LAND-USE/TRANSPORT INTERACTION MODELLING OF LONDON

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ABSTRACT

This paper describes the development of a new land-use/transport interaction (LUTI) model of London and adjoining regions, known as LonLUTI, and considers issues relating to its calibration and potential use. The component models within the LonLUTI model are the London Land-use model (LonLUM), run on DELTA software, and the TfL London Transportation Studies Model (LTS) converted to run on a PC by MVA Consultancy. LonLUTI forecasts through time in one-year steps, starting from a known situation in 2001, the pattern of land-use and economic activity across Greater London, East and South East England. The horizon year is 2026. There are some simultaneous linkages in the model but most of the responses - especially to changes in transport - involve time lags so that the impacts of change emerge gradually over a number of years. The model outputs a database containing the same variables, in the same details, as those input for the base year, so it works in the same way whether starting from an observed or from a forecast situation. The paper discusses the use of previous research in the calibration of the model, and other issues relating to the integration of land-use and transport models and to the assessment of the economic impacts of transport proposals.

Keywords: land-use/transport interaction model, London, DELTA, LTS

1. INTRODUCTION

Land-use/transportation interaction modelling draws from a number of different modelling traditions. Drawing on the short history in Eliasson and Mattson (2000), we note that these include urban economics, spatial interaction (gravity) models and discrete choice models. The field of urban economics (see for example Lösch, 1940; Wingo, 1961; Alonso, 1964) focuses on understanding the general, aggregate behaviour of a city in terms of the location of citizens of different types, land prices or rents, commuting patterns, etc, in order to help planners and researches achieve a better knowledge of what planning could achieve and what it could not, and which kinds of measures could improve the functioning of a city. Later the bid–rent approach, which introduced (among other things) the possibility to model the land rent market in a more consistent way, was proposed and implemented in urban models such as MUSSA (Martinez, 1992) and RURBAN (Miyamoto, 1996).

The second tradition, the spatial interaction models of the Lowry type, came from the need of practitioners to be able to make at least crude forecasts of traffic flows, trade patterns etc. This tradition started with Hansen's work on accessibility(1959) and the highly influential Lowry model (1964), and was developed by a large number of modellers including for example Wilson (1970), Putman (1973), Senior and Wilson (1974) and Mackett (1990).

The third approach is the theory of discrete choice based on random utility theory (Luce, 1959; McFadden, 1974; Domencich and McFadden, 1975). The first applications in transport modelling dealt with mode and destination choices, but soon the classic "four-step model" was considered as an individual discrete choice model (Senior and Williams, 1977), along with the generalization of the multinomial logit to the generalized extreme value (GEV) model, with the nested multinomial logit model as a special case (Williams, 1977a; McFadden, 1978).

These three lines of development – the often abstract urban economics, the spatially explicit accessibility/interaction modelling, and the better understanding of behaviour in discrete choices – were integrated as described by Hunt and Simmonds (1993) into a series of powerful models implemented in the MEPLAN (Echenique et al., 1988) and TRANUS (de la Barra, 1989) packages, which combined a strong theoretical basis with practical applicability and usefulness. These models assumed a high degree of equilibrium in urban systems. In contrast, Wegener (1985) developed the IRPUD model of Dortmund model by applying ideas from urban economics and discrete choice to the processes of change over time, with less emphasis on spatial interaction modelling and much more on dynamic behaviour. The design of the DELTA (Simmonds, 1999; Simmonds and Feldman, 2007) sought to combine Wegener's insights and focus on change with the practicality of the MEPLAN/TRANUS models; the London work described here is one of the results of that convergence of ideas.

This paper describes the development and use of a new land-use/transport interaction (LUTI) model of London and adjoining regions. Transport for London UK (TfL) commissioned David Simmonds Consultancy Ltd (DSC) to work on the development of a land-use/transport interaction model of London and its adjoining regions, so as to provide TfL with the capability to assess the land-use impacts of the range of scenarios and strategies which were to be considered in the London area. The land-use/economic element of this modelling used DSC's DELTA package, with the transport model being TfL's long-established London Transportation Studies Model (LTS). LTS is a 4-stage strategic multi-modal model for

London and its surrounding area calibrated on data from a large number of household, roadside and public transport surveys. The LTS model has traditionally been run on mainframe computers but was converted to run on a PC by MVA Consultancy. The new DELTA application is known as LonLUM (London Land-Use Model), and the full DELTA/LTS-pc system as LonLUTI. DSC and MVA worked in close collaboration throughout the development of LonLUTI.

LTS-pc is run in every fifth year, whilst LonLUM involves running DELTA for each one year period. The base run of LTS-pc for 2001 provides inputs to the first five-year cycle of LonLUM, ending in 2006 when the output planning data (persons, households, employment, workers) are passed from LonLUM to LTS-pc. LTS-pc is then run for the 2006 situation, and the resulting generalized costs of travel are passed back to LonLUM for use in calculating accessibilities and other measures from 2006 to 2010, influencing land-use and economic change from 2007 to 2011. The process can continue in this way for as long as necessary, currently to 2026.

