THE USE OF LAND-USE/ECONOMIC MODELLING IN TRANSPORT PLANNING: EXPERIENCE WITH DELTA

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ABSTRACT

This paper reviews the different ways in which land-use and economic modelling can contribute to the transport planning process, and considers some of the issues that arise in this. It is based on the authors' experience with the DELTA package, which has been widely used in the UK over the past decade.

The paper begins with brief outlines of land-use/transport interaction modelling and of the DELTA package. It then considers the contributions of land-use/economic modelling to transport modelling and planning under three headings: the development of land-use/economic scenarios and the supply of land-use input for transport modelling; forecasting the land-use/economic impacts of transport proposals; and contributing to the formal appraisal (ex ante evaluation) of transport proposals.

1 INTRODUCTION

This paper is concerned with the different ways in which land-use and economic modelling can contribute to the transport planning process, and with some of the issues of model development and model use that arise in this. It is based on the authors' experience with the DELTA package, which has been widely used in the UK over the past decade.

The paper begins with brief outlines of land-use/transport interaction modelling and of the DELTA package. It then considers the contributions of land-use/economic modelling to transport modelling and planning under three headings: the development of land-use/economic scenarios and the supply of land-use input for transport modelling; forecasting the land-use/economic impacts of transport proposals; and contributing to the formal appraisal (ex ante evaluation) of transport proposals. The last of these is explored with examples from the use of the South and West Yorkshire Strategic Model.

The term 'land-use' as used in "land-use/transport interaction modelling" (LUTI) tends to refer mainly to the activities which use space – in particular, where people live and where they work. LUTI modelling generally less concerned with the physical use of land itself. In many cases "space" is measured in floorspace rather than land[†].

A theme which we have been developing for a number of years is the need to understand land-use/transport interaction in terms of the decisions made by different categories of "actors", within the markets in which they interact. The scope of LUTI and the role of transport are illustrated in Figure 1. It identifies

- the population, as individuals and as households, and
- firms and other productive organisations.

The latter are divided into firms in general plus three categories of firms of special interest:

[†] There are of course "land-use models" which consider land-use in the strict sense but which are not "land-use/transport interaction models" and are therefore outside the scope of this paper. See, for example, the various versions of the California Urban Futures Model (Landis, 2001).

- property developers,
- transport infrastructure providers, and
- transport service providers (e.g. public transport operators),

all of which may be special cases either of private sector firms, or of government activity, or both. Government interventions are not explicitly shown, but can affect any of the actors and markets through investments, regulations and taxation; much of the use of LUTI models is to forecast the impacts and consequences of such interventions.

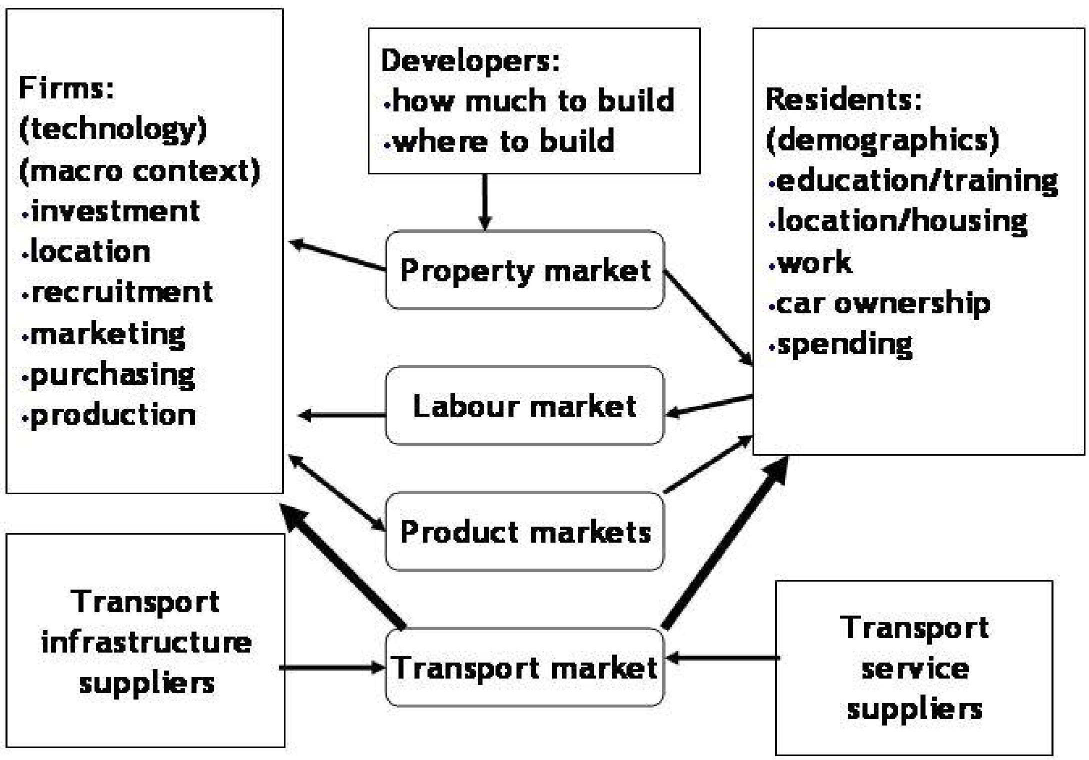

Figure 1 Key decisions by land-use actors

Residents and firms interact with each other through the markets shown in the centre of the diagram, namely the markets in property, labour, goods and services, and transport (the latter often being mediated by congestion rather than by price). Through these interactions, changes in transport may have indirect impacts on people or businesses that have no direct interest in the transport change at all.

