Modelling Transport and the Economy in London

Framework and Literature Review

December 2007

Volterra Consulting Ltd
Colin Buchanan and Partners Ltd

Contents

1 Executive Summary

Motivation

There has been growing interest in the role that transport has in stimulating, growing and supporting the economy, as explored in the Eddington Review. This report builds on earlier work on the TANDEM (transport and economy model) developed for GLA Economics.

Land Use and Transport Interaction models, and modelling more widely, are a useful tool for planners. The aim of this report is to understand how, and if, they address the key questions facing the role of the transport system in the London economy.

London Focus

The evidence base for the interaction between the economy and transport has been growing in London. Work has explored the link between earnings and employment density, between accessibility and employment density, and between crowding on tube lines and the levels of growth experienced. Meanwhile, we have observed the broad changes in the distribution of employment in London as different sectors have experienced growth and decline, and as the availability of transport has shifted.

For a modelling framework to fit well in London, it needs to be able to incorporate these key issues, which may be more strongly present in the capital than elsewhere.

A Broader View of Modelling

A large amount of intellectual effort has gone into developing and building models of urban systems, land use and transport over the past century. The 1960s in particular saw the introduction of large scale comprehensive models drawing on analogies from the sciences. In recent years much academic interest has been directed towards cellular and agent based modelling, drawing on the growing body of complexity sciences.

A number of substantial challenges face modellers. Validation, the process of checking that a model produces results which match the real world, is particularly difficult given both data and time constraints, and faced with the immense complexity observed in real urban systems. It is however completely necessary if the models are to be used and believed in a policy context. Getting the question right, and making sure that the model contains enough detail to address this whilst the model itself is simple enough to be understood, become essential payoffs for the modelling endeavour to succeed.

Finally, urban, land use and transport models are not primarily economic models. Generally, these models handle the economy in a limited way. Increased effort will therefore be needed to find the correct framework for introducing economic impacts.

The Models

We examined three models in detail, and assigned each a tagline and short summary. A more precise discussion is available in the text and from the cited reports.

- **LASER v3**, *WSP Group* – Solving for Household Location
  The model uses fixed 'base' employment scenarios, and solves to find where all population and locally serving jobs will go.
- **DELTA**, *David Simmonds Consultancy* – Modelling Choice
  The model typically uses fixed forecasts for employment and population at a regional level. Each period new and relocating employment and population choose where they would like to move and bid to see where they do go.
- **UDM**, *Steer Davies Gleave* – Evolving locations
  Total employment is not fixed. Each period growth rates for zones are adjusted in response to the local conditions. In particular they are stimulated to grow until constraints are reached, while making sure that the balance of jobs, workers and sites are maintained.

While the models contain useful analysis of the implications of economic scenarios, and generate outputs which can be used in the estimation of Wider Economic Benefits, none of them currently embraces the feedbacks implied by the economic theory behind them. In particular output and productivity are not typically variables within the models, and therefore do not respond to the location of growth.

This is also true of the three additional models we examined: the Tyndall Model (*Mike Batty UCL*), TIGRIS (*RAND Europe and TRC Netherlands*) and California Land Futures (*John Landis, Berkeley*). For each the focus has been on the distribution of employment, rather than levels of growth. The three additional models are interesting case studies, due to their approaches to GIS presentation and calibration.

Conclusions

Given the limited treatment of economic issues in current Land Use and Transport models, and the difficulty of validating the models once additional processes are added, there is a very strong need for a deepening of the evidence base for the interactions. In particular, understanding the balance between simple redistribution of growth following transport change, and the extent to which actual growth or decay happens. Also, further exploration of the role of productivity, wages and commuting on development patterns, is needed.

In order to move forward, new data sets will need to be explored, and existing data sets brought together and used in a new way. This should be done transparently so that evidence can be used to calibrate existing models, as well as to develop new ones. It may be necessary to construct smaller models that collate and test the relationships in the data.

We propose that research is needed to examine local links between businesses, those linking further a field, the way in which incomes are passed through the spatial economy and the broader way in which economic development has occurred alongside accessibility.

2 Motivation

2.1 Background

This report builds on earlier work commissioned by GLA Economics investigating the links between economic growth and transport investment which culminated in the development of TANDEM (Transport AND Economy Model).

The aim of the report is to better understand the way forward in modelling transport and the economy. To this end it considers the issues facing London, the broad context of urban modelling and presents an in depth literature review of three of the key land use and transport interaction models in policy use today.