The DELTA/LTS modelling system is one in which nearly everything affects everything else - to a greater or lesser extent, and either immediately or gradually. The regional economic model forecasts the distribution of growth across employment sectors and across the modelled region, representing both investment decisions and input-output linkages. The employment location model represents firms' decisions about where within each area to locate, given the investment decisions and the resulting space requirements, the competition for space and their requirements in terms of accessibility. DELTA models demographic change temporally in the transition model, capturing the main stages of the human life cycle and the characteristics of household formation which impact on economic activity, car-ownership, travel demand and location choice. DELTA models household relocation, representing households' responses to changes in housing supply, accessibility, changes in the local environment, area quality and the costs of housing. The rents for business and households are iteratively adjusted until a combination of density and location changes equilibrates the current demand and supply of floorspace. The levels of floorspace in the model, which activities compete for and determines location of, are adjusted in the development model. Public sector development and large scale projects have to be input exogenously.

The pattern of land-use largely determines travel patterns, and the patterns of accessibility or congestion (calculated in the transport model) influence subsequent land-uses. LonLUTI therefore can be seen to fill in the detail of the changes in the spatial patterns of activities and the patterns of travel between activities, between a set of "top level" inputs which define the economic and demographic scenarios for the modelled region as a whole, and a set of "bottom level", spatially detailed inputs which describe the planning and transport interventions in particular locations and particular parts of the network.

This paper presents the workings of LonLUM and its interactions with LTS-pc and considers a range of issues arising in relation to calibration and other issues in the application and use of the model. Section 2 explains the key model components. Section 3 discussed the calibration of the model, and section 4 discussed other issues that have arisen from a review of the model. Section 5 concludes.

2. MODEL STRUCTURE

Modelling area

The LonLUM zone system is shown in Figure 1; it covers the Greater London, East and South East of England, and is the same as in the earlier LASER 3.0 model (see Atkins et al, 2009, Appendix A.2). There are 338 zones in the model, of which 297 internal zones cover Inner London (45 zones), Outer London (75 zones), East of England (69 zones), South East of England (108), and 41 external zones which cover major airports and ports in London-East-South East Regions (15 zones) and other external zones (26 zones) which cover the rest of the UK. The LonLUM zones are aggregated to 32 internal and one external areas which correspond as far as possible to functional areas derived from travel-to-work data (or aggregations of functional areas, in outer parts of the modelled region); zones represent finer units within these. The functional areas were originally identified in earlier DSC/MVA work (Feldman et al, 2005) for the Department for Transport.

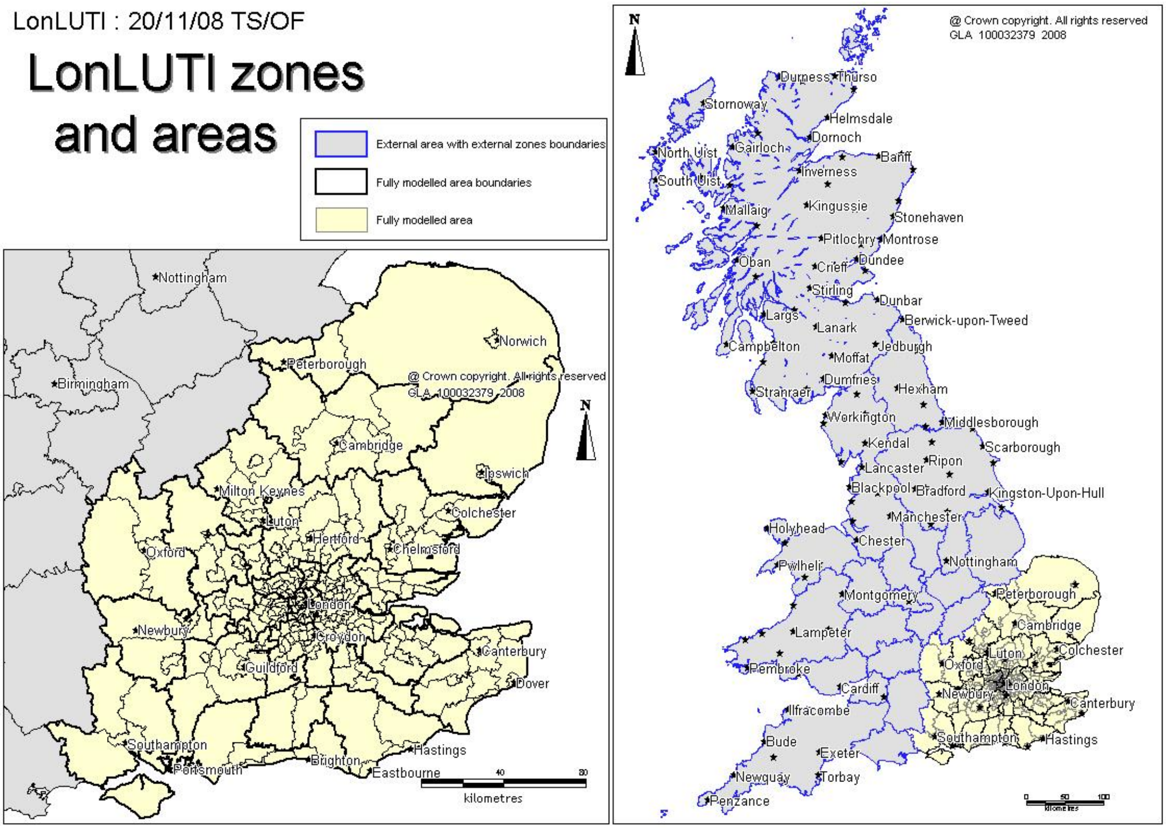

Figure 1 – LonLUTI modelling area

LonLUTI model structure

The LonLUTI model can be summarised as consisting of the four components illustrated in Figure 2. These are:

- The LTS-pc transport model to which LonLUM is linked;
- the economic model;
- the urban land-use model;
- the migration model.