It is important to recognise that the 'land-use' system is never static, and that 'transport' is only one of the factors that influence how it changes. The treatments of all the other factors - such as demographics, the workings of the development process, etc. - are among the things which distinguish the different approaches to land-use modelling.

2 THE DELTA PACKAGE

The DELTA package is designed to model the actors and markets described above through distinct but closely linked models of the different processes of change. The full package consists of six urban and three regional sub-models. The urban levels models (working at the zone level) forecast changes in

- Households and population;
- Car ownership;
- Location (of households and of jobs);
- Employment and commuting;
- Physical development; and
- Housing area quality.

The regional sub-models work at a broader spatial level (units approximating to travel-to-work areas) and forecast

- Investment;
- Production and trade;
- Migration of households between these areas.

These sub-models operate in a fixed sequence within each one-year period, as illustrated in Figure 2. Ideally the transport model would be run at the end of each one-year period, but this is generally impractical (in terms of computing times) as well as unnecessary (given the slight changes in congestion from year to year), and the usual practice is the run the transport model every fifth year (as illustrated in Figure 3) or (preferably) more often, eg every other year.

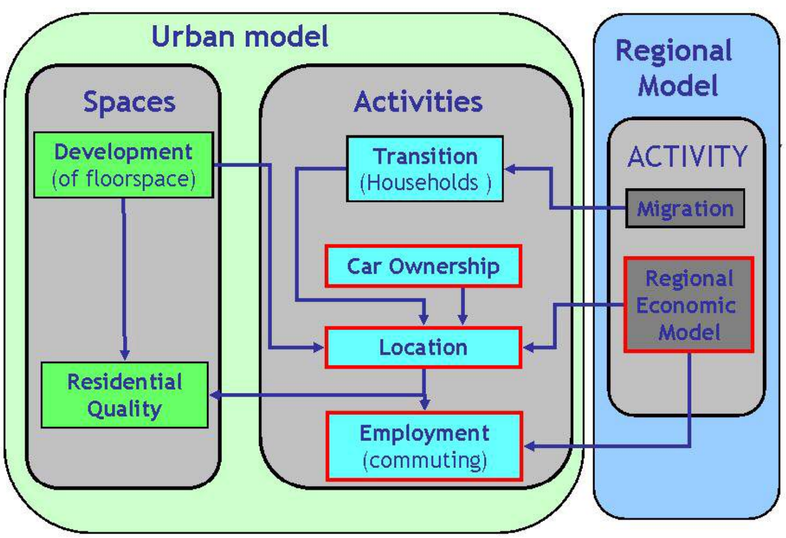

Figure 2 Sub-model sequence within a DELTA one-year cycle

The location or relocation model is the main focus of interactions both between activities and space and between land use and transport. Its main function is to predict the location of those activities that are mobile in this period, taking accounts of changes in accessibility, transportrelated changes in local environment, area quality and the rent of space. There are complex time-lags between years, so that the impacts of a significant transport change take a number of years to emerge (typically five to seven years for direct impacts on households, 10 years or more for impacts on employment). In addition to location, transport or accessibility conditions also impact directly on car ownership, employment/commuting, investment and production/trade (the components identified with a red border in Figure 2); the other sub-models are only indirectly affected by transport.

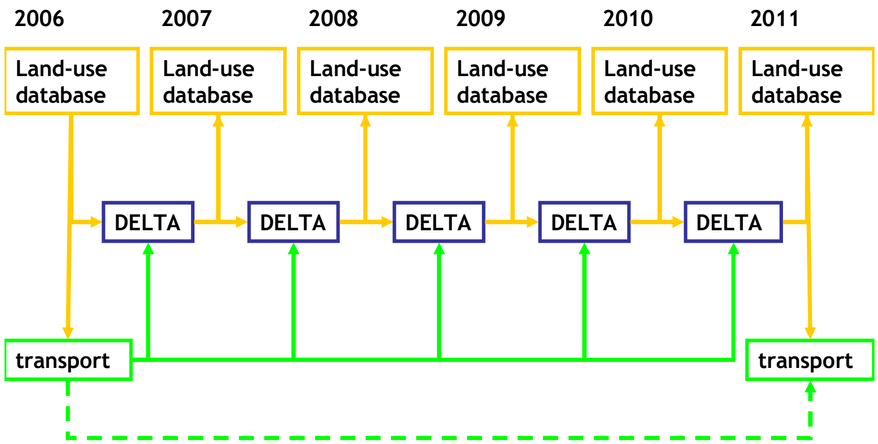

Figure 3 Land-use/transport model sequence over time

DELTA itself does not incorporate transport modelling capabilities but has to be linked to an appropriate transport model. The original DELTA design was explained in detail in Simmonds (1999). For a recent description, taking account of the various extensions that have been added, see Simmonds and Feldman (2005).

