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The assessment of transport impacts on land use: practical uses in strategic planning

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Abstract

This article, focusing upon the UK, examines the relevance to strategic planning of methods to estimate the impacts of transport policy on land use processes. The study applied three differing techniques for forecasting these impacts to a common study area, and assessed planners' views on each. The methods comprised a Delphi survey, a simple static land use model, and a linked land-use/transport model. It was found that many factors influenced planners' views on appropriate methods. In general, comprehensive-modelling methods could provide a tool suitable for the needs of planners, but only if the underpinnings of the model were clear. © 1999 Elsevier Science Ltd. All rights reserved.

Keywords: Delphi survey; Land-use/transport models; Planning methods

1. Introduction

Within the UK at present there is considerable interest among planners in integrating land use and transport planning, primarily to assist in reducing car based travel, and hence obtaining sustainable development patterns. As a result, the examination of land use and transport interaction has focused almost entirely on how land use patterns affect travel demand, and which urban forms are most energy efficient (e.g. Department of the Environment and Department of Transport, 1993; Hall, 1997; Coombe and Simmonds, 1997).

The converse, i.e. how transport in turn affects urban development, has received only cursory interest, and is only briefly mentioned in the UK Government's current (but due to be revised) advice on land use and transport planning, Planning Policy Guidance 13 (Department of the Environment and Department of Transport, 1994), or in the recent White Paper (Department of Environment, Transport and Regions, 1998). Yet there are strong reasons to support the view that these impacts should be studied; from the clear long term link between transport technology and urban form (Hall, 1989; Giannopoulos and Curdes, 1992), through micro level studies regarding complex transport influences on development, to theoretical arguments regarding urban dynamics over time (e.g. Hunt and Simmonds, 1993; Mackett, 1995). It is the methods to assess how transport can influence land-use which are the focus of this paper.

There is no history within the UK planning of consistently examining the impact of transport on land use. Previous research (Still, 1996), has found that these impacts remained external to the mainstream planning practice because:

- there is no requirement in policy to examine such impacts;
- there is a perception that unplanned development impacts resulting from transport can be controlled via the development planning process;
- there is a belief that the circumstances under which development can be directly attributed to transport changes are vague and difficult to predict;
- there is a widespread unfamiliarity with the methods to forecast impacts.

Comparative research in the USA has found that, in contrast to the UK, there is overt recognition of the importance of transport impacts on land use patterns, and hence on patterns of travel demand (Still, 1996). There are legislative requirements to examine these impacts for US urban areas failing to meet air quality regulations. Planners must show (through forecasting) that their transport policies will not worsen air quality through any mechanism, including land use response.

However, in common with the UK, in the USA there is still a debate over the most appropriate method to examine these impacts. This research therefore assesses the relative merits of different methods for the practical examination of transport impacts on land use. A wholly analytical

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Table 1
The range of methods for examining transport impacts on land use

	Method	Comments, example methodology
1	Individual planners' judgements	Often used in typical desktop based impact studies.
2	Informal use of group expert opinion	Professional panel from planning and property/ development sector.
3	Formal use of expert opinion	Delphi method, deriving quantified responses from a similar panel to (2).
4	Quantified assessment frameworks	Assessment via an explicit and systematic framework of relationships.
5	Simple modelling	Static land use models linked to standard or existing transport models.
6	Economic frameworks	Calculations of economic benefits, using outputs from transport models.
7	Complex modelling	Full land-use/transport model.

assessment of the range of methods would be difficult to achieve. Instead the criteria for assessment is based upon experience in using a variety of methods to consider a set of common policy tests in a common study area, and practising planners' own assessments of the methods and the results.

This paper begins by describing three methods selected from the range of possible techniques. An assessment is made of the methods based upon the criteria of (1) the validity of the method, and (2) the plausibility of the resulting forecasts. The remainder of the paper then focuses upon planners' reactions to the methods and the results. The planners were asked to make an assessment against a similar set of criteria, namely their views on: (1) the relevance of the outputs; (2) the validity of the methods; (3) the plausibility of the forecasts; and (4) the overall importance of the methods to strategic planning practice. Conclusions are drawn from these findings concerning the criteria necessary for a method to satisfy the planners' requirements.

2. The range of potential methods to examine transport impacts on land use

Table 1 outlines the possible methods for determining the impacts of transport on land use. The methods outlined in Table 1 are all 'operational' in that they have been used either in the UK or elsewhere to inform planning policy. Methods (1) planners' judgement and (2) informal use of experts' opinion, were identified from interview based research (Still, 1996) as the most commonly used in the UK. The Delphi method (3) is common in the USA, where a rapid method has often been required initially to meet the air quality legislative requirements. Simple quantified assessment frameworks (4) have been applied for several transport proposals (e.g. Halcrow Fox and Associates, 1996; WS Atkins Planning Consultants and ECOTEC, 1990), and generally tend to examine employment and development impacts only. Where these frameworks have a fuller theoretical economic underpinning (such as by Oscar Faber TPA, ERM and Cambridge Systematics, 1994), they have been classified as economic frameworks (6). Simple land use allocation models (5) can examine population and employment impacts, and again are common in USA (for example the use of DRAM/EMPAL; Putman, 1994), and have also been used in Sweden (Anderstig and Mattsson, 1992). Finally, land-use/transport models (7) are arguably the most comprehensive methods that can be applied, of which the 'Martin Centre models' have had the most applications (e.g. Williams, 1994).

To cover the spectrum of formal approaches, the illustrative methods applied in this research focused upon one example from each of (3), (5) and (7). Methods (1) and (2) were considered too informal, given that the planners' views would be sought in appraisal of the other methods. Method (4) is open to more subjective judgement than the modelling methods, and was not considered sufficiently rigorous compared to method (5). Method (6) would ideally have been applied, but information on the assumptions within known frameworks were not available in sufficient detail to enable them to be developed within the resources of the study.

3. Application of three methods to the case study area

3.1. The case study area and the policies tested

Edinburgh was selected as the study area for this research for a number of reasons. Firstly it, and the wider Lothian region, are expanding in terms of economic growth and population, and are of sufficient size to warrant strategic planning. Edinburgh, in common with many other UK cities, is facing decentralisation pressures among certain household types and employment sectors. It is also a city of high architectural and cultural value, yet one in which increasing traffic congestion is threatening to reduce its environmental quality.

Edinburgh has also been innovative in terms of its transport policy. The former Lothian Region was one of the first in UK to adopt an 'integrated urban transport strategy' (May et al., 1992), and the City Council is actively considering both light rapid transit (LRT) and road pricing, as potential elements in its plans to curb pollution and congestion within the city. The region has a number of transport models relevant to strategic planning. This includes a version of MVA's 'Strategic and Regional Transport Model' (START; initially discussed in Bates et al., 1991), which was made available for this research.

Fig. 1 shows the study area, subdivided into the 25 zones of the Lothian START model. The study area included the

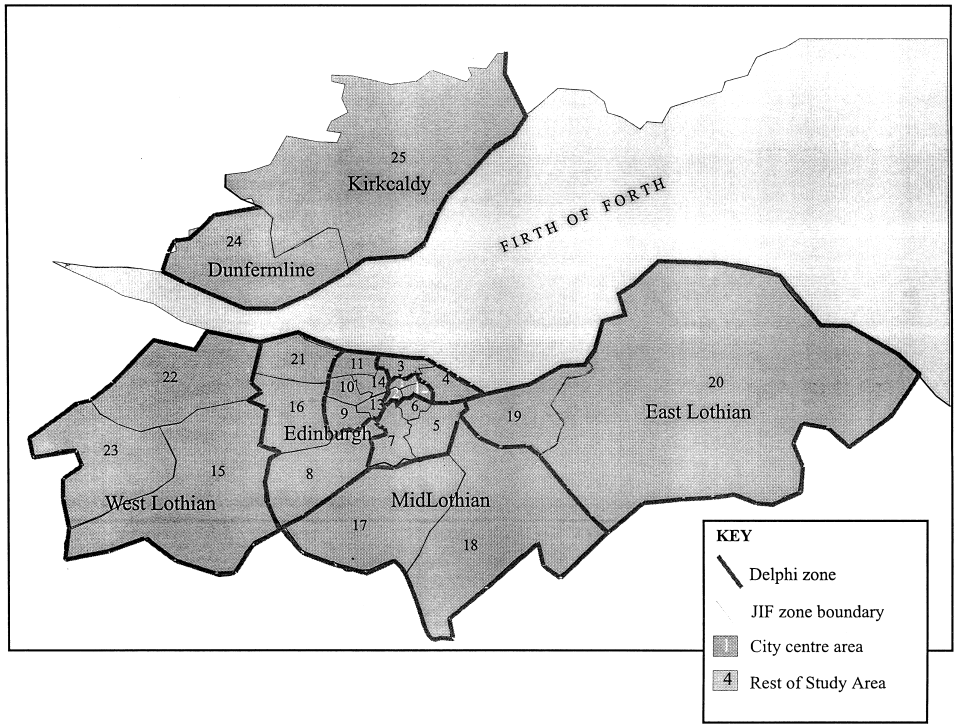

Fig. 1. Study area with START and Delphi zones.

districts from the former Lothian Region, as well as southern Fife (Dunfermline and Kirkcaldy). Fig. 1 also shows how these zones were grouped together for the nine zone aggregation used in the Delphi survey (the aggregation in which, for simplicity, the results in this paper are presented).