The transport and urban models work at the level of zones (note that the LTS-pc and LonLUM zones are not identical). The migration and economic models work at the broader level of areas (see Figure 1).

The *transport model* takes inputs which describe activities (different categories of residents and jobs) by zone, for a given year. From this and from input transport system data it forecasts travel by car and by public transport. In doing so, it estimates costs and times of travel between each pair of zones, allowing for congestion caused by the forecast traffic.

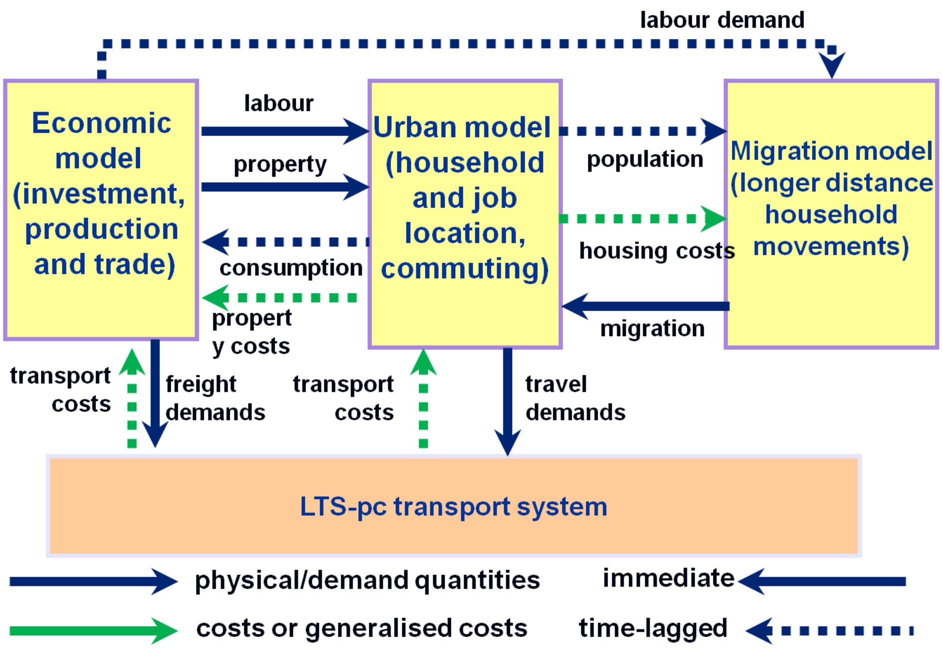

Figure 2 – Overall structure of LonLUTI model

Note: the link "travel demands" from the urban model to LTS-pc is currently implemented by passing data on the residents and jobs which generate/attract travel; and the freight demand linkage from the economic model to LTS-pc is not implemented.

The LonLUTI model has 3 distinct phases: initial, cyclic and end phase. The initial phase has been pre set to execute the LonLUM model only from year 2002 to 2006, using the "fixed" base LTS outputs from 2001. The cyclic phase of the LonLUTI model is a 5-year cycle of passing data from LonLUM to LTS, running LTS, passing data back to LonLUM, and running

DELTA for the following five years of LonLUM. The end phase of the LonLUTI model does the final year transport model setup within the test. An interface with the LonLUTI model has been built using MS Excel so that any user can setup and run the model. A user can selects from the various options presented to setup and run the LonLUTI model.

The two models operate with different zoning systems. Two sets of factors were derived in order to convert the zoning system from LonLUM to LTS and vice-versa. Household based conversion factors are used for converting household and population data, and jobs based factors are used for converting employment data.

LTS produces generalised costs by purpose between each production and attraction pair for two main passenger modes, car and a combined public transport/"slow" mode, and for goods vehicles. The highway generalised cost includes travel time, vehicle operating cost (fuel and non-fuel cost), toll and parking. The PT generalised cost includes the in-vehicle time, wait time, and walk time and PT fares. These are produced in the LTS zoning system. These costs representing LTS zone to zone movements are trip-weighted and converted to the LonLUM system through a set of factors matrices derived using the point-in-polygon method. LTS is considerably less detailed in its treatment of transport supply and congestion outside London. Since DELTA is essentially an incremental model this means that the changes in the costs of travel are modelled in less detail, which is an acceptable limitation in a model intended to focus on interventions within London. The model also calculates a measure of traffic, 12 hour pcu km by zone, which may in future be used as an environmental indicator in LonLUM.

The *economic model* forecasts the growth (or decline) of the sectors of the economy in each of the areas modelled (for sectors see Table 1 below). Its inputs include forecasts of overall growth in output and productivity. The forecasts by sector and area are influenced by costs of transport (from the transport model), consumer demand for goods and services (from the urban model), and commercial rents (from the urban model). Forecast changes in employment by sector and area are passed to the urban model.

The *urban model* forecasts the zonal location of households and jobs within the areas that are modelled in detail. Locations are strongly influenced by the supply of built floorspace, and hence the urban model is a set of property models as well as a set of inter-related location models. Each floorspace type represents a distinct property market; it is assumed for example that planning regulations will prevent offices being used as residential dwellings or vice versa. (The markets are not wholly independent, in that office construction in a zone may (and usually will) increase office-based jobs there, leading to an increase in labour demand which will for example have some impact on the housing market.) Location choices are also influenced by accessibility, with different measures of accessibility influencing different activities, and by environmental variables. Households are influenced by accessibility to workplaces and services. Businesses are influenced by accessibility to potential workers and customers.