The DELTA package was first applied to Edinburgh (Still and Simmonds, 1998). It has since been used in a number of major land-use/transport interaction models including the Greater Manchester Strategy Planning Model (Copley et al, 2000), the South and West Yorkshire Strategic model (Simmonds and Skinner, 2001), a more extensive model of Edinburgh (Simmonds et al, 2005) and the Strathclyde Integrated Transport/Land-Use Model (Aramu et al, 2006). It has also been used to implement a number of more limited models, mainly of land-use without full land-use/transport interaction. Several other applications are in use or under development, including a research project version, SimDELTA, in which the household/population modelling is carried out by microsimulation (see Feldman et al, 2005).

3 LAND-USE/ECONOMIC SCENARIOS AND INPUTS TO TRANSPORT PLANNING

The need to provide forecasts of households, population and employment as inputs to transport modelling has long been accepted. What is noticeable is that current trends in transport modelling – even in the application of relatively conventional aggregate, trip-based models – are requiring increasing levels of detail especially about households and persons. (More advanced models, especially activity models, require even more detail, typically as microdata of the kind produced by SimDELTA.) The conventional approach to producing "planning data" for transport modelling has been to assume (based on planning policies) future quantities of new development by zone and their occupancies, initially assuming unchanging occupancy of existing development; and then to scale the results of these assumptions upwards or downwards to match overall household, population and employment forecasts for the area in question.

The kind of land-use modelling provided in DELTA is improving on this in a number of ways. First, it can take account of the significance of demographic dynamics: given the present mixture of households, and the differences in behaviour between different kinds of households, which areas will show most/least change in population composition over the next 10 or 20 years? Such results can be significant: zones with a high proportion of families, and low tendencies to relocate, may show decreasing populations (as the families become "empty nests") even in areas where total population is growing markedly.

Secondly, land-use modelling can also help in forecasting the impacts of planning policies given those scenarios: it can for example allow for the likelihood of an increasing proportion of traditional "family" housing being taken up by single person households or couples without children, with consequences for travel demand and indeed for other aspects of planning (such as educational provision). The modelling process can also help in looking beyond the horizon of present land-use planning, and in taking account of how plans will adapt to changing conditions; these are significant contributions given that in many cases the transport planning and modelling process needs to look further into the future than is usual in land-use planning. One of the areas of current development is to move away from representations of planning policy that rely on strictly quantifying how much development of each type may take place in each zone in any future year, towards an approach which allows for the fact that plans are periodically updated, and for the fact that (especially in the UK[‡] and similar planning systems) there is no attempt to specify in advance how certain types of development (especially commercial development) will be accommodated; rather, potential developers put forward applications for development permission which are (in principle) accepted or rejected according to established principles and rules.

Thirdly, the land-use modelling process takes account of the interaction between residential location and employment location, and can thus help to develop consistent scenarios for transport planning. Some of this analysis is now being taken up in land-use planning itself, which (in the UK as in many other countries) tends to be much less formal and less quantitative than transport modelling. At least one city is now using a DELTA-based model to predict the impact of major new developments as part of the land-use planning process, taking account not only of the characteristics of the housing etc but also of the housing market and of the way in which the mix of residents will change over time.

[‡] There are differences in planning systems, and particularly in transport appraisal practice, between the component countries of the United Kingdom. We have not attempted to consider these differences in this paper.

4 FORECASTING THE LAND-USE/ECONOMIC IMPACTS OF TRANSPORT PLANS

The facility to forecast the land-use and economic impacts of transport policies and investments has always been one of the major reasons for developing LUTI models. The need to assess these impacts is increasingly recognized in planning practice, in the UK and elsewhere. At the same time, increasing attention is being given to how such impacts are used to assess welfare and economic benefits, as discussed in the following sections.

As an example of the assessing and appraising the impacts of transport on land-use and economic activity, we show some of the results which we produced regarding the proposals to reopen the railway between Airdrie and Bathgate in Central Scotland. This would provide greatly improved public transport from the Airdrie eastwards, notably to Edinburgh, and from the Bathgate area westwards, especially to Glasgow (see Figure 4).