Each of the three methods was implemented for two policy tests, which were based upon elements of the best performing strategies in the Lothian integrated transport strategy, as outlined in May et al. (1992). The first was a road pricing cordon around the city centre (zones 1, 2 and 12 in Fig. 1). A charge of £1.50 (1991 prices) was applied for traffic passing each way through the cordon, operating all day. The second was a light rail (LRT) system, with two lines operating with a 5 min headway, each passing through the city centre (Waverley Station). The 'East–West' line ran from the airport (zone 16) to Leith (zone 4), the 'North–South' line ran from zone 3 down to the 'South–East wedge' (zone 5), an area earmarked for major housing and commercial development. LRT fares were assumed to be set equal to bus fares. Each policy was compared with a 'do-minimum', which assumed no additional transport infrastructure, and fares, prices and frequencies following historic trends.

3.2. Method 1: formal expert opinion-the Delphi method

The Delphi method aims to obtain quantified opinions from a sample of experts in a subject area, in a systematic and non-biased manner using repeated questionnaires. Each panellist remains anonymous to the others, hence reducing the risk of 'interpersonal static' and individual bias. Panellists can adjust their responses to the questions, once presented with the results from the previous round. This process aims to obtain a consensus on the direction and magnitude of the impacts within the panel.

The use of experts in this way has been investigated and justified by Amara and Lipinski (1972). Experts provide more than merely a sensible guess to the results, as they bring to bear an in-depth understanding of relationships leading to results. Hence Amara and Lipinski argue that such forecasts, even from small samples of experts (as low as 8–12), are more likely to be realistic than from larger samples of 'lay persons'.

The Delphi method has not been applied widely in transportation studies, and is most commonly used in assessing the impact of new transport technologies. In assessing transport impacts on land use it has been applied in the United States (Cavalli-Sforza and Ortolano, 1984), and also to forecast the impact of the Sheffield Supertram (Antwi and Hennebury, 1995). However, it has also been used at the early stages of strategic plan formulation (e.g. Smyth, 1995), and hence is not unknown amongst practising planners.

In these cases the Delphi offered a relatively cheap (compared to most model development projects) and practical means of obtaining opinions on likely impacts, using experts in the subject area, without the expense of

Table 2
Professional experience of the Delphi sample

Sector	Number working in sector
Development and construction	14
Investment	11
Transport planning	6
Land use planning	8
Surveying and valuation	5
Property transactions/other	14

developing a mathematical model. However, as a tool in planning it is limited because it cannot be used to test the impacts of strategies other than those considered in the questionnaire. Further, the sample must be carefully selected (and ideally multidisciplinary) to encompass a variety of perspectives and minimise strategic bias. There is also a limit to the length of the questionnaire that can be successfully applied without respondent fatigue.

The panel approached in this research consisted of property experts from the study area (property agents, surveyors and developers), planners from the local authorities, and planning consultants. It was considered that these groups would complement each other (e.g. planners being stronger on the demographics, the property experts stronger on the price indicators, but both with some knowledge of the other indicator). The sample completing the entire Delphi consisted of 18 members, a typical and sufficient number for a Delphi exercise (Amara and Lipinski, 1972). Table 2 gives the specialisms listed by each panel member.

The Delphi developed for Lothian was more ambitious than the previous 'transport impact' Delphi studies referenced above in terms of the spatial disaggregation, but considered fewer indicators as a result of this. The indicators selected were retail and office rents, and population distribution. Rents were selected due to their role as intermediary variables in market processes, and as indicators of demand changes. Population was selected as an example of planning data used in strategic planning. The 25 zones shown in Fig. 1 were aggregated to nine zones for the Delphi, as it was clear during piloting that forecasting for 25 zones was too arduous for a respondent to consider. The implications of this zoning difference are highlighted below.

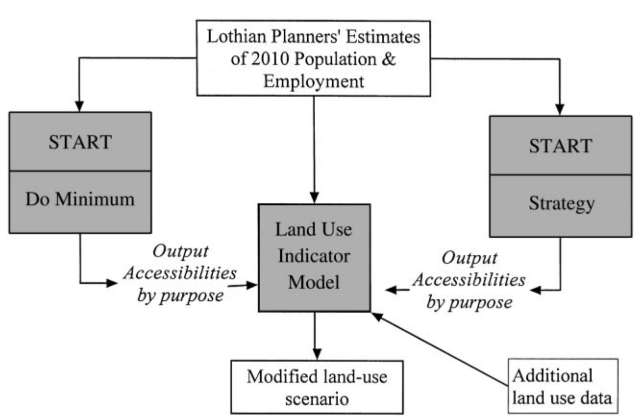

Fig. 2. Structure of the LUCI (and START) static land use model.

The aims of the questionnaire were to obtain responses regarding the expected trends in population distribution, office and retail rents over the next 15 years in each zone (i.e. a do-minimum forecast); and then the scale and timing of any changes (expressed as percentage changes from the do-minimum forecast year) due to the LRT strategy and the road pricing strategy.

In addition, respondents were encouraged to give reasons for their predictions, and space was given on the questionnaire for this (although responses were often limited). Two questionnaire rounds were undertaken over a period of six months. The general results showed a reduction in the standard deviation of the responses in the second round, suggesting that a better consensus was being obtained. However, resources did not permit more than two rounds of questionnaires to be undertaken.

3.3. Method 2: simple modelling—the static land use change indicator model

Static land use models can work in a variety of ways. The typical basis is that they allocate activities (i.e. population, households or employment) in response to changes in accessibility from a transport model. The land use change indicator model (LUCI) used for this study was originally developed in 1990 (Simmonds, 1991). The structure of the LUCI model is shown in Fig. 2. The model used exogenous population and employment forecasts supplied by Lothian planners in 1990. Spatial-interaction type accessibilities by trip purpose were calculated using these exogenous forecasts and the forecast year matrices of generalised cost from the START transport model. Changes in the pattern of forecast year accessibility between a do-minimum and a given strategy were used by LUCI to redistribute the future year population and employment (termed *activities*) relative to the do-minimum scenario (more details can be found in Roberts and Simmonds, 1997).

From Fig. 2 it is evident that time is not represented in LUCI. Rather the differences in accessibility act to relocate activities between zones, with the sensitivities determined by the calibrated co-efficients. For example, in the residential choice model, the following logit model was applied:

$$P_i^2 = P^* \frac{P_i^1 \exp(\alpha(A_i^2 - A_i^1))}{\sum_i P_i^1 \exp(\alpha(A_i^2 - A_i^1))}, \quad (1)$$

where P_i^2 is the new zonal population resulting from an accessibility change; P^* the fixed total study area population; P_i^1 the exogenously forecast do-minimum population of zone i; α the calibrated coefficient on accessibility; A_i^2 the accessibility to work for zone i for the transport strategy (2); and A_i^1 the accessibility to work for zone i for the do-minimum strategy (1).

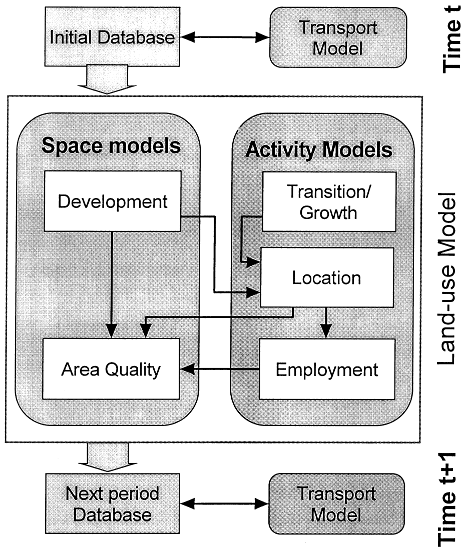

Fig. 3. DELTA land use model structure.