The locations of households and jobs are fed back to the transport model to generate travel demands. Household numbers are also used to calculate consumer demand for goods and services in each area, for use in the economic model. The rents arising from competition for property in each area affect both the economic and migration models. Information on job opportunities is passed to the migration model.

The *migration model* forecasts migration between areas within the modelled area. (Movements within areas are forecast in the urban model.) The inputs to this model include job opportunities and housing costs, from the urban model. Job opportunities are a strong incentive to migration; housing costs are a generally weak disincentive.

Economic scenario: targets

The overall economic scenario is implemented so that total employment is consistent with the combined total of the London Plan figures for the Greater London plus the Department for Transport's standard projections (TEMPRO) for East and South East of England. There are 19 economic activities in LonLUM which use 9 floorspace types and are aggregated to 10 Regional Economic model sectors as listed in Table 1. To create the forecast, growth rates by industry in 5-year steps were calculated by combining figures from work supporting the London Plan (Spooner and Cooper, 2007) for Greater London, and from the special tabulations of TEMPRO for East and South East of England. The resulting growth rates by region and industry were applied to the 2001 data to establish the overall (Greater South East) targets which the LonLUM economic modelling aims to match.

Table 1 LonLUTI economic activities, regional economic sectors and floorspace

Employment activity	**...occupies floorspace type**	**Sector in Regional Economic Model**
A;B Agriculture; hunting; forestry and fishing (Non Manual)	Office	Agriculture
A;B Agriculture; hunting; forestry and fishing (Manual)	None	
C;D;E Mining and quarrying; manufacturing; and electricity; gas and water supply (Non Manual)	Office	Mining and Manufacturing
C;D;E Mining and quarrying; manufacturing; and electricity; gas and water supply (Manual)	Industrial	
F Construction (Non Manual)	Office	Construction
F Construction (Manual)	Industrial	
G Wholesale and retail trade; repairs	Retail	Retail and Hotel
H Hotels and catering	Hotel	
I Transport storage and communication (Non Manual)	Office	Transport
I Transport storage and communication (Manual)	Industrial	
J Financial intermediation	Office	Financial and Real Estate
K Real estate; renting and business activities	Office	

L Public administration and defence; social security (Non Manual)	Office	Public Administration
L Public administration and defence; social security (Manual)	Office	
Primary and secondary education(part of M)	Primary/Secondary Education	Education
Adult/other education (part of M)	Adult Education	
Higher education(part of M)	Higher Education	
N Health and social work	Health	Health
O;P;Q Other	None	Other Employment

These projections envisage steady and substantial growth of total employment in each region, varying between 16% and about 25% (22% in the fully modelled area) over the forecast period.

Demographic scenario: targets

The demographic scenario is implemented in the model by a fairy complex process of modelling household change. This is necessary to provide both the number of new and existing households by composition, socio-economic status etc. which influence mobility and residential preferences in the household location process, and the number of persons as input to the travel demand modelling. There are 108 household activities in LonLUTI, 10 main household compositions disaggregated by the number of workers and socio-economic level as listed in Table 2. Obviously, given the irreversibility of human ageing, a significant proportion of the transitions between these categories are impossible. There are four person types in LonLUM, namely children, workers, non-workers and retired.

Table 2 LonLUM household classification dimensions

Household composition (NB "couple" includes any two adults)	**Number of workers**	**Socio-economic level**
single adult, younger, no children	no workers, 1 worker	professional and managerial occupations associate professional, technical and trades occupations clerical, sales and skilled operators elementary occupations
single adult, older, no children		
single adult, retired, no children	(none)	
single parent	no workers, 1 worker	
couple household, younger, no children	no workers, 1 worker, 2 workers	
couple household, older, no children		
couple household, children		
couple household, both adults retied, no children	(none)	
3+ adult households, no children	no workers, 1 worker, 2 workers, 3 workers, 4 workers	
3+ adult household, children		

The model input coefficients were estimated so as to reproduce, as closely as practical, the TEMPRO-based forecast for East and South East were used and London Plan forecast for Greater London. Growth rates from TEMPRO and LTS planning data were used. Overall, households and population are assumed to increase by 27% and 16% respectively with the highest growth of 30% and 19% expected in the East of England. Household size is declining over the modelled period from 2.36 to 2.17 people per household.

Planning policies

Planning policy is input to the model mainly in terms of the amount of development by floorspace type that is permitted in each zone at any time. These “permissible development” inputs define how much floorspace the modelled development processes can build. “Permissible development” that is input but not immediately used is carried forward to the next year and remains available until used. The permissible development figures are assumed to represent absolute controls and the modelled quantity of development cannot exceed these. There are time-lags (one year for housing, two years for non-residential building) from when permissible development is “used” by the development model to when the resulting floorspace is added to the stock of floorspace and becomes available to occupiers. Exogenous developments may also be defined in addition to the modelled process - these may use some of the permissible development quantity, but do not necessarily do so. Nine floorspace categories are modelled in LonLUM, namely: housing, retail, office, industrial, hotel and catering, primary/secondary education, adult education, higher education, health. As already noted, each of these represents a distinct property market and can only be occupied by a particular group of activities.

To estimate 2001 housing floorspace, the 2001 Census dwelling data was aggregated into the four main dwelling categories: detached, semi-detached, terraced and flats for both occupied and vacant dwellings. The number of dwellings of each type of four types was tabulated and dwelling numbers were converted into square metres of residential floorspace on the basis of floorspace estimates by dwelling type (Nationwide Building Society research). The starting housing rents were estimated from estimates of 2001 sale prices obtained from Land Registry data.