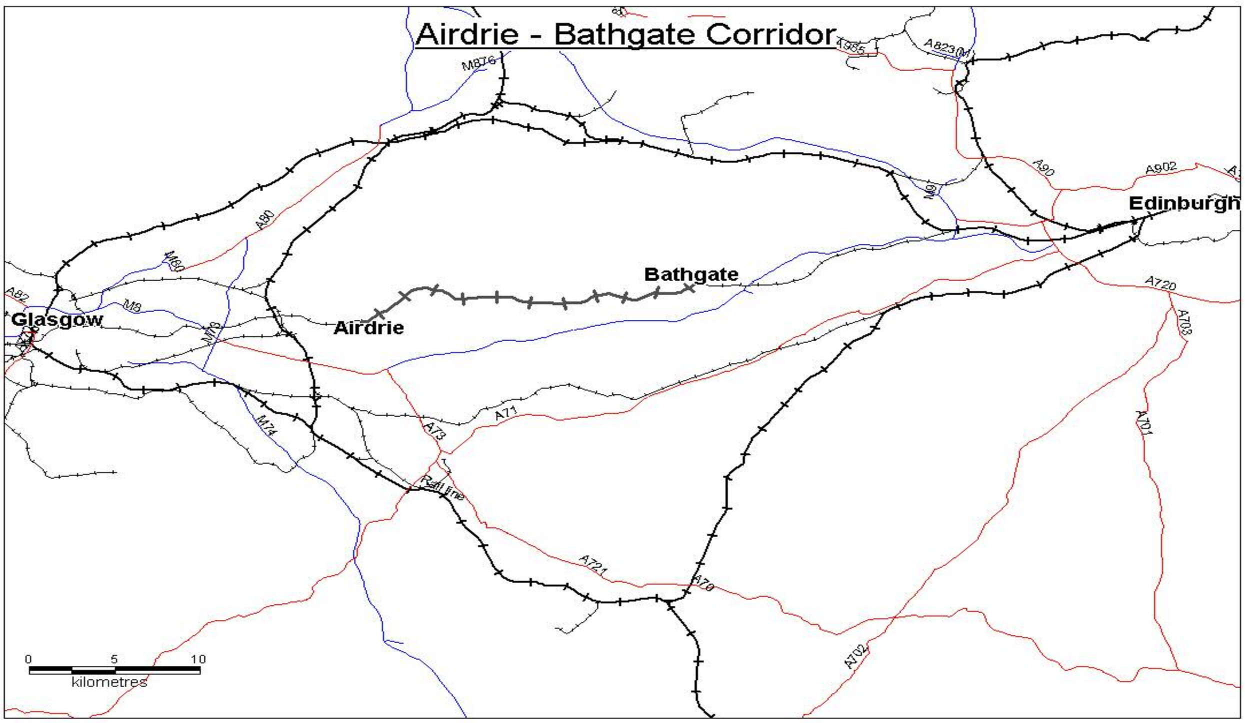

Figure 4 Location of the Airdrie-Bathgate railway reopening scheme

For reasons of space, no attempt is made here to present the details of the model, except to note that it used both the urban and regional levels of DELTA and that the upper level covered the whole of Scotland and therefore represented the whole of the national economy. Figure 5 and Figure 6 show just two aspects of the results, the forecast impact on employment by zone in 2021 (10 years after the assumed reopening of the railway) and the profile of population impacts by district over those 10 years. These illustrate two aspects of the modelling which are important in the use of such results:

- the ability to consider both local spatial impacts (as shown at the zonal level) as well as wider impacts (in this case, the total impact on the districts and on the Central Belt relative to the rest of Scotland)

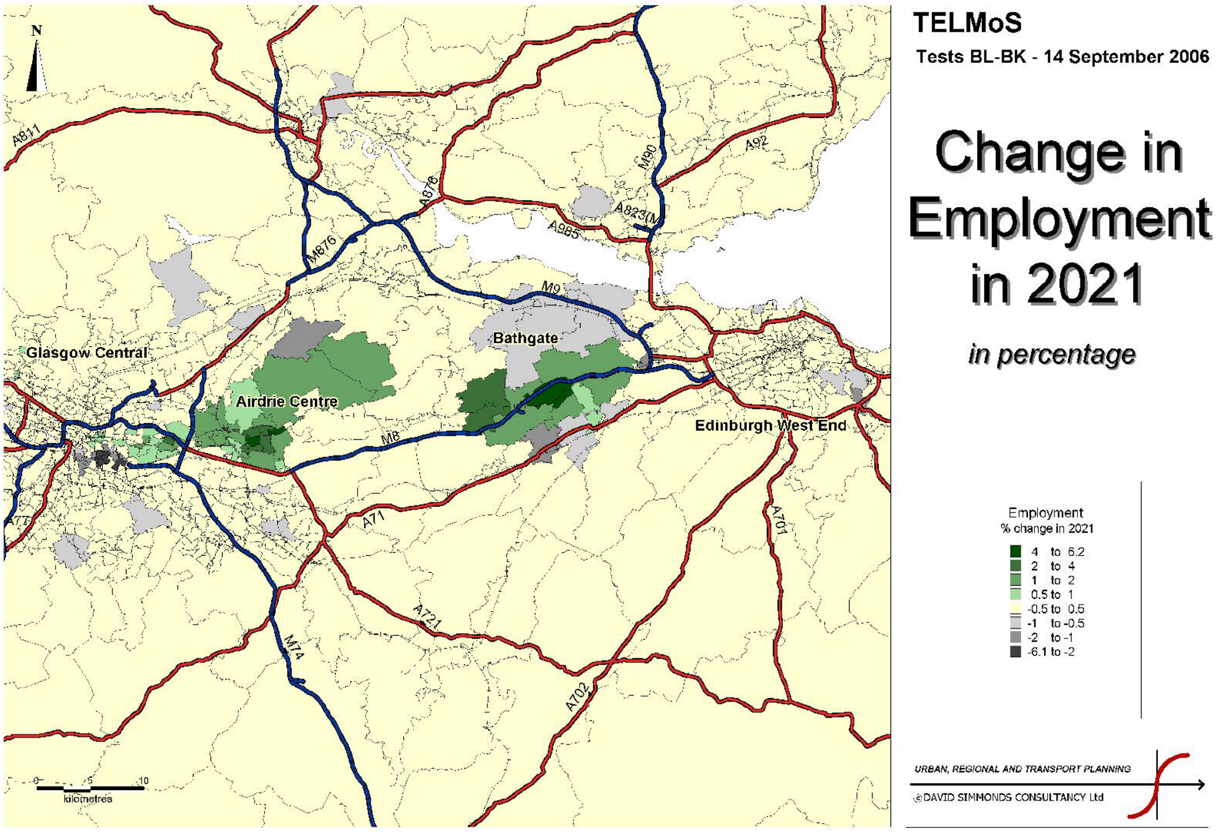

Figure 5 Employment impacts of the railway reopening (zones, %, 2021)