Retail and non-retail service employment were represented in a similar way (non-service employment was assumed not to be sensitive to accessibility changes), although a multiplicative function was found to allow the best calibration. Constraining the study area totals, the resultant incremental model for retail employment was:

$$E_i^2 = E^* \frac{E_i^1 (A_i^2/A_i^1)^\alpha}{\sum_i E_i^1 (A_i^2/A_i^1)^\alpha}, \qquad (2)$$

where E_i^2 is the modified zonal employment in zone i; E_i^1 the do-minimum retail employment in zone i; E^* the fixed study area total retail employment; A_i^2 the accessibility (to residents) by zone for the transport strategy; A_i^1 the accessibility (to residents) for the do-minimum strategy; and, α the coefficient on accessibility.

Other than changing accessibility, all other variables in the urban system that could influence location choice were assumed constant (although some static models can represent floorspace supply and market clearing mechanisms). LUCI, as implemented neither included any of these feedback relationships nor any constraints concerning the amount of land or floorspace available in each zone. For these reasons the model outputs are termed *indicators* rather than forecasts, as they are both simple and abstract measures.

The model, not being iterative, could be run very quickly once set up, and required minimal additional resources beyond the transport model. The LUCI model had been previously calibrated using cross sectional data (Simmonds, 1991), and used the zoning system shown in Fig. 1. However, it did not extend into Fife; zones 24 and 25 (unfortunately to implement the model for these zones was beyond the resources of this study).

3.4. Method 3: the land-use/transport model: DELTA/START

Significant study resources were devoted to the development of a linked land-use/transport model for the Edinburgh study area, in conjunction with David Simmonds Consultancy and MVA. The START model formed the transport model (as with LUCI), but was modified to run dynamically at intervals of two years. To this was added a new land use model, DELTA, which represented the urban processes of development, demographic and economic (employment) change, location choice, changes in urban area quality and employment market matching. The philosophy underlying its design was that the submodels represent familiar urban processes (and associated markets) that were felt to be important in urban development. In particular time is explicitly incorporated, with the model moving forward in two year steps, which allows time lags to be represented (such as in the construction of floorspace).

The main sub-models of DELTA, and their linkages in one time period, are shown in Fig. 3. Some of the model system's key equations related to choices are presented below.[1] Note that feedbacks and lags over time are as important to the model's operation as the links within one time period. Indeed, the model is largely incremental in operation, taking a detailed representation of the base year (1991), and forecasting changes from this situation.

Further details on the DELTA design can be found in Simmonds (1999) and on the implementation in Simmonds and Still (1997).

The *development model* of housing and commercial floorspace represents the private sector development process for greenfield and brownfield sites. The model initially calculates the (unconstrained) demand for floorspace, for example;

$$F(U,G)_t^u = \alpha_t^u \sum_i F_{ti}^u \left\{ \frac{\sum_i (r_{ti}^u - c(G)_{ti}^u) F_{ti}^u}{\sum_i F_{ti}^u} \right\}^{\beta_t^u}, \qquad (3)$$

where $F(U,G)_t^u$ is the total unconstrained floorspace of type u to be started in time t on Greenfield sites; α_t^u a scaling parameter for the entire function; β_t^u a parameter expressing the elasticity with respect to average profitability; F_{ti}^u the floorspace in zone i of type u in time t; $c(G)_{ti}^u$ the cost of building floorspace type u during time t on Greenfield sites; and r_{ti}^u the rent of floorspace type u in zone i in time t.

The term in the main bracket in Eq. (3) represents the average profitability of starting to build floorspace of type u on Greenfield sites. This development is then constrained following the notion that developers will seek to retain a stock of developable land, and will not use all of their stock

[1] Note that the equations presented were taken from the DELTA reference manual (David Simmonds Consultancy, 1998), and that the design of the DELTA model was not an element of this research project.

within one period (how much they develop will depend upon the size of $F(U,G)_t^u$ relative to the total available stock). Development is then allocated to zones on the basis of zonal expected profitability using a weighted logit formula.

Demographic change is represented via a Markov-chain type 'transition' model of probabilities that households of one type will transform into other types (e.g. by the processes of childbirth, children leaving home, migration, divorce, death, etc.). The transition rates were calculated from the British National Household Panel Survey (Buck et al., 1994). In and out migration was taken from previous Census estimates, and study area *employment growth* by sector from local authority Structure Plan forecasts.

The *location choice model* for employment and households takes into account several factors influencing location choice, namely utility of consumption, accessibility, area quality and transport related environmental quality. The utility of consumption for each household is calculated using a Cobb–Douglas function based upon two goods; space demanded, and all other goods and services (OGS). Households are assumed to adjust the mixture of OGS and space until they maximise their utility of consumption. For each household type the change in the utility of location is then calculated as:

$$\Delta V_{ti}^h = \theta^{hU}(U_{ti}^h - U_{(t-n)i}^h) + \theta^{hA}(A_{ti}^h - A_{(t-n)i}^h) + \theta^{hQ}(Q_{ti}^h - Q_{(t-n)i}^h) + \theta^{hR}(R_{ti}^h - R_{(t-n)i}^h), \quad (4)$$

where ΔV_{ti}^h is the change in total utility to be gained in a zone for a given household type; U_{ti}^h the utility of consumption for households h locating in zone i at time t; A_{ti}^h the accessibility of zone i for household type h at time t; Q_{ti}^h the quality of housing in zone i at time t; R_{ti}^h the transport related environmental quality as perceived by households h in zone i at time t, and; θ are parameters on each term which determine the relative sensitivity of households between accessibility, the environment, quality and utility of consumption, and also the overall sensitivity of households to each factor.

Note that more complex accessibility measures were used by DELTA, being specific to each activity type. The $(t-n)$ subscripts show that the change in the variable can be from the previous time period, or from several time periods ago. This change in utility ΔV_{ti}^h is then used in an incremental logit model location function to locate households for that given year, expressed as:

$$H_{ti}^h = H_{t^*}^h \cdot \frac{H_{ti}^h.(F(V)_{ti}^h/F_{ti}^h)\exp(\Delta V_{ti}^h)}{\sum_i H_{ti}^h.(F(V)_{ti}^h/F_{ti}^h)\exp(\Delta V_{ti}^h)}, \quad (5)$$

where H_{ti}^h are households of type h choosing zone i in time t. $H_{t^*}^h$ are the total number of households to be located H_{ti}^h are the households of type h living in zone i at current time t F_{ti}^h is the total residential floorspace for at this time $F(V)_{ti}^h$ is the available floorspace in the zone ΔV_{ti}^h is the change in utility of location as in Eq. (2).

The location model iterates, adjusting rents until all the 'mobile households' are located. Note that most households remain 'immobile', i.e. not changing location or entering the property market in any one time period. Employment activities use a similar, but simpler form of Eq. (4), with the utility of consumption for households replaced by cost minimising behaviour, and the environmental variables excluded.

Once activities are located in zones, the demand for employment must be met by the available workers in the study area. An *employment matching submodel* thus adjusts the number of workers in households until the supply matches the demand. Note that the system is modelled as a single labour market, i.e. the location of a household relative to a job has no bearing on the likelihood of a worker obtaining that job.

Finally, the *area quality model* represents changes in the quality of the urban fabric as a linear lagged function of the average income of the residents living there.

The DELTA model is designed so that the individual submodels are calibrated individually, and follows the ideas used in the various implementations of START (Roberts and Simmonds, 1997) of using pre-existing parameters for model sensitivities, from a variety of sources. The parameters in the *development model* were estimated from changes in available floorspace data over time, although the tight planning controls in Edinburgh meant that development tended to occur as and when land became available. The co-efficients for the *transition model* have already been outlined. Existing cross sectional calibrated co-efficients from elsewhere in the UK were used for the *location model* (later enhancements to the parameters from stated preference research are reported in Wardman et al., 1997).

3.5. Initial assessment of the validity of the methods

How valid is each of these methods for assessing transport impacts on land use? The three methods represent different places on the spectrum of forecasting methods that are available for spatial planning (from Table 1), and it is useful to highlight the central differences in their approaches.

The distinction between the Delphi and the more formal modelling approaches is straightforward. The Delphi approach does not use a mathematical model, or any explicit accessibility measure. Instead it relies upon the judgement of its panel. As such, while the models are deductive in approach, the Delphi is inductive; making use of the mental models of the panel members.