This body of work has been necessitated by the growing evidence linking transport improvements to economic success, as explored in the Eddington Review. The role of cities as productive centres for a service economy is increasing, and transport policy is recognising the need for improvements to strengthen and support them in this role. As a result there is a growing need for analytical techniques which refine and improve the estimates for the impact of transport on the economy.

Within London, evidence for these interactions has been developed on a number of different fronts. The economic case for Crossrail[1] argued that public transport capacity acts as a constraint on the growth of London, and developed a methodology for valuing this impact. The methodology has since been incorporated into the 'Wider Economic Benefits' guidance note[2]. In the case of Crossrail these benefits were at least as large as the traditional transport benefits and in some scenarios several times larger.

GLA long term employment projections, meanwhile, showed that incorporating accessibility changes could either restrict or enhance local employment opportunities, compared to a forecast based either on structural trends or site availability.

At the same time, Land Use and Transport Interaction models have been developed to be used in estimates of a broad range of impacts expected from transport and planning policies. The models consider to different extents the inter-relationships between transport and the economy. The models have been used in a wide number of different cities and regions, and to a more limited extent are being applied in London itself. There is therefore a need to better understand how these models treat the economy, and to what extent they incorporate Wider Economic Benefits.

2.2 Lessons from the TANDEM model

The work on TANDEM started with a simple and transparent model structure that looked to link the transport impacts of schemes with the impacts on the levels of population and employment in London. The model aimed to incorporate a number of important features:

[1] Economic Benefits of Crossrail, May 2007, Colin Buchanans and Volterra Consulting
[2] http://www.dft.gov.uk/pgr/economics/rdg/webia/

- It was focussed on the issues affecting London – in particular, capacity constraints, employment growth and agglomeration
- Both population and employment were redistributed following transport changes
- The location of business activities impacted on economic performance (in the form of agglomeration and boosts to business)
- Increases in generalised costs deterred some passengers from living in London

The model aimed to use elasticities derived from the LTS model to inform the aggregate relationship between demand and generalised cost and vice versa. In doing that a number of issues came to the fore:

- The treatment of crowding in the existing transport models (LTS/RailPlan) and in particular the lack of a capacity constraint on rail modes means that they are inappropriate tools for doing this;

- It has been agreed that LTS elasticities capture the short term and cross sectional responses to transport and do not reflect longer term behavioural changes;

- Agglomeration is a powerful force in determining the distribution of employment and especially the distribution of employment growth and should be incorporated into modelling frameworks;

- The distribution of population growth is closely related to accessibility to employment, as shown by research for GLA economics[3].

The latest TANDEM work showed that applying elasticities derived from the LTS model did not produce sensible results and therefore the model presently relies on assumptions about relevant elasticities, based on professional judgement. In order to move forward it was agreed that a new approach was needed. This report is the next step in this process, providing an opportunity to bring together the key issues, and to understand what models are currently available.

2.3 Aim of this Report

This report therefore aims to present and explore the issues arising from modelling the economic impacts of transport investment, and to examine in detail what available models do and do not cover.

We begin, in Section 3, by discussing in depth the key issues faced by London, and the growing evidence base for the ways in which infrastructure can support, enable and improve economic growth. In Section 4, we examine the broad history of modelling in this context and consider the key lessons and challenges faced by modellers.

Section 5 contains an in depth discussion of three of the largest land-use transport interaction models in policy use in Britain today. The review focuses on the different

[3] Colin Buchanan, 2003, Transport Accessibility: Case for London Technical Report 1, GLA Economics

approaches used, how the models can be tested against the real world, and finally teases out the way in which the models treat the economy. In particular we explore the ways in which Wider Economic Benefits are included, or not, within the model frameworks. We finish with a quick overview of lessons from three other models. Finally we conclude in Section 6 with a consideration of the way forward.

2.4 Workshop

On the 1st October, TfL hosted a workshop on the issues of transport and economy modelling. Bridget Rosewell and Amy Horton from Volterra presented to representatives from GLA, TfL and Colin Buchanan and a detailed discussion followed.

This report has benefited greatly from the contents of that discussion. A number of key issues were raised, which should form the context for decisions on how to proceed:

- The importance of understanding the difference between economic growth and the distribution of employment – when does transport contribute towards growth?
- Understanding how the London economy grows and its relation to the wider global economy and to migration patterns
- The challenge of developing validation strategies to examine how well the model matches with the real world
- The importance of time – the way in which imbalances persist through time

More specific concerns included:

- Understanding the various effects on in work time, leisure, commuting and freight trips – and how each affects the economy
- The difference between capital and operational investments such as subsidies. What type of impacts do subsidies have on growth levels?
- The importance of choosing the right metric for accessibility – should it be generalised costs for journeys to central London, number of jobs nearby, or some other measure? How should this be affected by capacity issues?
- Which spatial levels are important? Does the model need to consider highly disaggregate zones, or is a simpler larger scale model sufficient?