The housing planning database is founded on four data sources (Dwelling Stocks by Council Tax Band; Annual Monitoring Reports – Housing Trajectories; London Plan 2008; and Plan Panel Reports of the East and South East of England). Data for 2001-2006 was obtained from the Dwelling Stocks by Council Tax Band report[1] and compared with DELTA estimations. Annual Monitoring Reports (AMRs) and the London Plan 2008 provided housing trajectories at borough level. Plan Panel Reports for East and South East of England provided housing strategies at district level. The net projected completions in the housing trajectories are based mainly on the estimated implementation of planning permissions. Some AMRs also include Local Plan allocation figures. In some areas the distribution of future permissible dwellings to zones had to be assumed; where necessary this was done

[1] http://neighbourhood.statistics.gov.uk/

assuming that additional development will be proportional to existing stocks. Once the number of new dwellings by zone was calculated, it was multiplied by the 2001 zonal estimates of average floorspace per dwelling to obtain inputs in terms of floorspace.

Published data was available on commercial floorspace data at ward level in 2003 as well as 2001-2006 data at the Local Authority level. To produce 2001 zonal data for LonLUM, the 2003 ward data was aggregated to LonLUM zones and scaled to match the 2001 data at the Local Authority level, according to the 2003 ratios between Local Authorities and wards. Once the initial floorspace database was constructed, the LonLUTI employment data was reconciled with the assembled floorspace so that zonal densities were valid. A recurrent problem in land-use modelling is to reconcile floorspace and employment data; in LonLUM, where the implied job densities were found to be implausible, the floorspace figures were adjusted to accommodate the employment.

To estimate retail floorspace growth in 2001-2026 in London, East and South East regions the growth rates in the wholesale and retail employment were used under the assumption of the constant employment densities within each region. The floorspace was assumed to be built exogenously. For office and industrial LonUM floorspace types, Roger Tym & Partners provided DSC with the GLA sites database, which outlines developments in the planning process for the period 2001-2021. This data was geocoded and converted into LonLUM zones. For the period 2022-2026, the planning policy files were extrapolated from the growth in the period 2011-2021. For Hotel and Leisure development, the GLA sites database only had developments to 2006. For the period 2007-2026 within London, the floorspace growth in London was assumed to grow in-line with the hotel and catering employment growth in London, so as to keep the floorspace per worker values constant within the London area. For office, industrial, hotel and catering floorspace in East and South East regions the growth rates were estimated from the corresponding growth rates in employment. The floorspace was added as permissible development. The distribution of the floorspace was estimated from the employment distribution using East of England or South East of England Regional Assemblies planning data.

Education forms three floorspace types within the model, primary and secondary, adults and higher education. Primary and secondary and adult education floorspace were both calculated based on the assumption of constant floorspace per worker. The employment growth rates for the whole Fully Modelling Area were calculated, and then multiplied by the corresponding 2001 floorspace per worker; the resulting floorspace figures were then distributed to zones in proportion to the planned residential development. Higher education was calculated in a different method to the other two education floorspace types, as higher education in England (and particularly in London) is related to national and international rather than local demands. Rather than being linked to residential development, the floorspace was built exogenously by region. Using the growth in employment forecast for each region, a growth rate was used to grow each zone within the region at that specific rate. The end result is that employment densities remain constant within each region. The floorspace calculated differs from other types in that it is exogenously forecast to be built. Health floorspace is calculated in the same way as adult education. For each region, the proposed amount of total floorspace needed to keep densities constant is calculated. This is then allocated to zones, as permissible development according to the proportions of residential development occurring in each zones.

3. DISCUSSION: MODEL CALIBRATION ISSUES

At the time of writing, a round of work to refine the model and to create a new Reference Case is ongoing, and it is not possible at this stage to present results for discussion. Instead, we propose to take the opportunity to consider some of the issues which were raised by the Peer Review Group which TfL convened to provide an independent assessment of the model. These issues were also raised in a paper subsequently published by two members of the Peer Review Group (Wenban Smith and van Vuren, 2009), and are relevant not only to LonLUTI but to any comparable model of the processes of urban change. In this section we consider the question of calibration; other issues follow in the next section.

The LTS transport model used within LonLUTI is, like the majority of transport models, calibrated on the basis of cross-sectional relationships, assuming that choices are in equilibrium with the transport conditions and other factors prevailing at the time. The LonLUM model, however, works very largely in terms of gradual changes over time, and hence cross-sectional calibration is neither possible nor appropriate. There are no standard sources of data that provide all the information needed for such calibration, and no tradition of carrying out semi-standard surveys (such as those common to many major transport modelling exercises) for land-use modelling purposes. Small-scale survey work can be encouraging but does not necessarily provide data which can immediately be used reliably to calibrate even one part of a LonLUM-like system (see Feldman and Simmonds, 2009). The calibration of DELTA models therefore relies very much on drawing in information on linkages, impacts, sensitivities and (ideally) quantified coefficients or elasticities from other research.

This approach was always part of the intention in the DELTA design (Simmonds, 1999), and was a deliberate reaction to previous generations of land-use models which existed in a world of their own, unrelated to the growing corpus of relevant work in urban geography, urban economics, sociology, demographics and so on. The implementation of such an approach is not easy. It is often surprisingly difficult to establish the exact definitions of variables used in published analyses, and even more difficult to find analyses which have used variables directly comparable to those which are used (or could be used) in DELTA – "accessibility" in particular being a key concept which can be operationalised in many different ways. There are also the issues of whether spatial units are comparable, and questions arising from the use of disaggregate rather than aggregate data. Despite these difficulties, however, progress can be made.