The key difference between the LUCI/START and DELTA/START modelling approaches is that the former uses exogenous planners' forecasts, while the latter generates its own unique forecast. DELTA represents the effects

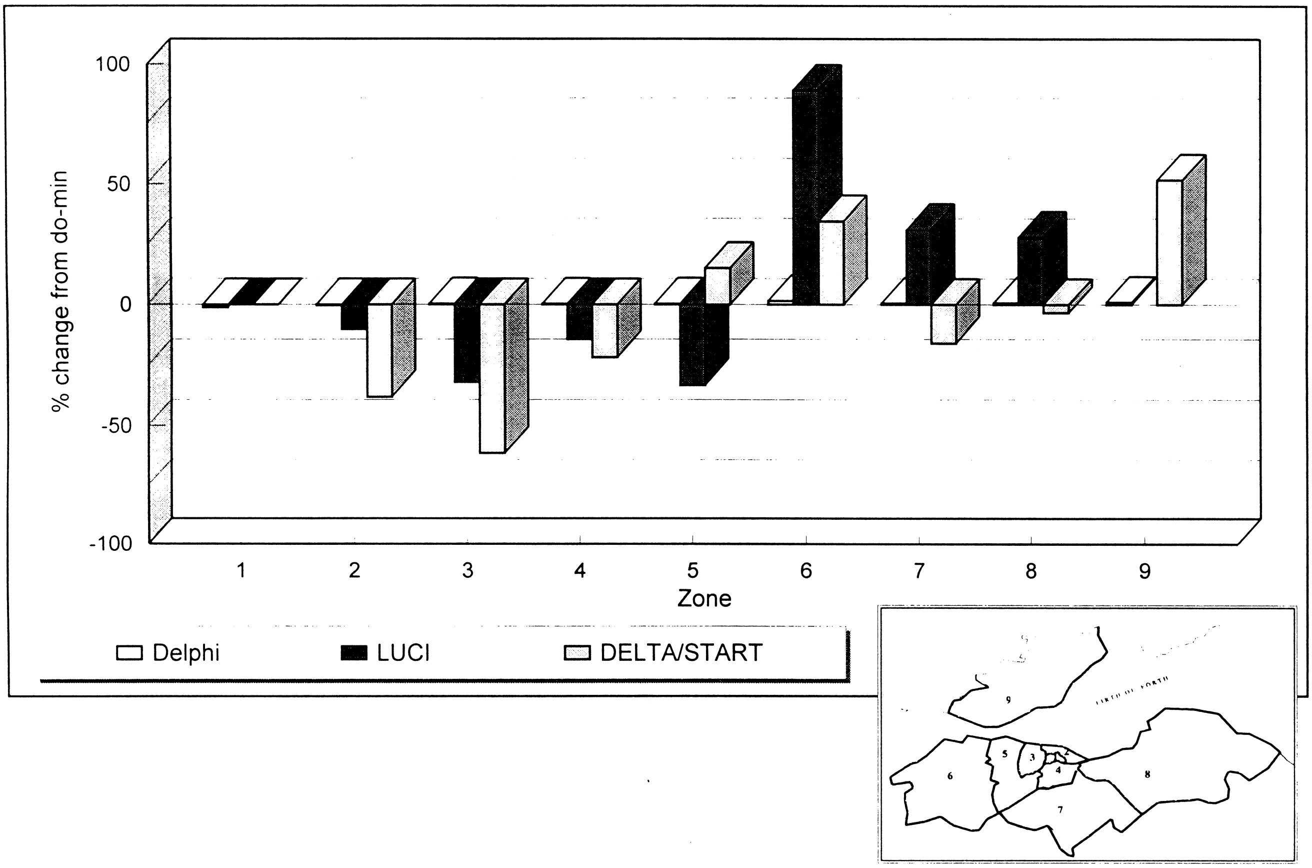

Fig. 4. DELTA/START, LUCI, Delphi: Do-Minimum population changes. Percentage changes 1991–2011 (Delphi zones).

of several influences on location choice considered by the model developer to be important (such as floorspace constraints, environmental conditions, rents and demographic change), while LUCI only represents accessibility. LUCI uses accessibility by travel purpose only, while DELTA calculates an accessibility for each activity summing over relevant travel purposes. Finally, DELTA follows a behavioural and process based approach (incorporating supply side constraints), while LUCI takes a much simpler, but less intuitive structure, with no supply side constraints.

Several factors serve to limit the validity of each approach as applied here. The Delphi cannot offer a clear or unified explanation for its forecasts, and can give only a selection of indicators with limited spatial disaggregation, given the demands this places on the panel. The LUCI method holds many variables constant, has no process based structure, and is very dependent upon the quality of the local area calibration. DELTA is very complex, and implementing the model is a significant undertaking. It also places higher demands on the linked transport model. It too requires some local calibration, but places greater reliance on the notion of ‘adaptable co-efficients’ from other research.

As a result, there is little doubt that, from a research perspective, the ‘theory rich’ DELTA approach, incorporating the main land-use–transport interactions considered important for examining impacts, and producing a wide range of indicators, is preferred to the simple but less robust LUCI approach. The Delphi method is much more of a complement than a substitute, being an entirely independent source of forecasts, but is severely limited by the amount of data that can reasonably be obtained.

4. Comparison of the results from the three methods

4.1. Introductory comments: comparison of the do-minimum situations and policy tests

All reasonable efforts were made to ensure that the starting situations of the methods were comparable in terms of the starting year data, zoning and do-minimum forecasts, although differing model requirements meant that they could not be identical.

In terms of data for the starting year (1991), for the Delphi, initial base year population and rent estimates by zone were not supplied to the panel. An option to supply these was rejected due to the additional data burden that this would have placed on the respondents. The Delphi therefore

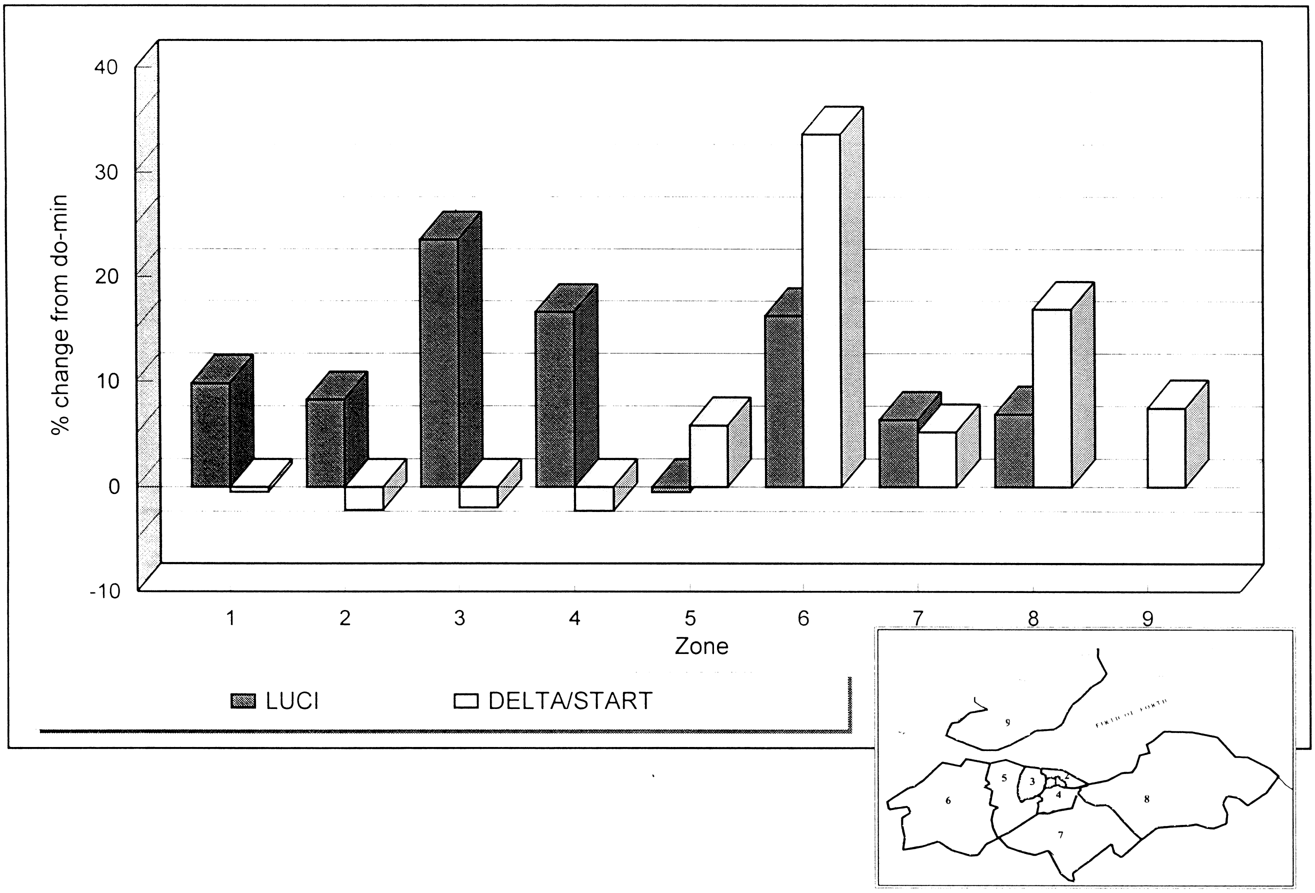

Fig. 5. DELTA/START, LUCI, Delphi: Do-Minimum employment changes. Percentage changes 1991–2011 (Delphi zones).

relies upon the panel having an understanding of the current situation in the study area.