3 London Focus

3.1 Cities and the Spatial Location of Activity

In recent years there has been a renewed focus on the spatial location of economic activity and its determinants. Cities have always acted as the main drivers of economic development and this has garnered further interest amid globalisation and the growth of the service sector economy. The characteristics of urban regions in terms of their competitive advantage have become the focus of notable works including those by Sassen (1990)[4], Krugman (1991)[5] and Simmie (2001)[6].

This section provides an overview of the concepts at the heart of urban competitiveness, such as the role of density and agglomeration. The experience of London, in how industrial change has influenced its spatial development and travel patterns is also considered. It also reviews the key concepts of how transport influences the location of employment and supports economic growth and considers the policy implications for transport planners and modellers in attempting to predict transport-economy interactions in London.

3.2 Agglomeration

A significant part of the analysis has been concerned with the concept of agglomeration as a source of economies of scale and productivity growth. The forces of agglomeration have existed since the beginning of the first urban settlements, where farmers and merchants gathered at trading posts to do business and exchange news. Meeting in one location removed the need to conduct transactions separately and reduced the cost of doing business. At this basic level of understanding it is easy to see why cities today have evolved due to the forces of agglomeration.

Today cities exist as dense concentrations of human capital, services, infrastructure, markets and information. Our understanding of the importance of agglomeration has therefore become more complex. The growth of service industries – and particularly traded services such as banking, finance and professional services (FBS) has seen a resurgence of large cities and central business districts (CBDs), where close proximity enables the capture of agglomeration benefits and reduced costs. There are four specific elements of agglomeration that can be identified as follows:

- Labour – access to a larger and deeper labour market reduces the cost of search and training for specialised and highly qualified staff.
- Specialised Inputs – specialised support and services are more easily available and their cost can be spread over a large number of firms. Supporting institutions eg training associations, regulators are also easily accessible.

[4] Saskia Sassen 1990, **Economic Restructuring and The American City,** *Annual Review of Sociology*, Vol. 16, (1990), pp. 465-490

[5] Krugman, Paul, 1991, **Increasing Returns and Economic Geography**, *Journal of Political Economy*, University of Chicago Press, vol. 99(3), pages 483-99, June

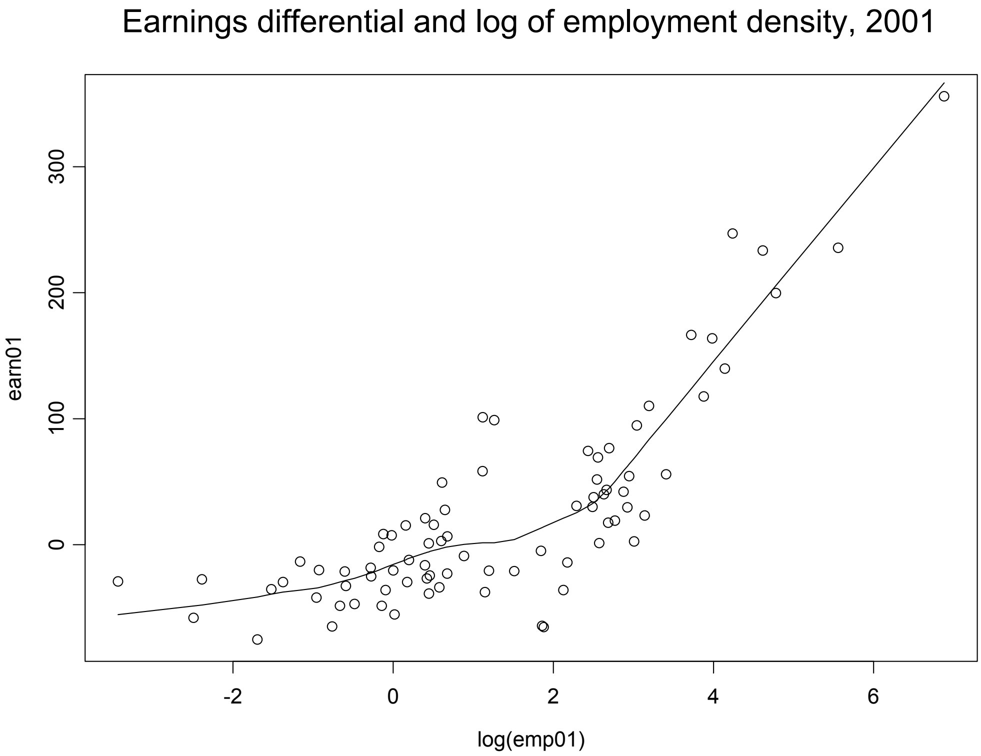
[6] Simmie, J. 2001 (ed) Innovative cities. London: Spon Press

- Knowledge and information diffusion – ideas, contacts and techniques are more easily shared and learnt when there in close proximity between complementary activities
- Market – access to a larger potential pool of clients and contacts, in the case of London on a global scale.