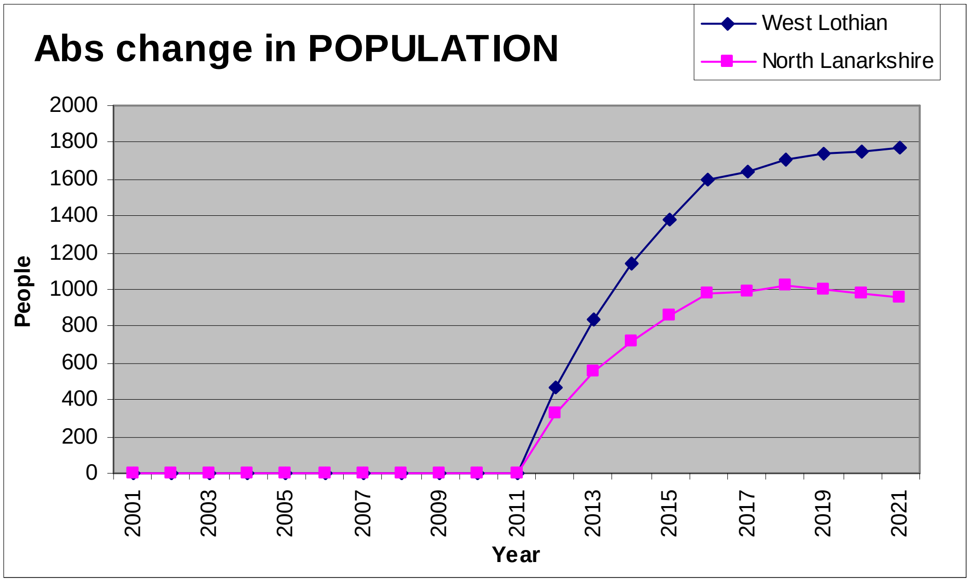

Figure 6 Population impacts of the railway reopening (districts, absolute)

- the ability to consider the pattern of results over time, with the main forecast impacts on employment building up over about a decade after the assumed opening of the railway (the impacts on population were forecast to take even longer).

5 THE APPRAISAL OF TRANSPORT PLANS AND PROPOSALS

Conventional transport economic efficiency appraisal as applied in the UK and elsewhere is incorrect when the patterns of land-use are forecast to change as a result of the strategy. It is appropriate to begin by clarifying the reasons why conventional measurements alone are incorrect in such circumstances.

The conventional approach to measurement of transport user benefits is based upon estimating the changes in consumer surplus accruing to transport users by applying the rule-of-a-half calculation to each component of demand. The basis of the rule-of-a-half calculation is shown in Figure 7. In the Base situation, the generalised cost of using this particular part of the transport system (e.g. one mode from one origin to one destination during one period of the day, for one purpose and type of traveller) is c^B, and the number of trips made is T^B. In the Alternative situation, as a result of an Alternative transport strategy, the generalised cost is reduced to c^A, and the number of trips increases to T^A. We can draw a line through the points $\left(T^B, c^B\right)$ and $\left(T^A, c^A\right)$ to show the *demand curve*, and for the purposes of analysis we can extrapolate it to the vertical axis.

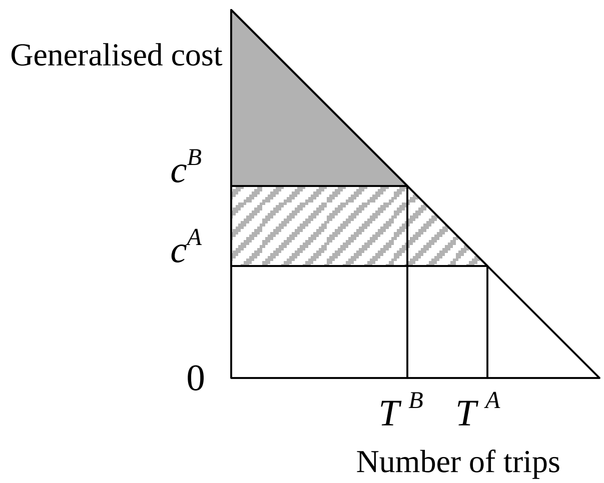

Figure 7 The rule-of-a-half calculation of transport user benefits.

The key economic concept that now comes into play is that of *consumer surplus*, which is the difference between what consumers are willing to pay in generalised cost (money, time and inconvenience) for a good or service (in this case, for a particular kind of trip) and what they actually pay. The total consumer surplus in the Base situation is given by the shaded triangle. The change in consumer surplus due to going from the Base situation to the Alternative is given by the hatched strip. If we make a number of assumptions[§], including the assumption that the demand curve is a straight line between the Base and Alternative points, then the area of that strip can be calculated by some very simple geometry as

$$\Delta S = -\frac{1}{2}\left\{\sum_i \left(T^A + T^B\right)\left(c^A - c^B\right)\right\} \tag{5.1}$$

This is known as the rule-of-a-half. To calculate the benefits resulting from an Alternative strategy, this has to be applied to all of the travel options in the system whose generalised costs may possibly change as a result of adopting the Alternative strategy rather than the Base. In real applications to congested urban systems, even a simple strategy will have many complex impacts on generalised costs and on the use of the different parts of the transport system. It can be shown that the total benefits estimated by applying rule-of-a-half (5.1) to all the components of the transport system will be sensibly calculated (subject to the other assumptions) provided that all of the changes are attributable to generalised cost changes within the system.