More important were differences in the zoning. There are two issues here, firstly the more aggregate zoning used in the Delphi, and secondly the inclusion of Fife in the DELTA model. The implications of different zoning systems were discussed in depth with the planners (see below). However, at this point it is clear that (1) the Delphi technique is limited in spatial resolution due to the demands this would place on the panel to estimate a large number of impacts, and (2) within the DELTA/START system, activities have the option to locate in Fife, which they do not in LUCI/START. This means that the same policy applied in both systems would be expected to give slightly differing locational impacts.

There were some differences in the implementation of the do-minimum strategies (and hence in the results, see below). In DELTA, as outlined above, floorspace allocations were obtained from the structure plan, and then the model decided whether they were developed and occupied. In the LUCI model, these steps are determined by the planners themselves in producing the original exogenous population and employment forecasts.

These differences in the base assumptions do of course make systematic comparisons between the methods more difficult. Certainly some of the inconsistencies could have been overcome if further resources had been available, for example, to implement the LUCI model for the Fife zones. Nevertheless, as the key comparisons were to be made on the differences between the respective do-minima and the policy tests, it was felt that informative comparisons could still be made.

4.2. The do-minimum

Figs. 4 and 5 present some illustrative results for the population and employment do-minimum forecasts. This is given in the nine-zone system used in the Delphi survey, and hence the zone numbers in the text below refer to the Delphi zoning (the more detailed model forecasts were aggregated to the Delphi zone level).

From Fig. 4, it is clear that there is disagreement between the methods on the distribution of population change, in some cases in terms of direction, but mostly in terms of the magnitude of impact. The Delphi results predict growth throughout the study area, but are of a much lower magnitude (around 5%) compared to the planners' predictions used from LUCI, or the DELTA model. By far the largest population growth was forecast by Lothian planners

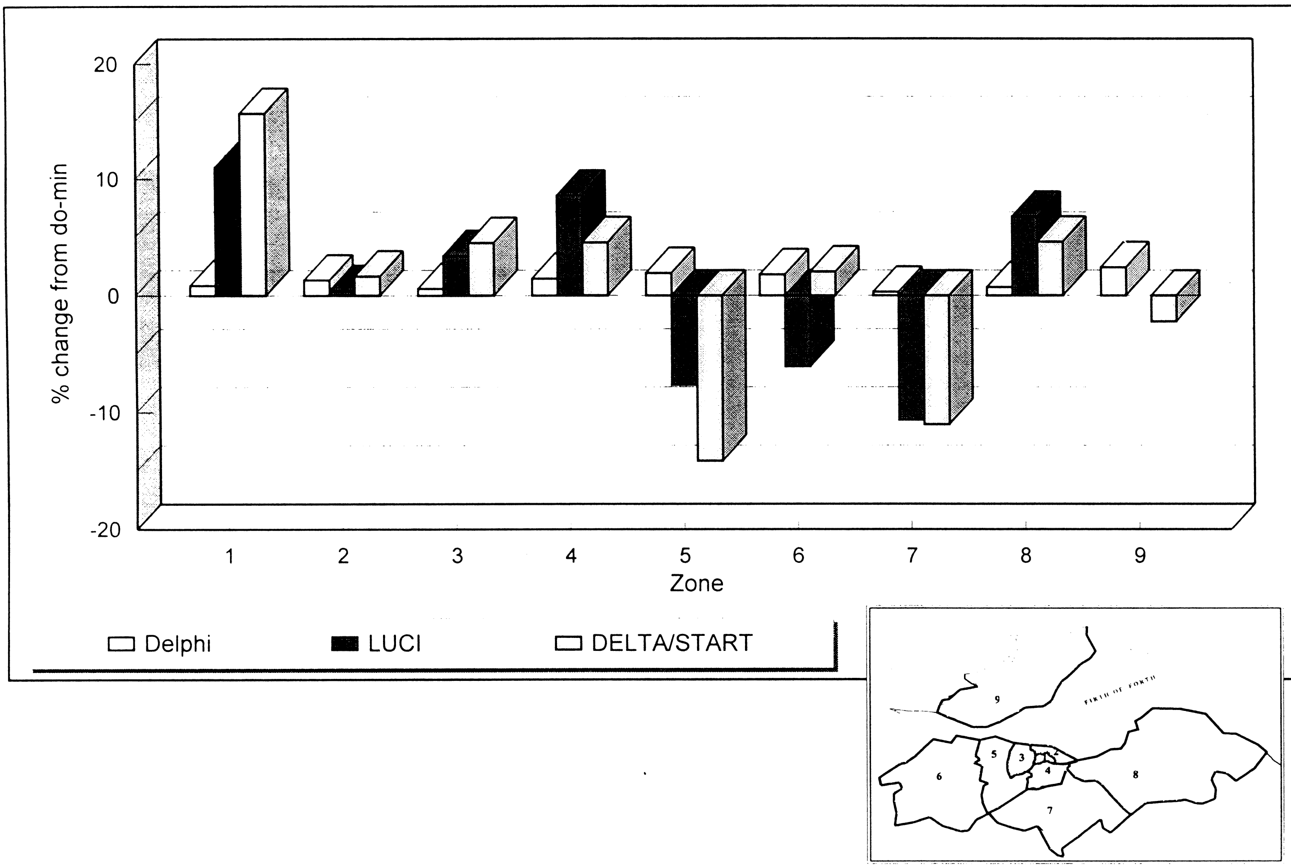

Fig. 6. DELTA/START, LUCI, Delphi: Do-Minimum population impacts from LRT. Percentage changes from respective 2011 do-minima (Delphi zones).

for West Lothian (Delphi zone 6), which is also the zone of absolute highest growth for DELTA.

The DELTA model and the planners providing the LUCI forecasts also gave estimates on the distribution of employment growth (Fig. 5). While the Lothian planners (LUCI estimates) predicted further growth in the centre, the DELTA model estimates greater decentralisation of employment. This can be traced to the availability of floorspace in the outer areas, coupled with lower commercial rents than in the city centre or the rest of Edinburgh. Both LUCI and DELTA estimate employment growth in the Gyle edge of town commercial centre (Delphi zone 3), although for DELTA at the START zone level there are declines in surrounding zones, giving a net fall in the larger Delphi zone. This is a good example of how the changes in zoning can influence the interpretation of results.

In short, the do-minimum forecasts appeared different, but each represented a degree of net decentralisation over the forecast period. Further, the differences, especially between the DELTA and LUCI models, were explainable. One area of concern remains why the Delphi forecasts of change in distribution were low for all indicators (and constant across zones) compared to the models. The models were clearly more sensitive to likely future supply conditions than were the judgements of the Delphi panel.

4.3. The impacts from the transport tests on population

Fig. 6 shows that LRT is forecast by the models (although not by the Delphi panel), to have a large impact on the distribution of population. This is due in part to the high frequency of the LRT service in the transport models having a large influence on accessibility. In addition to this, in DELTA/START land use shifts occur over time, which reinforce the patronage of LRT, with higher growth in zones along LRT corridors. LRT is predicted by all the methods to encourage population centralisation in Edinburgh. This is due in the models to the response to improved zonal accessibilities.