The overarching principle underpinning each of the above elements is competition. When there is concentration of firms or workers this encourages competition and provides an incentive to innovate. This is why large cities and central business districts are often the most dynamic regions of whole economies and why businesses are willing to pay higher property costs or fund urban infrastructure schemes. Evidence of this is borne out by a recent study showing a link between productivity and urban density[7].

Figure 3.1 illustrates the positive relationship between productivity and urban density, with productivity generally higher in the largest urban areas. There is a positive relationship between earnings differentials and employment density even at relatively low levels of density, but the relationship intensifies beyond a critical point. The observations to the right of this point are Greater Manchester, Tyne and Wear, West Midlands, and 27 London boroughs – in other words, dense urban areas. Inner London, as the densest urban area of the UK, is estimated to be 38% more productive and London overall 27% more productive than the UK average.

Figure 3.1: The Relationship between Urban density and Productivity



Source: Volterra

[7]. GLA Economics Working Paper 17 Why distance doesn't die: Agglomeration and its benefits

An appreciation of how density contributes to dynamism and productivity also needs to be taken in the context of London's global role compared to other UK cities. The globalisation of production has created increasing demand for a range of specialised management and support services, the availability of which only exists in a handful of large agglomerations around the world. As multi-national business has sought to coordinate their activities from a single location, cities such as London, New York and Tokyo have been described as 'global cities' (Sassen, 1990).

In addition, there is the role played by other factors, such as the presence of cultural and professional institutions in supporting density. The status and concentration of these features are again only rivalled on a global scale and make an important contribution to London's competitiveness and quality of life. As such it is important to understand that the unique appeal of London is in global proportions and emanates from the concentration and combination of a number of different elements (Glaeser 2000[8]).

3.3 London Experience

London's role as a major global centre was established during the British Empire when finance, trading and maritime services formed the core of its international offer. Increasingly in the 19th and well into the 20th century this global role expanded further through the rise of large-scale manufacturing. The capital's economic primacy during this period was perhaps underlined by an all time peak in population of approximately 8.6 million at the onset of WWII.

Prior to 1900 London's population was confined largely to the inner area (essentially today's Inner London boroughs). Population became increasingly dispersed after 1900 with the advent of the new underground lines linking outer areas and the active promotion of 'the suburbs' as a more pleasant alternative to the inner city. For many years prior to this London's geography was characterised as a 'city of villages'[9], referring to surrounding centres such as Hampstead, Richmond and Clapham. Such areas can be viewed as the earliest forms of London's suburbia that were only accessible by private carriage before the introduction of trams and trolley buses.

As the pace of suburbanisation accelerated from the latter part of the 19th century, population growth in the 1900s onwards was most visible in outer London. The areas between the inner area and surrounding centres were more intensely developed and the outer area saw the development of large, low rise private housing estates served by new or extended underground lines and arterial roads. Between 1901 and 1951 the population of outer London increased by nearly 3 million while inner London's population declined by roughly 1.2 million.

Although the outward push of the suburbs was checked by the introduction of the greenbelt after WWII, changes in public transport provision and the growth in car

[8] Glasear, Kolko, Saiz (2000), Consumer City, Harvard Institute of Economic Research, Discussion Paper
[9] City of Villages: Promoting a Sustainable Future for London's Suburbs URBED report for GLA (SDS Technical Report 11)

ownership further encouraged the decentralisation and dispersal of London's development. The replacement of tram/ trolley bus routes by the early fifties, which served much of inner London and surrounding centres, by less frequent bus services to free up road capacity was one factor behind this. As Table 3.1 indicates, the share of commutes by tram/bus modes dropped sharply after WWII and was accompanied by an increase in the share accounted for by car trips although these had stabilised by the 1980s. The table also underlines the growing dominance of rail and underground travel over the same period, accounting for an average of roughly 64% of all commutes by the 1980s.