One important source of empirical analysis is that of hedonic price and rent studies, which attempt to explain the market prices or rents (or asking prices/rents, as a proxy for market values) in terms of a range of variables including locational and/or accessibility terms. Very often, the "accessibility" terms are simply the distance from a central point, usually within the

Central Business District of the dominant settlement. This is not ideal for use in a modelling system which relies upon measures of accessibility based upon the generalised costs of travel, rather than upon distances. It is possible, though not ideal, to relate the (negative) value of distance from the centre to accessibility by regressing levels of accessibility against distances, and make the necessary substitutions.

A more helpful approach, however, is if the analyst carrying out the hedonic price study can use among the independent variables the kinds of accessibility measures used in DELTA (and many other) models, which represent the expected general cost of travel to a particularly category of destinations (technically, these are logsum terms from nested logit models of mode and destination choice). The one example to date is Ismail's (2005) work on residential markets in Glasgow, in which she used as one of the independent variables an accessibility measure output from the base year of the Central Scotland Transport Corridor Studies (CSTCS) LUTI model, a DELTA model similar in overall structure to LonLUTI which DSC developed for the Scottish Executive some 10 years ago. Using that and a large number of other variables, she estimated a number of different models, and found significant coefficients on the accessibility measure showing that an increase of one minute (implying an increase of one minute in the expected all-mode average travel time from the zone to all work opportunities) would reduce the value of an average Glasgow property by 1.7% to 2.4%.

To use this kind of result in adjusting or validating an incremental model such as CSTCS or LonLUTI, it is necessary to run the model both for a Reference Case and for a significant transport alternative, to extract the residential rent changes that occur as a result of the transport scheme in the year after its opening, and to regress these against the changes in the relevant accessibility measure between the two tests. The rent impacts in the first modelled year after the transport change are used for this kind of analysis because the timelags in the model are such that these show the impact on demand for housing, due to the changes in accessibility modifying the preferences of locating or relocating households, before any other modelled consequences such as changes in employment or changes in floorspace supply can occur.

Although the accessibility changes resulting from the transport change are the sole cause of the output rent changes, the impacts on rents in individual zones are complicated by the facts that household responses are affected by a number of accessibility measures, whereas in the regression we are considering only the one most closely matching that which Ismail took from the CSTCS outputs; the household responses are also affected by the mix of households in each zone and by the distance deterrence effect in household moves. As a result of these complications, the rent changes are strongly rather than perfectly correlated with the accessibility changes that cause them. Since accessibility is measured in units of expected generalised cost of travel, the regression line for this relationship is expected to have a negative slope – increases in expected generalised cost will lead to reductions in rent. The regression line will not necessarily be expected to pass through the origin: if the transport test used to generate the rent changes is an overall improvement, zones which do not benefit from this improvement (or which benefit least) are likely to experience negative rent changes (as demand moves away from them to the zones which do benefit) and hence the intercept will be negative. In the longer run, if the transport change is significant enough to expand the economy, to increase employment and incomes, and to encourage in-migration, we would expect the line to shift upwards as the overall demand for housing increases – but also to be complicated by the effects of other changes arising from the scheme.

We have used this approach for work on LUTI models in Scotland. To use Ismail's results in modelling London obviously raises questions about the applicability of Glasgow results to the London situation, though it can be argued that in so far as the estimated values of accessibility represent a willingness-to-pay for accessibility then there should be some relationship between values in the two cities, related to the impact of income levels on that willingness-to-pay (the differences in transport systems should of course be captured in the accessibility measures, so that it might take a more substantial investment to reduce expected generalised costs by one minute in a city with a better initial transport system). There is however a London-specific set of housing price analyses carried out by Gibbons and Machin (2003), using similar methods to Ismail but different variables – and including analysis of the impacts of the Jubilee Line Extension and the Lewisham Extension of the Docklands Light Railway (DLR). Their "headline results" (p19) are as follows.

- Their "most conservative estimates" indicate that a 1Km reduction in distance to access points to the London Underground and Docklands Light Railway is valued at around 1.5% of local dwelling prices.
- Places that became nearer to stations as a result of the Jubilee Line Extension and Lewisham DLR Extension experienced dwelling price rises of at least 1.5% for each 1Km reduction in station distance.
- Valuation of station access varies by the service level provided. Station service frequency variation is capitalised in dwelling prices close to stations at the rate of 0.1% per train-per-hour for London Underground services, and at 0.3% per train per hour for Network Rail services.
- The effects of proximity to Network Rail stations is harder to pin down, because it varies enormously with distance to Central London, and because we have no recent Network Rail innovation to supply us with a natural experiment for our research.
- Households value choice amongst alternative stations, as well as distance to the nearest station. For a given minimum station distance, dwellings with a number of stations at that distance attract a higher premium than those with just one close station.

Frequencies are measured in trains per hour at each station. It is assumed that the JLE opening would add 20 trains per hour each way (40 trains per hour in total) to the level of service at existing stations. In the Gibbons and Machin model this would produce a 4% increase in prices of property close to these stations. Around the wholly new stations (Southwark, Bermondsey, Canary Wharf and North Greenwich) one would also expect increases in the values of properties for which the new stations are nearer than existing stations or add to the effective choice of stations. This would be particularly important at

Bermondsey and North Greenwich, which were previously remote from LU/DLR stations (and not particularly close to NR stations). The results of LonLUTI are being compared against this analysis, bearing in mind that the effects described by Gibbon and Machin are only for properties close to new or better-served stations, and that the relatively large zones of LonLUM include residential areas at a wide variety of distances from any new stations,.