Fig. 7 shows that all the methods' predictions agree that the impact of road pricing on population distribution in the city centre is slight, relative to the changes resulting from the LRT. Elsewhere the impacts on population are also minor, with DELTA predicting growth in the south and west of Edinburgh. The Delphi predicts a similar pattern of increased population decentralisation, but to zones outside the city. The LUCI model predicts that population rises slightly in the city centre, due to a small improvement in accessibility caused by reduced congestion. This improvement is not seen in DELTA/START, in which there was a rise in single person households in the city centre, relative to other household types. This illustrates

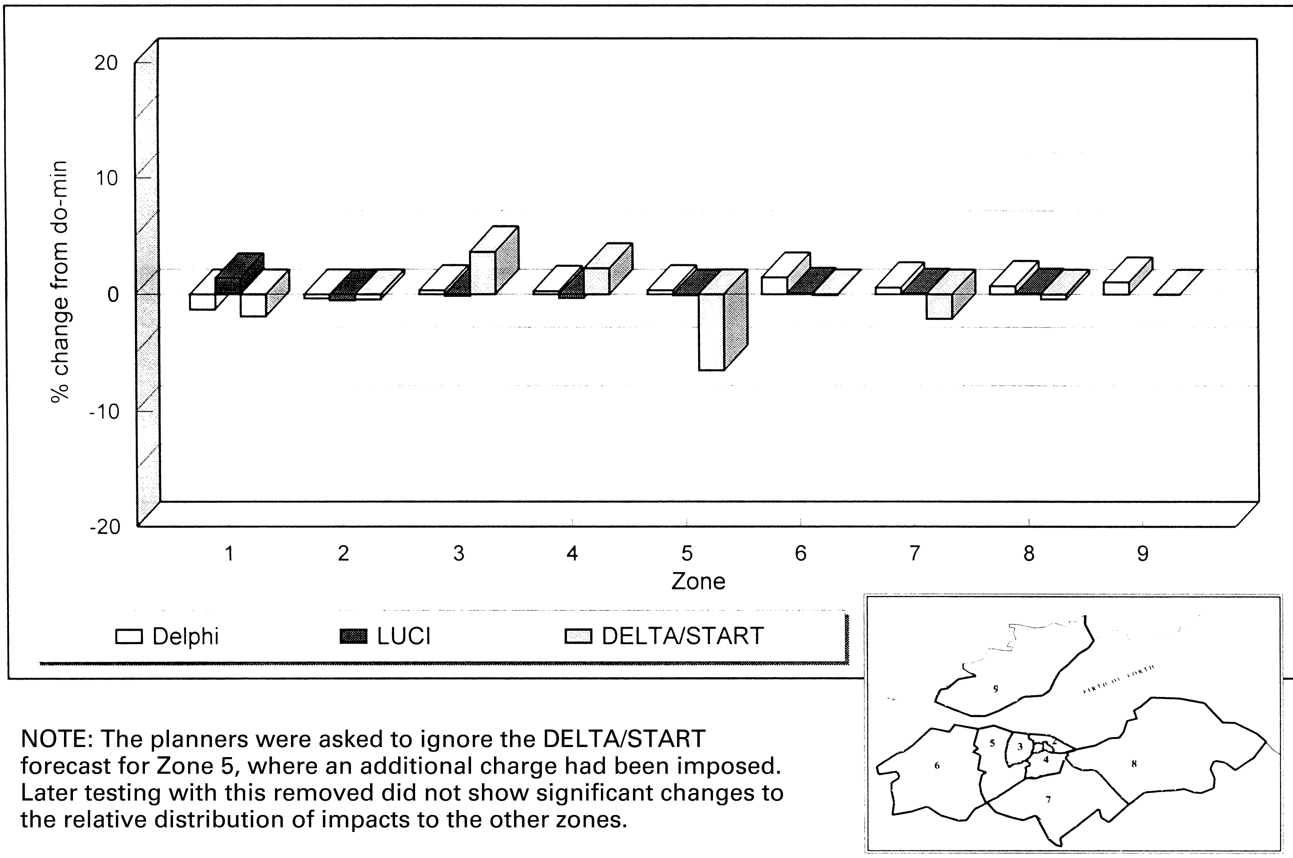

Fig. 7. DELTA/START, LUCI, Delphi: Do-Minimum population impacts from road pricing. Percentage changes from respective 2011 do-minima (Delphi zones).

how more complex land use models can reflect changes in the composition of households in different areas.

4.4. The impacts from the transport tests on employment and commercial rents

The predicted impacts on commercial activities and rents are more marked than on population. Fig. 8 shows the employment impacts from the LRT. Both models (plus the rent indicators from the Delphi), estimate that the city centre will benefit in terms of jobs and/or incur higher rent levels from the LRT. Growth continues in DELTA until supply side constraints affect in the city centre several years after the introduction of the LRT. There is a general pattern of lower growth or decline in the other zones (relative to the do-minimum) to compensate for this. Note that the larger percentage changes predicted by the LUCI model for Delphi zones 6 and 7 are a little misleading, as these are relatively small absolute figures. Overall, the models agree on the direction of change for about 80% of the START zones.

The impacts from road pricing are not as large as from the LRT (Fig. 9). The main effect was the negative impacts on employment within the cordoned area (Delphi zone 1). The Delphi panel and DELTA also predicted strong depressive effects on office and retail rents within the cordon. Again, the magnitude of the change forecast by the DELTA model was greater than that given by the Delphi panel. The LUCI model predicts a relatively even pattern of increases elsewhere, not focusing on the Gyle developments, but responding only to the zones where accessibility remains highest. The DELTA model shows more growth where available floorspace is greatest outside the city, for example Zone 6 (West Lothian).

4.5. Initial assessment of the plausibility of the results

While the main focus of the research was on planners' assessments of the plausibility of these forecasts (described in the next section), some comments at this stage are appropriate. The results need to be treated with caution, since the range of tests is small, and the sensitivity of the approaches to different price and frequency levels is thus not known. While the methods all predict some decentralisation, the differences between them are marked. The smaller, more uniform distribution of changes predicted by the Delphi panel, appear very cautious, and the rationale behind them cannot be tested. These factors must serve to limit its plausibility. Moreover, the detail of the Delphi results is also constrained by the more aggregate zoning pattern.

The distribution of relocation among outer zones appears

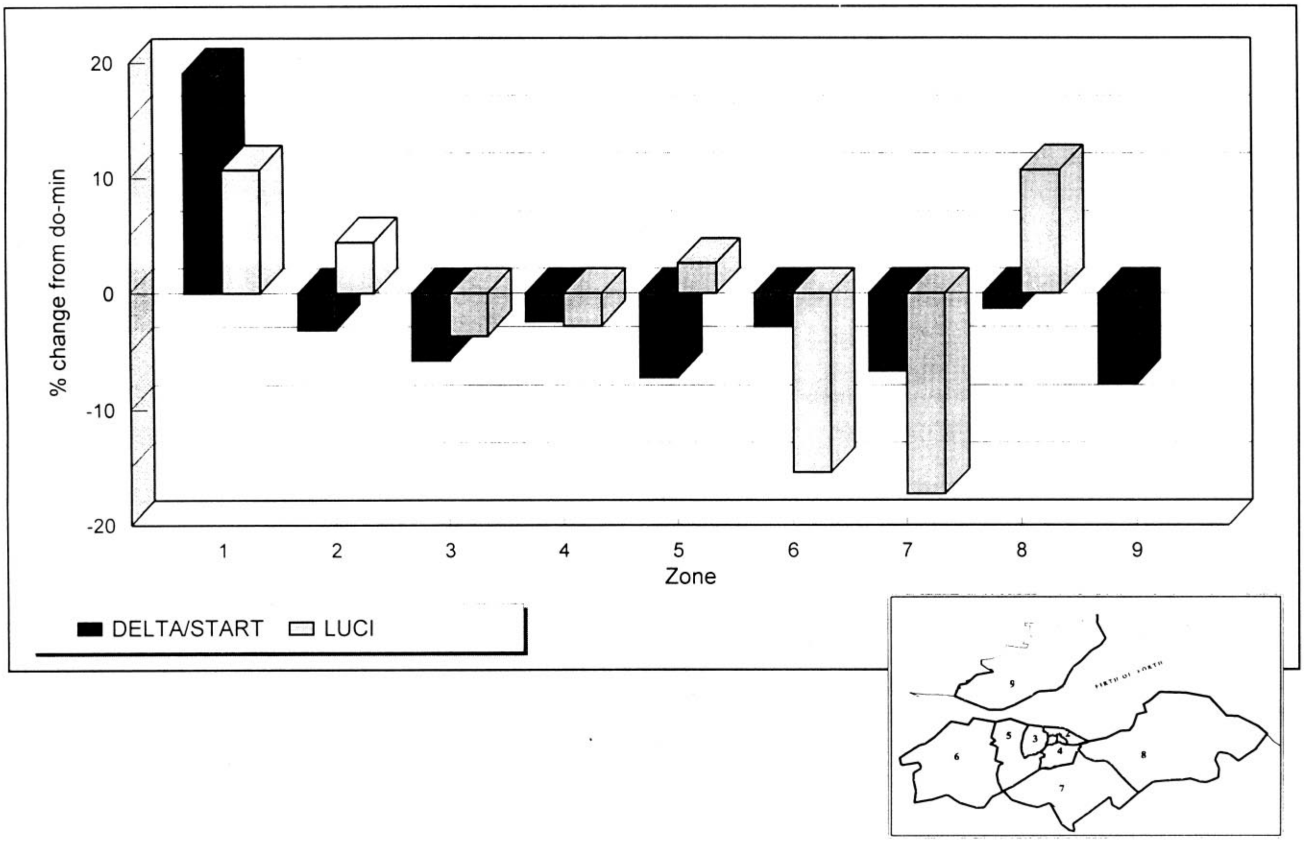

Fig. 8. DELTA/START, LUCI, Delphi: Do-Minimum employment impacts from LRT. Percentage changes from respective 2011 do-minima (Delphi zones).

more plausible in DELTA than in LUCI as the growth in individual START zones is not so extreme (particularly in areas of potentially high growth such as The Gyle); this is explained by the floorspace constraints and rent mechanisms in DELTA, which prevent unfeasible growth beyond supply capacity.