However, as soon as we introduce changes that are not represented in generalised cost, this conventional approach becomes less reliable, and may be wholly misleading. This risk arises whatever the reason for introducing such changes. The case of interest is of course that of land-

[§] Typically, the assumptions upon which it is based do not hold, but it is accepted as a practical approximation. A particularly significant group of assumptions relate to perfect competition both in the transport-supplying sectors and in the transport-using sectors. These assumptions, and the implications of market imperfections, are discussed in Chapter 4 of SACTRA (1999).

use changes, whether these are estimated by a model or by professional judgement. Consider for example a land-use change associated with the Alternative strategy which makes a particular destination more attractive but draws more trips into a congested part of the network, exacerbating the congestion. The rule-of-a-half based on generalised cost will detect the worsening congestion but not the increased attractiveness of the destination; as a result, the strategy will appear to produce disbenefits to travellers, even in cases where it can be shown that all travellers are either unaffected or enjoying benefits (the increased attraction of the destination) compared with the Base situation. In general, it can only be said that if the Alternative involves changes which affect travellers' choices in any way except through generalised costs, the rule-of-a-half calculations based on (5.1) will estimate an arbitrary set of partial changes, with the potential to reach a wholly misleading total.

This is clearly an unsatisfactory situation with regard to the appraisal of strategies which may involve and/or result in land-use changes. Further work is needed to develop a full land-use/transport economic efficiency appraisal method compatible with the dynamics (and very limited equilibrium) of land-use/economic models such as DELTA. This is not only challenging in itself, but the application of such a method probably implies changes in how land-use planning policies are considered as well as in transport appraisal. In the meantime, the standard approach is to combine a **formal** quantified transport economic efficiency analysis (TEE) carried out on a transport-only basis (ie for selected forecast years with the same land-use patterns in Base and Alternative cases) with an **informal** assessment of whether the land-use/economic impacts would redistribute economic activity in ways which would support other government policies. For example, the Airdrie-Bathgate railway reopening mentioned earlier was shown to produce additional, non-transport benefits through the forecast that it would increase the number of employed residents in areas of high unemployment and deprivation, even though this would be at the expense of other parts of Scotland.

The Department for Transport (DfT) has in addition introduced Wider Economic Benefit methodology seeking to develop a better understanding of the relationship between transport investments and the wider welfare[**] benefits (such as journey time savings, reliability, environment factors, etc) and GDP effects of transport schemes. The methodology for consideration of Wider Economic Benefits published by the DfT (2005) identifies the following categories of such benefits:

- Agglomeration (WB1) - the increase in productivity which has been identified as resulting from higher densities of employment;
- More people working (GP1) - the increase in output arising from better transport encouraging more people into work;
- Move to more productive jobs (GP3) - the increase in productivity identified as resulting from relocating jobs into higher productivity areas;
- Increased output in imperfectly competitive markets (WB3) - the increase in production expected to result from transport improvements; and
- Benefits arising from increased competition as a result of transport improvements (WB2).

[**] "Welfare" is the total well-being of the society. It is impossible to measure the level of welfare but it is possible to estimate impacts resulting from a policy or scheme implementation.

A fifth category WB2 was identified by DfT as theoretically possible. However there is little evidence to be found on the relationship between transport and competition and on that available, DfT does not expect that there will be significant wider benefits owing to increased competition. This category has accordingly not been considered in application of the approach.

6 CALCULATING WIDER ECONOMIC BENEFITS USING SWYSM

The South and West Yorkshire Strategic Model (SWYSM) is a land-use/transport interaction model based on the full DELTA land-use/economic approach and the START strategic transport model developed by MVA Consultancy. The area covered by the model is shown in Figure 8: it consists of a Fully Modelled Area, covering the area of policy interest and a significant adjoining area; and a Buffer Area, a set of large zones surrounding the Fully Modelled Area. External zones (not shown) cover the rest of the UK and allow for interactions between the modelled area and its wider surroundings. SWYSM has a base year of 2000 and a horizon year of 2020. The model has been extensively used for the appraisal of transport interventions using the DfT Wider Economic Benefit approach.