Whilst analyses of the impacts of transport change on prices or rents are helpful, and model outputs that confirm to the results of those analyses are encouraging, they are not sufficient. At a practical level, whilst they are of interest, and may be of importance as an influence on subsequent physical regeneration (because higher values will encourage development or redevelopment), they are not generally of as much interest as the effects on the demand for space, ie the impacts on households and on employment location. Theoretically, there is also the limitation that rent increases in the model are a consequence of the demand changes; looking at rent increases alone, it is impossible to rule out the possibility that a "good" result is due to an exaggerated rent response to an under-estimated demand response, or vice versa. More attention to the impacts on demand, ie on households and employment, is therefore required.

A good example of the kind of study which seems most helpful in this respect, and the one of which we have made most use to date, is that by Bramley and Leishman (2005). This consists of a set of five models estimated on panel (time series) data for a set of local authority groupings in England. The spatial units of these models (small groups of contiguous London Boroughs, and shire counties) correspond in scale to the higher-level "area" units in LonLUTI. The five models estimate for each such unit

- gross within-UK in-migration rate, persons aged 30-44 as proportion of resident persons in that age group;
- gross within-UK out-migration rate, persons aged 30-44 as proportion of resident persons in that age group;
- new private housing completions per 100 households;
- average real mix-adjusted house prices;
- private sector housing vacancy rate.

Each of the models is a mixture of simultaneous and time-lagged terms. The model for in-migration, for example, includes terms relating to the claimant unemployment rate, estimated net household incomes, and the rate of growth in number of jobs. By careful analysis of the published coefficients results it is possible to estimate the expected impact on the working age population of a typical area of (for example) an additional 100 jobs, this impact coming about through the changes in unemployment, in incomes and the growth in the numbers of jobs themselves, taking account of the impacts on both in- and out-migration. The LUTI model itself can then be run to find what forecast of change in working-age population per 100 additional jobs it will produce as a result of an arbitrary increase in business investment in any one area. If for a range of different areas, these results are compatible with those expected from the Bramley and Leishman analysis, then we would argue that some degree of indirect validation has been achieved. As with the common process of validating transport models by testing their ability to reproduce flows on networks, there are always further questions to be considered of whether the model is producing the right results for the right reasons; the first step in this direction would be to extract further detail of the model outputs so as to look at the gross in-migration and out-migration impacts separately.

Whilst it is difficult to find previous research studies whose results can be directly related to the coefficients and responses of models such as LonLUTI, we are making progress both in identifying such material and in developing new or better ways to make the necessary linkages between our own models and those of others. We regard this approach not as a poor substitute for local calibration, but as at least an important adjunct to it. In cases such as the Bramley and Leishman analysis, where the previous research considered draws on much larger datasets, over a wider but relevant region and over a longer period, than we could possibly assemble for an individual project, we would argue that the use of such research is positively preferable, enabling our modelling to draw on a much richer range of observed experience.

4. DISCUSSION: OTHER ISSUES

The Peer Review Group were also preoccupied with the fact that there appear to be two sets of “travel to work matrices” in LonLUTI – one set in LonLUM and one in LTS. The fact that both are influenced by changes in the generalised cost of travel, and that those in LTS are adjusted within a conventional doubly-constrained model structure whilst those in LonLUM are less constrained at the residence end, does appear to be leading the model into the sin of double-counting the effect of transport change, or that of inconsistency between the land-use and transport models, or both.

These concerns are in fact exaggerated. The matrices in LTS are indeed trips, from home to work, but those in LonLUM are matrices of persons living in zone *i* and having their usual place of work in zone *j* (including, of course, the possibility of people living and working in the same zone, $i = j$, which is highly significant at this scale of analysis). Whilst the two sets of matrices should be compatible, there is not necessarily a simple relationship between them. Differences may arise from complications such as differing frequencies of travel to work (eg people living close to their work may be more likely to return home for lunch) and to differing patterns of trip chaining (not everyone goes straight from home to work each day). We would therefore not expect a simple proportionality between the two sets of matrices. The more thorough the treatment of intermediate destinations implicit in LTS, the more complex the relationship is likely to appear in the base data (since a home – shop – work journey in should appear as a shopping trip from home to shops, and a non-home-based trip from shops to workplace during processing of the Household Interview Survey data from which LTS trip rates are derived).

In terms of the changes to these matrices that are forecast within the model, there are two inter-related issues to consider: the way in which the pattern of trips changes in response to generalised costs, and how this is linked to “land-use” changes – the latter including residents moving from employment to unemployment, or vice versa, as well as changes in residential or job location. The present approach is that the trip matrices in LTS (split into two socio-economic groups) are redistributed in response to generalised cost changes as part of the transport model run (ie in simultaneous equilibrium with the transport supply changes themselves), in a conventional doubly-constrained framework. This approach stems directly from the original TfL requirement that – in order to maximise consistency with other modelling work – LTS should remain as far as possible unchanged from its normal "stand-alone transport model" form, the only changes being those essential for it to take land-use data inputs, differing for any one year according to previous years' policy inputs, from the land-use model. The double constraint imposes the conditions that the number of home-work trip productions from any zone is in any one run a fixed function of the numbers of residents in work, and that the number of home-work trips attracted to any zone is a fixed function of the numbers of jobs there. Within one single run of LTS, there is therefore no scope for residents to shift (for example) from unemployment to employment as a result of improved accessibility to jobs.