Table 3.1 Main mode of transport for journeys to work in London (%)

Time period	Bus/tram/ trolley bus	Rail - Overground	Rail- Underground	Car/van/motor bike	Bicycle	Walking
1890-1919	35.0	24.2	4.8	0.7	5.2	28.7
1920-39	30.1	38.9	9.9	5.4	4.0	11.5
1940-59	19.9	44.7	17.8	4.8	5.6	6.6
1960-79	10.3	45.7	23.4	14.1	1.5	4.7
1980-98	12.5	41.8	21.8	14.4	5.8	3.4

Source: Pooley & Turnball (2000)

The emphasis on decentralising London's growth was also expressed in the co-location of housing and jobs. The ongoing expansion of manufacturing with an increasing need for large sites saw the development of industrial estates alongside private suburbs in outer London and mainly served by road. A good example of this policy in action can be seen in north London around the North Circular ring road. This approach was extended further in response to the growth of office work from the 1960s onwards, most evident in the locating of office blocks in suburban centres as a conscious aim of planners.

By the 1970s it was apparent that the continued loss of Britain's manufacturing competitiveness was severely affecting outer London employment as well as parts of inner London (which was already losing traditional manufacturing and port jobs). Given the importance of manufacturing to the capital's economic viability, the extent of the job loss resulted in an overall decline in London's total population, hitting a census low of 6.8 million in 1981. By the 1970s, however, the service sector had begun to establish itself as the main source of employment, accounting for more than 50% of private sector jobs by 1974. Table 3.2 summarises how London's employment composition has changed since the 1970s. It underlines the decline of the manufacturing and related employment share, and rise of the service sector, most notably in business services.

Table 3.2: Employment Structure in London

	% Share of Employment				
	1974	1984	1994	2004	1974 - 2004
Primary & utilities	1.6	1.3	0.8	0.3	-1.3
Manufacturing	**21.9**	**15.1**	**8.7**	**5.6**	**-16.3**
Construction	5.2	4.6	3.1	3.2	-2.0
Wholesale Retail	13.8	14.7	15.2	14.6	+0.8
Hotels & restaurants	3.8	4.5	5.5	7.5	+3.7
Transport & communications	11.1	10.2	9.1	7.6	-3.5
Financial services	5.9	7.3	8.5	8.0	+2.1

Business services	**11.2**	**13.8**	**20.0**	**23.7**	**+12.5**
Public administration	8.5	7.7	7.3	6.1	-2.4
Health & education	13.9	16.6	15.5	16.5	+2.6
Other services	3.2	4.3	6.3	6.9	+3.7

Source: NOMIS

In addition, as shown in Table 3.3 the decline in manufacturing employment and heavy industry has seen outer London lose in the region of 695,000 jobs over the last 30 years. This has only been partly offset by the growth of service sector activities. Over the same period, although Inner and Central London have also lost jobs in previously important sectors, although much bigger proportion of this loss has been compensated for by growth in service sector work, and especially business services.

Table 3.3 Central-Inner-Outer London employment change

	Overall Job Change 1974-2004		
Broad Sector	Central London	Inner London	Outer London
Primary, Manufacturing & Construction	-104,148	-185,615	-695,551
Retail & Distribution Services	-103,417	-53,187	84,502
Finance & Business Services	107,711	186,341	274,351
Public, Health & Other Services	13,643	35,156	79,583
All Employment	**-86,211**	**-17,305**	**-257,115**