However, the relative scale of impact of LRT and road pricing in both LUCI and DELTA is perhaps surprising, and would merit testing with a range of frequencies and prices. It is particularly high compared to general conclusions from several empirical studies (e.g. Grieco, 1994; Walmsley and Perrett, 1992), although it must be remembered that Edinburgh itself is a city with high economic growth, and this was predicted to continue in the modelled scenarios. The centralisation of population resulting from LRT in both LUCI and DELTA is the prediction which appears least consistent with past studies (e.g. Kreibich, 1978). One factor of importance is that the LRT as implemented only served the inner zones, which thus attract population from the outer suburbs. This highlights the importance of examining changes over a wide spatial area.

5. The planner interviews

Information on the methods (similar to that given in this paper, but excluding any mathematical specification), plus more detailed results, were given to an ‘evaluation panel’ of strategic planners (both land use and transport) from the Lothian Region study area. The sample were asked to fill in a questionnaire, and interviewed to determine their views on the relevance of the methods and forecasts to UK strategic planning. This element of the research was undertaken in 1996.

Given the very specific subject area for these interviews, a statistically significant sample was impossible and it was realised at the outset that the sample of suitable planners would be very small. In the event the interview sample consisted of six planners employed by different planning organisations concerned with structure planning in the study area. Their fields of work covered land use and transport planning, research, method selection and policy formulation.

The issue of whether this sample size was sufficient for meaningful analysis was given considerable thought. The sample size within the study area could not have been increased easily, and obtaining another sample from planners in another region would not have been appropriate, as they would not have familiarity with the study area. The small number of key planners with strategic experience of the Lothian region were all in the sample, and given the general consensus that emerged during the interviews, the

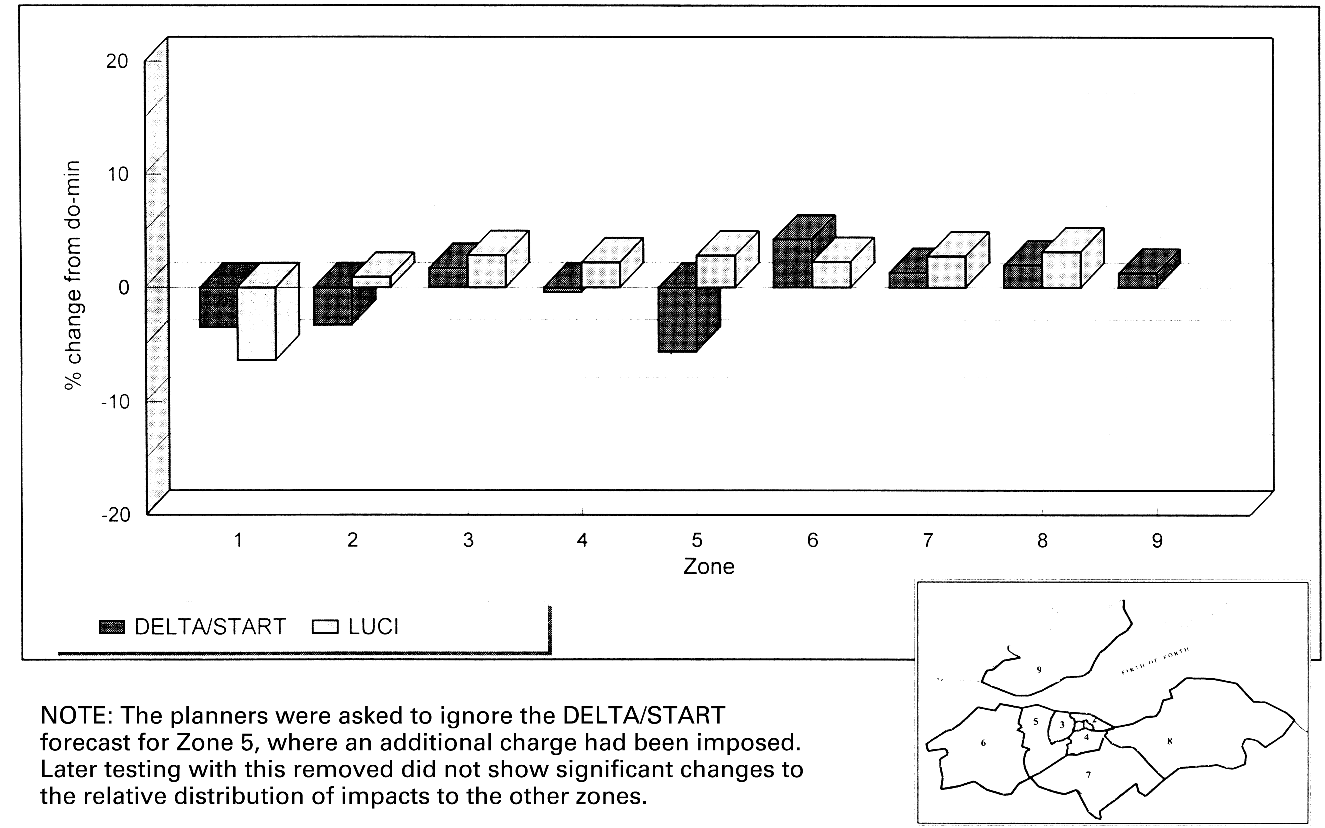

Fig. 9. DELTA/START, LUCI, Delphi: Do-Minimum employment impacts from road pricing. Percentage changes from respective 2011 do-minima (Delphi zones).

sample size was considered sufficient for general conclusions to be drawn concerning the appropriateness of these types of methods in this type of planning regime.

Care had been taken not to involve potential members of the evaluation panel in the Delphi study (although some members were used in the Delphi piloting).

The planners were asked to consider the appropriateness of the methods based on four criteria:

1. The relevance of the indicators produced by the methods.
2. The validity of the methods used.
3. The plausibility of the results produced.
4. The importance of these methods to different aspects of planning.

Each criterion was divided into several questions, which are discussed in detail in Still (1997). Here a summary of the main findings are presented.

5.1. Relevance and choice of indicators

This topic involved identifying the most appropriate forecast variables and level of segmentation. Those indicators considered essential for planning tasks tended to be 'final' outcomes, such as the estimates of the distribution of households, population and employment. These were important because of their current role in conventional transport forecasting, and planning work. The planners treated those indicators with which they were unfamiliar with caution, both in terms of how they would make use of such indicators in planning, and of whether the results appeared sensible. This caution applied especially to those indicators from DELTA/START which were relatively novel, such as the disaggregations by socio-economic group or household type.

The planners were more interested in 'horizon' years, than outputs for intermediate years. Clearly this suits methods, which only work to a given forecast year (Delphi or LUCI), and indicates that the temporal data, while essential for the theoretical underpinning of any comprehensive land-use/transport model, has limited appeal as an indicator in itself.

The choice of spatial scale was very important. The planners wanted information on a fine scale, in order for the distribution of the impacts to be clear. However, all the methods in this study used large 'strategic' zones, often of widely differing size, with finer zoning focusing only upon specific (and pre-determined) areas of interest (typically the city centre). However, several planners noted that too many zones can hinder analysis and hence different levels of planning require different levels of aggregation. The implication is that the methods need to work with fine zones, that can be aggregated to meet individual authorities' needs.

5.2. Validity of the methods

This topic focused upon the planners' views of the methods in general, regardless of the results they produced in this study. As expected, their views reflected their stance on modelling in planning generally, and in particular the additional complexity for transport modelling implied by the incorporation of land use. The planners had varying levels of experience with land-use modelling methods, but less knowledge of linked land-use transport models such as DELTA. Without this understanding the planners felt that the models were still akin to a 'black box' approach. This implies that for real policy testing studies, a great deal of interaction is necessary between the modelling team and planner clients during complex model-based projects to explain the operation of the models.

Despite this, complexity was perceived by the planners as beneficial if it made explicit the processes that underlay the model results. For example in DELTA, the production of intermediate indicators such as rents and accessibilities was seen to aid transparency. It was clear from the interviews that the transparency criterion contributed a great deal to the planners' confidence in a given method. In contrast to DELTA, the Delphi was criticised as offering little formal explanation of the views of the sample (a criticism of this application rather than of Delphi surveys in general). Several planners commented that if they had greater knowledge of who comprised the panel of experts, they would be in a better position to appraise the results (although clearly this runs counter to the emphasis upon anonymity in the Delphi methodology).