In the runs of LonLUM in the immediate following years, the changes in generalised costs are used to recalculate the redistribution of trips, but within a framework which is less constrained at the residential end and which does allow for transfers of residents between employment and unemployment (as well as adjusting for the changes in labour supply as a result of changes in households and their locations). In effect, therefore, LTS provides what can be regarded as a short-term response in which every resident's employment status and residential location are fixed, whilst LonLUM provides a medium-term response in which these characteristics are variable. Provided that LTS correctly responds to the changed land-use data from LonLUM in the following LTS run (five years later), it may be accepted that the short-term response within the first LTS run and medium-term response through the combined workings of LonLUM and LTS five years later will be different. There is however the question of whether the doubly-constrained form of LTS is the most appropriate model to estimate the short-term impact. Some members of the Peer Review Group argued that the redistribution effects in LTS should be switched off, so that the short-term response to generalized cost changes would be limited to choices of mode, route and time of day. This is a question which will need to be considered further, since whilst it would be simple to implement it would have the effect of moving LTS further from its original, standard form, and would make it more difficult to use the results of this form of LTS in the appraisal calculations (cost-benefit analysis) required by the UK Department for Transport. (As noted below, members of the Peer Review Group had serious concerns about those requirements themselves.)

The Peer Review Group rightly pointed out that there is a growing interest in understanding how spatial and transport planning can impact on the overall economic growth of a metropolitan region such as the Greater South East, as well as on the distribution of activities within the region. LonLUTI as it currently stands is constrained to maintain a given scenario of total economic activity for the whole region: the design that achieves this was adopted because for much of the history of DELTA it was a requirement of UK transport appraisal that any assessment of land-use or economic effects should be done on this basis. This is now changing for some aspects of appraisal; we have argued elsewhere (Simmonds and

Feldman, 2009) that the effects now recognized by the UK Department for Transport (2005) should for consistency be brought within the structure of models such as LonLUTI, rather than being treated as separate calculations after the modelling has been completed (this current practice is reported in Feldman et al, 2008). A particular case is the "more people in work" effect - the extra benefits (outside the conventional consumer surplus calculations) from increased labour supply[2] due to better transport effectively increasing real wages (net of commuting time and cost). The issue that has to be addressed in bringing the labour supply response into the LUTI modelling is that the existing DELTA design, like most models in the LUTI tradition, constrains the overall labour supplied – residents in work plus net in-commuting – to equal the labour demand determined by the workings of the regional economic model. From a modelling point of view, it is obviously unreasonable to represent an increase in the number of residents in work without considering where they work (or indeed whether there are further workers available). Moreover, to record a benefit from "more people in work" without accounting for the additional congestion and environmental impact that are likely to result from their travel to work is difficult if not impossible to defend.

To implement a working model of the "more people in work" effect therefore requires that the response should be treated as one of labour **demand** rather than labour **supply**. The **demand** for labour has to be made elastic with respect to the changes in real wages resulting from the transport scheme under appraisal; the model's normal mechanisms for matching supply to demand will then ensure that the additional jobs are filled (or the reduction in jobs is matched), and impacts on commuting patterns, congestion and environment will follow automatically. In addition, the model will also take account of multiplier effects arising from the additional employment, including not only the increase in consumer demand resulting from the net increase in incomes but also the impact of increased income (and of increased employment itself) on car-ownership. Increases in car ownership will of course further modify the travel, congestion and environmental impacts – and may quite possibly arise from public transport (transit) improvements as well as from highway investment.

Members of the Peer Review Group also argued that the whole approach to transport appraisal in the UK needs to be overhauled to pay more explicit attention to long-term effects, especially spatial ones such as impacts upon regeneration and the distributions of population and employment. This is part of a wider reaction (see also Metz, 2008) against the orthodoxy of conventional transport cost-benefit analysis, which assumes that in most cases any non-transport consequences of transport change (such as the redistribution of land-use) are transfers or transformations of benefits, with no impact on net benefits, and

[2] More precisely, the DfT methodology identifies the extra benefit as the additional direct taxes paid by people who would be brought into work as a result of the transport improvement; it assumes that the net benefit to those people is captured as part of the conventional consumer surplus measure in the transport economic efficiency calculations. This will not always be the case: in many transport models (including LTS), the production of trips to work is constrained at the residential end and hence (whether or not the model is constrained at the workplace end) will not allow the travel changes corresponding to the labour supply response that would produce that element of consumer surplus. In that case we believe that the whole increase in GDP resulting from the additional employment should be counted as an additional to the conventional analysis, rather than just the tax component.

that their spatial distribution is irrelevant. This is not so much an issue with the model as an issue with the context in which it may be used, and a suggestion of a growing concern that models such as LonLUTI should be applied to understanding (if not necessarily to formal appraisal of) the impacts of major proposals and strategies.

5. CONCLUSION

The work described here represents a new departure in offering Transport for London and the other planning agencies within the Greater London Authority system a more comprehensive capability to explore the likely consequences of possible future interventions in transport and in spatial planning, separately and in combination. The authors of the present paper believe that the model is capable of making a valuable contribution to analysing the expected impacts of future decisions in London, and that the need for this capability will continue to grow over the coming years.

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