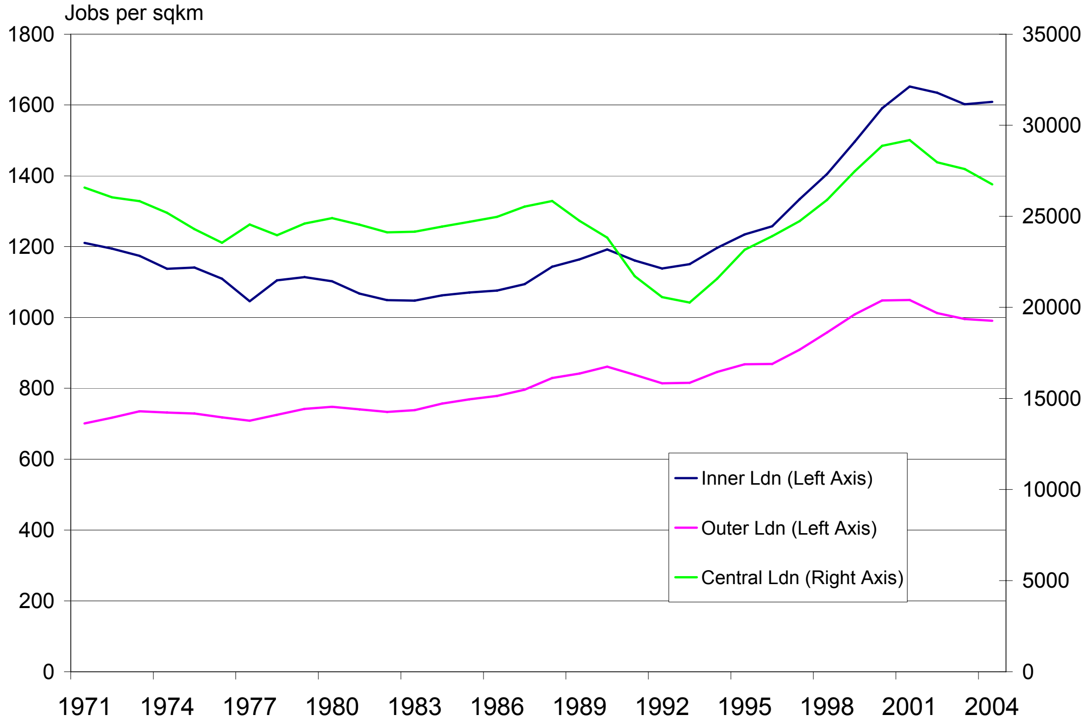
Source: NOMIS

The figures highlight in broad terms the shift in job growth towards central and inner areas. More importantly, they highlight that a large proportion of these jobs have been in the high productivity financial and business service activities. The trend has intensified over the last 10 to 15 years as FBS have become more globalised and London has gained an increasing share of the export market in such activities. As highlighted earlier it is these elements of the service industry with the greatest tendency to locate in dense central and inner areas where they can capture agglomeration benefits.

The result has been a reversal of the trend of decentralisation of employment, with growing employment concentration in central and increasingly inner areas. Employment densities in outer London, on the other hand, have increased to a lesser extent. Figure 3.2 summarises this pattern for the three areas, (central London densities are grossly in excess of the other areas and therefore are labelled on the second axis).

The data shows a narrowing of the gap in densities between Outer London and Central and Inner areas until the early 1980s, followed by a broad stabilisation until the early 1990s. Beyond the early 1990s and amid accelerating growth in FBS employment the gap begins to widen. Service sector employment density in Central and Inner London rises faster than in outer London before dropping back in response to the post-2001 economic slowdown.

Figure 3.2 Service sector employment density in Inner and Outer London



Source: NOMIS and Colin Buchanan

3.4 Accessibility-Density Research

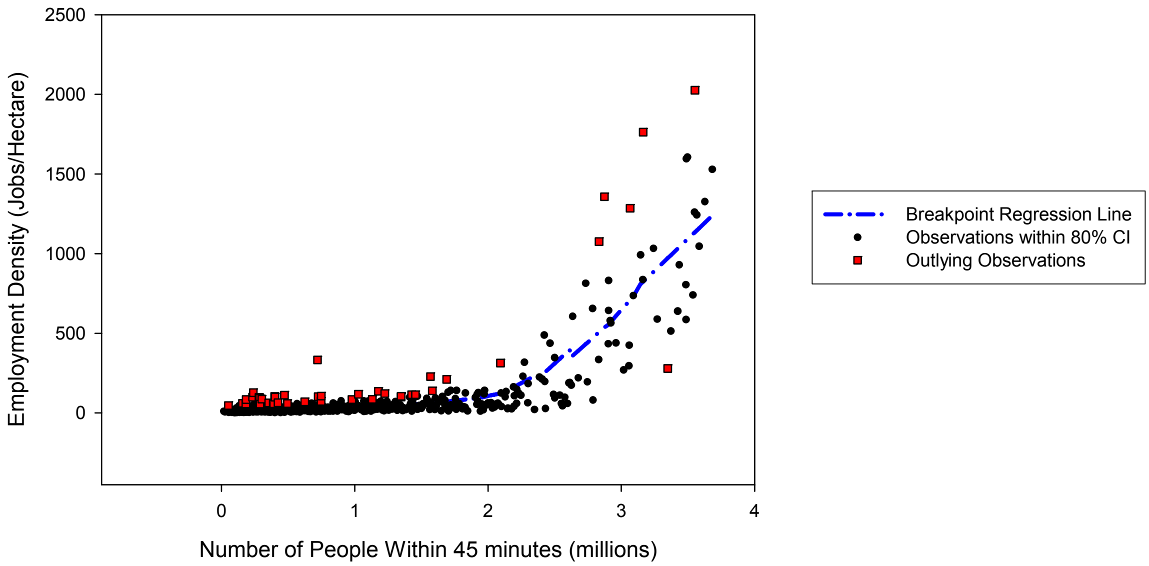
Against a background of increasing centralisation of London employment over the last 20 years and growing appreciation of the role of density and agglomeration in promoting economic growth, a number of studies have focused on how transport investment can facilitate the dynamics of agglomeration.

