5582.82
HAREHILLS	TOTAL	AGGREG	19365.45	HEADINGLEY	TOTAL	AGGREG	19570.18
HORSFORTH	TOTAL	AGGREG	5068.57	HUNSLET	TOTAL	AGGREG	6352.50
KIRKSTALL	TOTAL	AGGREG	12208.01	MIDDLETON	TOTAL	AGGREG	1839.55
MOORTOWN	TOTAL	AGGREG	12292.59	PUDSEY N.	TOTAL	AGGREG	4413.55
PUDSEY S.	TOTAL	AGGREG	9193.32	RICHMOND H	TOTAL	AGGREG	8839.25
ROUNDHAY	TOTAL	AGGREG	7929.13	SEACROFT	TOTAL	AGGREG	13459.38
UNIVERSITY	TOTAL	AGGREG	24648.62	WEETWOOD	TOTAL	AGGREG	11536.05
WHINMOOR	TOTAL	AGGREG	3552.38	WORTLEY	TOTAL	AGGREG	4060.82

RESIDENTIAL INDICATOR NUMBER 8
DEFINITION: SCHNEIDER-SYMONS ACCESSIBILITY MEASURE

ZONE	GOOD	GROUP	PI SCORE	ZONE	GOOD	GROUP	PI SCORE
ARMLEY	TOTAL	AGGREG	33689.61	BEESTON	TOTAL	AGGREG	30965.86
BRAMLEY	TOTAL	AGGREG	26365.66	BURMANTFTS	TOTAL	AGGREG	36261.57
CHAPEL ALL	TOTAL	AGGREG	38760.40	CITY + HOL	TOTAL	AGGREG	41362.93
COOKRIDGE	TOTAL	AGGREG	33885.81	HALTON	TOTAL	AGGREG	22245.84
HAREHILLS	TOTAL	AGGREG	42864.81	HEADINGLEY	TOTAL	AGGREG	43366.53
HORSFORTH	TOTAL	AGGREG	21274.68	HUNSLET	TOTAL	AGGREG	25767.33
KIRKSTALL	TOTAL	AGGREG	33566.69	MIDDLETON	TOTAL	AGGREG	17408.32
MOORTOWN	TOTAL	AGGREG	36139.27	PUDSEY N.	TOTAL	AGGREG	19541.41
PUDSEY S.	TOTAL	AGGREG	28890.13	RICHMOND H	TOTAL	AGGREG	29333.54
ROUNDHAY	TOTAL	AGGREG	27807.80	SEACROFT	TOTAL	AGGREG	34421.18
UNIVERSITY	TOTAL	AGGREG	48031.79	WEETWOOD	TOTAL	AGGREG	32701.58
WHINMOOR	TOTAL	AGGREG	19244.01	WORTLEY	TOTAL	AGGREG	23253.96

TABLE 8: RESIDENTIAL PERFORMANCE UNDER THREE INVESTMENT SCENARIOS

	No change				Middleton + 2000				Hunslet + 2000			
	FS	SS	HA	CS	FS	SS	HA	CS	FS	SS	HA	CS
BEESTON		31.0	3011	10548		31.4	3033	10545		3032	31.4	1056
MIDDLETON	2500	17.4	332	9759	4500	18.4	576	10861	2500	334	17.7	978.
HUNSLET	1500	25.8	799	9050	4500	26.2	813	9054	6500	957	26.6	924

* FS floorspace; SS = Schneider-Symons accessibility;
HA Hansen accessibility; CS = Consumers' surplus

TABLE 9: DYNAMIC GROWTH PROFILES OF TWO SOUTH-CITY CENTRES

		FS(t+10)				β=0.5		β=0.5
	FS(t)	=0.1	=0.5	=1.0	FS(t)	FS(t+10)	FS(t)	FS(t+1C
HUNSLET	45000	30481	18878	73740	45000	19421	65000	35219
MIDDLETON	25000	1487	93553	85279	45000	93983	25000	91472

TABLE 10: A COMPARISON OF BETA VALUES AND MEAN TRIP LENGTHS FOR TWO SPATIAL SYSTEMS

	24 ZONES		729 ZONES	
BETA	GTL	RTL	GTL	RTL
0.	173.4	100.	1.972	100.
0.1	166.0	95.7		
0.2	132.7	76.5	1.531	77.6
0.3	107.9	62.3		
0.5	77.9	44.9	0.895	45.4
1.0	51.8	29.9	0.578	29.3
2.0	42.3	24.4	0.458	23.2
LIMIT	38.1	22.0	0.414	21.0

*

GTL = Gross trip length = $T(\beta) = \sum_{i,jkm} Y_{ij}^{km} c_{ij}^{m}$

RTL = Relative trip length = $R(\beta) = 100 * T(\beta) / T(0)$