Several planners mentioned two other factors that contributed to gaining confidence in a model-based method: firstly technical issues, such as the ease of calibration, validation and use of the model, coupled with the plausibility of the forecasts (see below); and secondly qualitative issues, such as the reputation of the model and the modelling team, perception of the success of past applications, and the training provided by the modelling team in the use of the method. The use of START (in both LUCI and DELTA) was significant here, being a transport model already well accepted by the interviewees and their organisations.

5.3. Plausibility of the results

The planners were asked to assess the forecasts of land use response (note that the planners were given more detailed results than presented in this paper). However, it proved difficult to separate the plausibility of the forecasts from the confidence in the method used to produce them.

As a starting point for their analysis of the results, several planners used the do-minimum forecast for each method and compared them against their own local knowledge of likely changes in the study area. The City planners tended to take the LUCI do-minimum forecasts as being most plausible, because they were derived by the former Lothian Regional Authority, and hence reflected an official view. This meant that the DELTA do-minimum was seen as more plausible than the Delphi, because it was closer to the Lothian forecasts in the LUCI model. Consequently, the Delphi forecasts did not fare so well. For example, there was a suspicion of strategic bias in the Delphi results, with members of the panel being suspected of opposing road pricing in central Edinburgh. One planner was critical of the Delphi results because of the 'positive' bias in its do-minimum forecasts (where no zone in the study area was forecast to undergo absolute decline in either population or the rent indicators). From these discussions it was clear that the do-minimum was an extremely important benchmark for the planners.

In determining the reasonableness of the forecast impacts of transport on land use there was much less to serve as a benchmark for comparison, as the planners had fewer preconceptions about what the distribution of impacts was likely to be. The LRT test was most contentious, with the planners not in agreement about the land use responses. For example, the impacts of LRT leading to household centralisation, as predicted by all the methods, ran counter to several planners' preconceptions. Another planner thought the LRT and road pricing results from the models were reasonable, but that the magnitudes of change were too high. This raises the important point that the relative impacts between zones can still be of interest, even if the absolute impacts were considered too large (in the case of DELTA LRT impacts), or too small (in the case of the Delphi).

5.4. Overall importance for planning tasks

The planners were asked about the types of planning tasks for which methods of assessing transport impacts on land use were relevant. In answering this question, the sample discussed planning in general, rather than their specific activities, and the comments were relatively consistent within the sample.

A task identified by those with land use planning backgrounds was in testing the links between land use and transport plans for the early stages of structure planning, when the broad impacts of policies were being examined. In particular this was related to how transport could influence the city's urban regeneration initiatives, and whether synergy could be obtained between land use and transport policy.

However, the main purposes identified by both land use and transport planners still focused on transport planning tasks, such as the appraisal of potential transport policies, their sensitivity to land use assumptions, and environmental impacts. The ability of land-use/transport models to show changes in trip distribution patterns over time was considered an important contribution to improving transport forecasting.

Thus in general the planners' comments were very favourable towards incorporating the assessment of transport impacts on land use into planning. However, the planners would not commit themselves upon whether the future forecasting commissions would incorporate these relationships, the key issue being that of additional cost. In other words the examination of transport impacts on land use within a modelling framework was still viewed as something of a luxury in the UK, given the lack of a policy requirement to do so.

6. Discussion

The application of different methods with common policy tests to a common study area is rare. Some examples do exist, for example the different models applied to the same cities in Phase Two of the International Study Group on Land Use and Transport Interaction (e.g. Mackett, 1991, 1995; Wegener et al., 1991), and Anderstig and Mattsson (1992), who applied four appraisal methods for assessing economic impacts from transport schemes in Stockholm.

None of these studies aimed however to examine which methods best met planners' requirements. The 'evaluation panel' methodology adopted in this research, given the small number of strategic planners in a given study area, coupled with the need for the methods to be of local interest to the planners (to obtain participation), is inevitably qualitative and somewhat subjective. This is further hampered by some inconsistencies in the methods such as the lack of a common zoning system, which limits a very detailed comparison between the methods and their results. Further, there are clearly limits to the generalisations that can be made from using an evaluation panel, as the needs of planners in different urban areas will vary.

However, the lack of totally consistent methods did not prevent the evaluation panel from examining the results, and responding to the four criteria discussed above. Further, the consensus in the responses from the panel did imply that some general views were being obtained about the three very different methods tested. Finally, given that planners in different cities do not operate in isolation from one another, it is felt that some general conclusions can be reached.

The two key issues to emerge from the research are those of zoning and method complexity. Zoning proved a key constraint during the application of methods because once imposed it is very difficult to adjust. Further, the level of zoning affects the results of the modelling. The evaluation panel was keen to have finer zoning, and there is no doubt that land-use response methods must move in this direction (subject to being able to aggregate zones for presentation and policy interpretation). However, it is important not to confuse fine zoning with more precise or accurate results. Fine zones impose high demands on data availability, and could potentially result in data such as floorspace or employment simply being artificially subdivided into fine zones. In such cases it would be more valid to remain with coarser zones, rather than risk potentially spurious model results.

A research-oriented planner in the sample commented that Geographical Information Systems (GIS) could offer a way forward, by permitting point based or very fine zone data. Examples of this do exist (e.g. Landis, 1994; Wegener and Spiekermann, 1995), but to the authors' knowledge, have yet to find practical policy applications. The possibility of combining GIS with land-use/transport models is an exciting prospect that needs to be examined in detail.

The issue of method complexity is perhaps the most difficult to summarise. The evaluation panel considered modelling methods to be more flexible and reliable than the Delphi expert opinion method. This is not surprising, and reinforces the conclusions from earlier interviews with planners in the USA (see Still, 1996) who considered that a modelling framework offered distinct advantages (of both forecasting flexibility and political credibility) over expert surveys or group discussion.

The evaluation panel also favoured the more complex modelling approach in DELTA over the simple static LUCI model. This is based upon the view that the more complex model is (1) easier to conceptualise as it described observable urban processes, and (2) provides a greater range of indicators to explain its operation. It is therefore more 'transparent' in that the results can be examined in intuitive ways, that are impossible with the LUCI model as implemented, and more difficult with static models in general. At the very least static models should include some representation of floorspace constraints and market mechanisms.

7. Conclusions

This paper began by arguing that the impacts of transport on land use are not consistently examined within strategic urban planning, and that many planners recognise this. Three methods to examine such impacts were applied—a Delphi study, a static land use indicator model (LUCI) and a full land-use/transport model (DELTA/START)—and the results were assessed by strategic planners practising in the study area. Care must be taken with the general applicability of these results, but it was concluded that the panels' comments would have relevance to those working in this subject area.

The methods themselves used different approaches, and produced differing distributions of impacts. This largely reflects the differing relationships (and their complexity) included within the models, although for the Delphi it was difficult to determine the mechanisms at work.

The panel evaluation interviews identified several criteria which any method for forecasting land use response to transport policy needed to satisfy. These can be grouped as follows:

1. There must be confidence in the method by the planners; this includes understanding:

- the theoretical structure(s) underlying the method;
- the relationships incorporated, and any assumptions;
- key sensitivities (for example to accessibility in model-based methods).

2. The method must be capable of producing forecasts of households, population (including workers) and employment indicators.
3. The method must be able to use a zoning disaggregation that is both sufficiently fine, and can be aggregated up into appropriate planning units (such as local authority districts).
4. The method must produce, or make use of, a do-minimum that the planners endorse.
5. The method must be as ‘transparent’ as possible to enable explanation of the results.

It was clear from the planners’ assessments that a land-use/transport modelling framework, that is intuitive and internally consistent, is best able to meet the ‘transparency’ criterion. However, if a modelling framework is complex and places high demands on the users in order to understand the model (to correctly the explain results) then confidence can be lost as a result. This was certainly an issue with the DELTA/START framework.

With regard to other methods, the Delphi approach can be seen as limited, but complementary to modelling work, whereas static land use models offer a relatively cost-effective method of examining land use issues, but fall short of offering a strong theoretical or transparent approach, and hence are limited in their explanatory power. This weakness is important, because any method must engender confidence through both its technical merit, and a clear process by which the plausibility of the results can be determined.

In conclusion, land-use/transport modelling methods appear best able to meet criteria 2–4, although some issues of spatial disaggregation remain. The key area is criterion 1, where land-user/transport models must aim to maximise explanatory power with minimal complexity.

Clearly, more use of these techniques will increase our awareness and understanding of the linkages between land use and transport. However, the sample of planners suggested that such methods are likely to enter mainstream use only if their costs can be reduced, or if there is a policy requirement to do so. Given the importance of understanding the impacts of land use on transport, future revisions to planning guidance should ideally incorporate such a requirement.

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