Earlier research for Greater London Authority[10] highlighted the link between transport accessibility and employment density in London. The findings indicated a strong relationship between the number of people who could access a ward within 45 minutes travel time and the employment density in that ward. The study also found that the relationship was notably stronger for public transport than for highway accessibility.

The relationship was such that at high levels of accessibility, employment density increases very sharply. More specifically, in the case of the City of London wards employment density was much higher than predicted by the analysis. This is partly attributable to physical characteristics such as the absence of large green spaces, but the evidence suggests that agglomeration plays a major role in influencing the locational choices of certain activities – with a preference for dense employment areas. This encourages higher development densities.

[10] Colin Buchanan (November 2003) Accessibility Thinkpiece for GLA Economics

Figure 3.3: Summary of Accessibility-Density Relationship



Source: Colin Buchanan

As Figure 3.3 highlights, employment density (as highlighted by the fitted regression line) is generally stable at low levels of accessibility. At these locations, employment is mainly related to population-serving activities such as grocers, newsagents, hairdressers etc and public services (with some remaining manufacturing). We can identify many of these locations in Outer London areas, where public transport infrastructure is more dispersed and roads play a much greater role in accessibility to local and major centres. Locations with relatively higher accessibility for the Outer area (eg Croydon) show higher employment densities.

The spike in employment density beyond a certain degree of accessibility reflects the fact that at more accessible locations firms can source a much higher potential labour force from a wider area. Also workers are also much more willing to travel longer than 45 minutes to access high salary jobs in the most accessible central area, and this is not represented by the analysis.

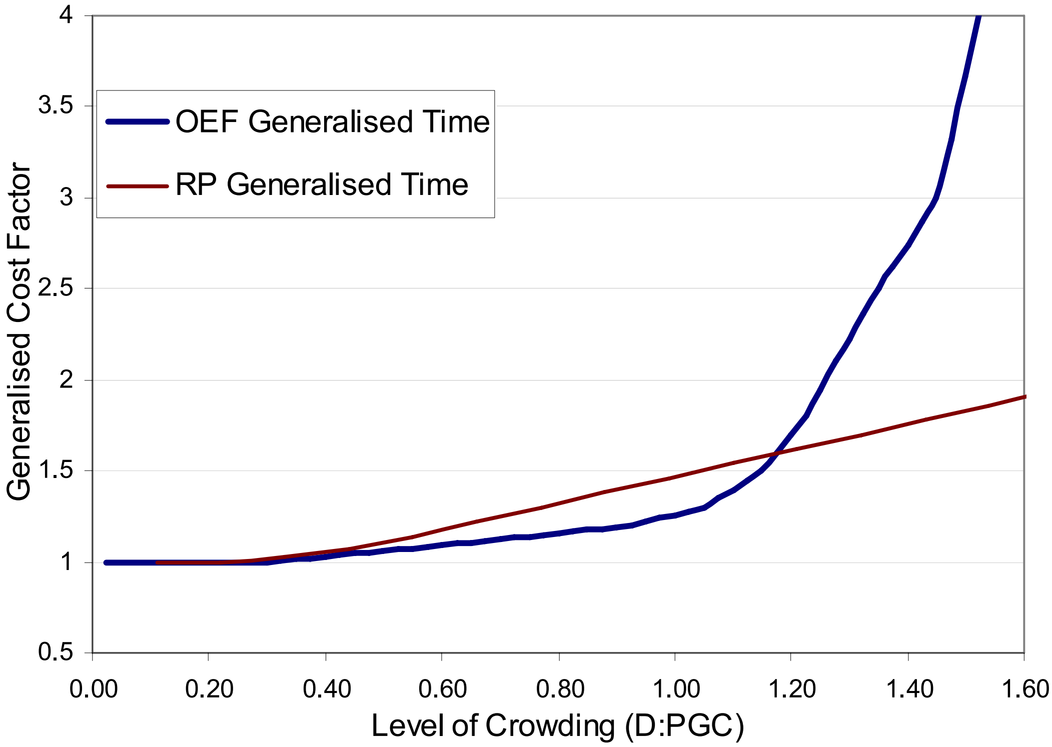
Similar analysis also examined the relationship between population density and accessibility to employment. Population density generally increases in line with rising accessibility, but declines at very high accessibility as residential development competes increasingly with demand for commercial space. The relationship generally holds across London though it is clear that accessibility is only one factor enabling higher population density alongside other important influences such as the attractiveness of an area and the quality of local services.