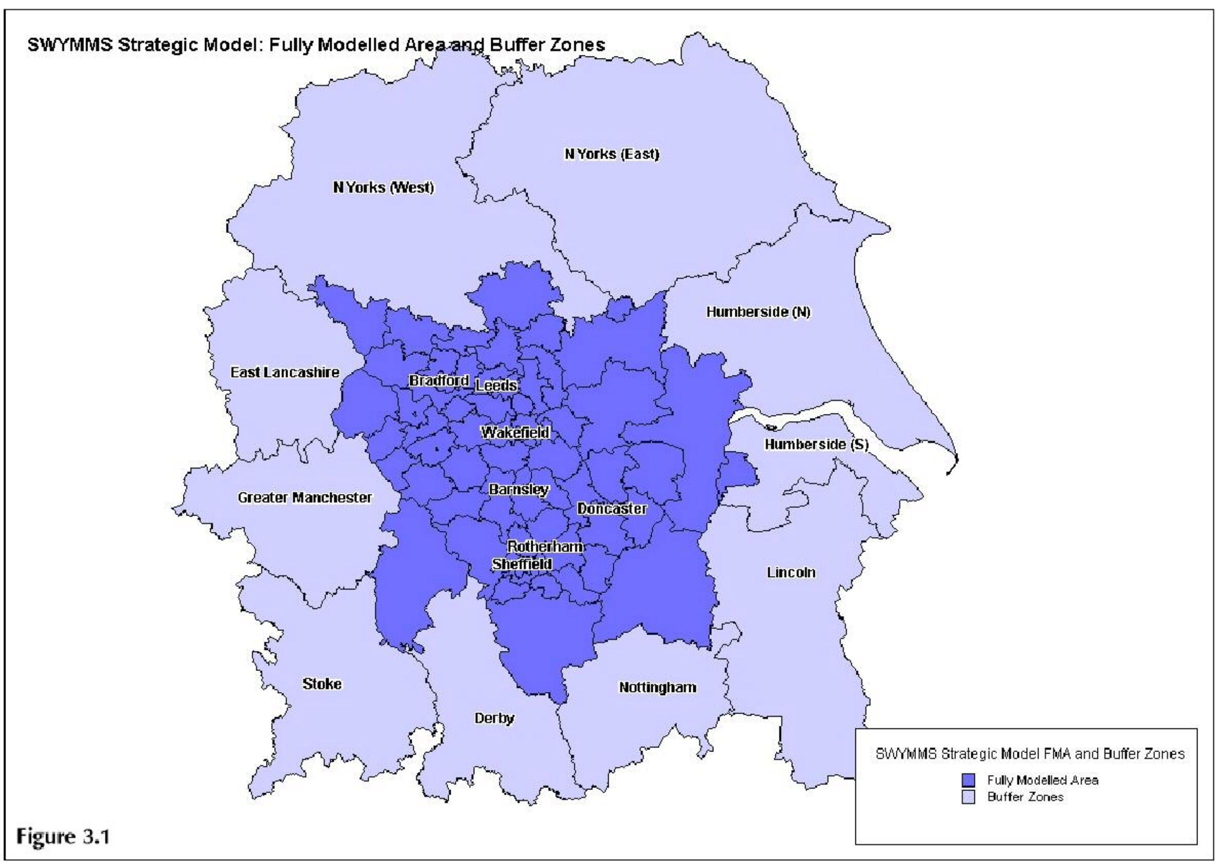

Figure 8 Fully Modelled and Buffer Zones in SWYSM

The equations which were used to calculate the benefits were those specified in the DfT methodology proposals, unless otherwise noted. The forms presented below have been rewritten in order to make the notation consistent both between the components of the wider benefits and with the level of aggregation or disaggregation in our calculations.

The agglomeration benefits (WB1) are calculated as

$$WB1 = \sum_i \left[\left[\left(\frac{d_i^A}{d_i^{B_0}} \right) \wedge e(WB1) - \left(\frac{d_i^B}{d_i^{B_0}} \right) \wedge e(WB1) \right] \times h_i \times E_i^A \right] \tag{6.1}$$

where

$WB1$ are the agglomeration benefits of the alternative situation (A), compared with the base (B), to be calculated;

i is a zone for which agglomeration benefits are being calculated - all of the modelled zones are included in the summation;

d_i^A, d_i^B are the employment densities of zone i in the alternative situation A and base situation A respectively, calculated using the formula (6.2);

$d_i^{B_0}$ is employment density of zone i in the base year (all other values are for the forecast year), likewise calculated using the formula using (6.2);

$e(WB1)$ is the elasticity of productivity with respect to employment density;

h_i is GDP per worker in i;

E_i^A is employment (in the alternative case) as predicted by SWYSM.

Employment density for this calculation is defined by DfT as a measure of the accessibility of zone i to jobs in all zones, calculated (in the base case) as

$$d_i^B = \sum_j \left\{ \frac{E_j^B}{g_{ij}^B} \right\} \tag{6.2}$$

where

g_{ij}^B is the generalised cost of travel from i to j in the base case B. All the modelled zones j are considered in the calculation, as is the intrazonal pair ($i=j$).

The generalized cost used is a weighted average over passenger travel (commuter and in-work purposes) and goods movement, traveller modes or goods vehicle types, car-ownership levels, for passengers, and times of day, routes and public transport sub-modes. The weights used in these steps are the numbers of trips (persons or goods vehicles) by mode and purpose in the base case. These weights are based on the numbers of trips between the pair of zones considered in each calculation, not just on the average numbers of trips across the whole model:

$$g_{ij} = \frac{\sum_p \left(g_{ij}^p T_{ij}^p \right)}{T_{ij}} \tag{6.3}$$

where

g_{ij} is the generalised cost of travel from zone i to zone j;

g_{ij}^{p} is the generalised cost of travel from zone i to zone j by purpose p;

T_{ij} is the number of trips from zone i to zone j;

T_{ij}^{p} is the number of trips from zone i to zone j by purpose p.

As usual in appraisal, a number of important practical issues needed to be resolved in implementing these calculations. In principle the agglomeration benefit could be calculated for every year in which the employment densities of the alternative are different from those of the base. In practice, given the large amount of data to be manipulated, the calculations were done only for the final year of the model forecast period (2020). Values for other years were interpolated assuming linear growth of effects from the introduction of the intervention up to 2020. After 2020, the transport cost and location impacts were assumed to remain constant, while 2020 GDP per worker figure were assumed to continue growing. The resulting sequence of estimates was used as input to calculating net present values.

Input values of GDP per worker for use in this calculation were forecast taking account of an assumed rate of economic growth (2% per year) inclusive of growth arising from agglomeration effects in the Reference Case.

The increase in GDP from more people working (component GP1 of the Wider Economic Benefits) is calculated as

$$GP1 = -\sum_i \left[\left\{ \frac{\sum_j W_{ij}^{A} \times \left(g_{ij}^{WA} - g_{ij}^{WB} \right)}{\sum_j W_{ij}^{A} \times y_j} \times \sum_j \left(m_j \times W_{ij}^{A} \right) \right\} \times e(GP1) \right] \tag{6.4}$$

where

$GP1$ is the more-people-in-work benefits of the alternative situation (A) compared with the base (B), to be calculated;

i is a residential zone for which agglomeration benefits are being calculated - all of the modelled zones are included in the summation;

j is a workplace zone;

g_{ij}^{WA}, g_{ij}^{WB} are the generalised cost of travel-to-work (commuting, purpose W) from zone i to zone j in the Alternative and the Base case respectively, as forecast by the model;

W_{ij}^{A} is the number of workers living in i and working in j (in the Alternative case) as forecast by the model;

y_j is the average wage of workers employed in zone j;

m_j is the GDP per worker entering the labour market in zone j in 2006;

$e(GP1)$ is the elasticity of labour supply with respect to wages.

There are additional welfare benefits arising from the consequences of GDP change for the exchequer, this amounts to 40% of the GDP impact.

This benefit could in principle be calculated separately for the four socio-economic groups distinguished in SWYSM, but due to the lack of data by socio-economic group on the average wage of workers employed in each zone, on GDP per worker entering the labour market or on the elasticity of labour supply with respect to wages, this benefit has so far calculated at an aggregate level. The generalized costs used in this calculation were an average of the separate costs by socio-economic group calculated in SWYSM. Disaggregation to values by socio-economic group would be of interest in policy terms: in simple economic terms, getting more high-income workers into worker would be of greater benefit than the same effect for an equal number of low-income workers; in social terms, the opposite might be the case. This benefit is again calculated for 2020 and assumed constant extrapolation to future years taking into account government advice on changing values of time.

The calculation of the GDP effect of the move to more productive jobs (GP3) is based on the change in number of jobs in each area multiplied by the average GDP for the modelling area in 2020 for the Reference case per worker and by the index of productivity per worker in each area, based on previous work for DfT to estimate the regional wage relativities.

This is calculated as

$$GP3 = \sum_i (E_i^A - E_i^B) \times PI_i \times k^B \tag{6.5}$$

where

$GP3$ is the move to more productive jobs benefit of the alternative situation (A) compared with the base (B), to be calculated;

i is a zone for which agglomeration benefits are being calculated - all of the modelled zones are included in the summation;

PI_i is index of productivity per worker in zone i;

k^B is the modelling area average GDP per worker in the reference case.

Regional productivity differentials are assumed to be constant for the whole appraisal period, with no adjustment for the effect of other interventions such as the Objective 1 programme in South Yorkshire. This again is a point of some concern for future policy making. No disaggregation by industry sector was done. This benefit was calculated for the final modelled year (2020). Values for other years were interpolated assuming linear growth of effects from the introduction of the intervention up to 2020. After 2020 the transport costs and location impacts were assumed to remain constant, while 2020 GDP per worker figures were assumed to continue growing.

There are also welfare benefits arising from the consequences of the GP3 results for the exchequer, which are estimated as 30% of the GDP effect.

All of these streams of benefit have been calculated, in various different projects, for a range of transport interventions. Full Transport Economic Efficiency analysis has also been carried out for the each of the interventions tested. Unfortunately, the actual numbers of the estimated wider economic benefits as well as more detailed land use and economic results cannot be quoted at this moment for confidentiality reasons, but the authors hope that some of the details will be released in time for the TRB meeting in January 2007.

7 CONCLUSIONS

The use of land-use/economic models, linked to transport models so as to provide detailed and consistent “land-use” inputs to the transport modelling, and to model the land-use/economic impacts of transport changes, is increasingly important in planning practice. Dynamic models, which produce a time series of results showing the gradual impacts of demographic change, transport improvements and other effects, are both theoretically superior to static, equilibrium models and intuitively more acceptable to the non-modeller users of results. The ability to assess the land-use/economic impacts of transport policies and proposals is increasingly important, though the methodology for the formal appraisal of the economic benefits flowing from land-use/transport planning continues to be developed to be compatible with complex dynamic models. The introduction of the Wider Economic Benefits guidance represents an important recognition that transport change can have a range of highly significant impacts beyond those considered in the previous appraisal methods or in current land-use/transport/economic models, and we envisage that this kind of analysis will become increasingly important.

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