The accessibility-density work has helped to further understanding of the wider economic benefits of transport schemes and support the argument for greater investment in urban public transport – particularly rail and metro schemes. As pointed out by Venables (2004), transport improvements are an important contributor to agglomeration because they release the constraint on achieving higher employment densities in cities, and especially central business districts. Through this mechanism they contribute to productivity potential of cities and hence their economic growth.

3.5 Crowding, Crossrail & Agglomeration

Key to the assessment of the benefits of transport investment has been the understanding of the effects of crowding on travel demand. Existing transport models such as LTS and Railplan assume a linear relationship between crowding costs (in terms of generalised time) and growth in trips for all levels of crowding. This is denoted in Figure 4 by the straight line, indicating that the marginal impact of increased congestion on a given link is the same at all levels of capacity. A different approach suggests that at existing high levels of crowding, (eg above 1.2x planning guidance capacity) the impact of additional passengers on a link is felt by all passengers, meaning the costs in terms of discomfort etc are magnified. Additionally high crowding means that passengers are frequently unable to board the first train thereby rapidly increasing their journey times. Therefore at high levels of crowding the line the cost curve rises steeply implying the relationship is more non-linear.

Figure 3.4: Linear and Non-Linear Crowding Curve



Source: OEF/Colin Buchanan

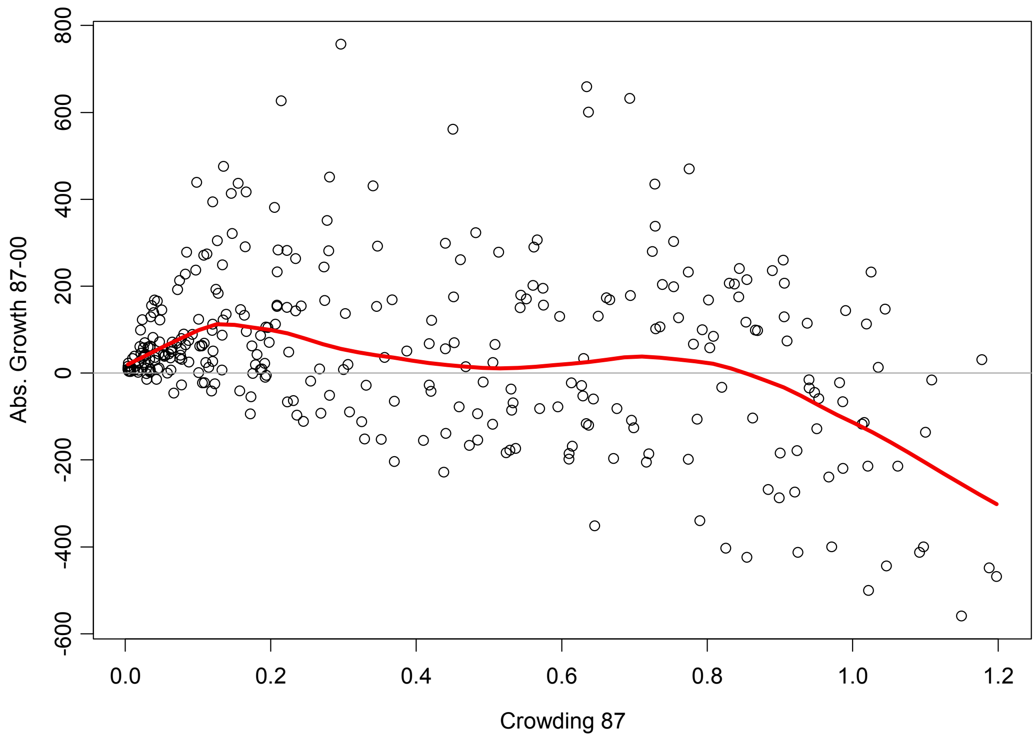
Over the last 20 to 30 years there has been continued rise in passenger numbers on the underground network with the exception of intermittent dips reflecting cyclical downturns in London employment. The current modelling approach assumes that although crowding increases total costs of travel to a particular zone the numbers of people working in that zone is not reduced, but instead take a different route to work.

On this basis it might be concluded that further growth in trips - as would be implied by the London Plan projections - could be accommodated on the existing rail and tube network.

Observed passenger behaviour on four London Underground lines (Central, Piccadilly, Victoria and Northern) over a twenty year period from 1981 to 2000, showed overall a negative relationship between crowding and the level of passenger growth. Further regression analysis showed that this relationship was more severe at particular periods where growth in passenger numbers were at or close to a peak in line with employment and for zones where crowding was already at high levels. In other words, growth in passenger trips was reduced by higher initial levels of crowding.

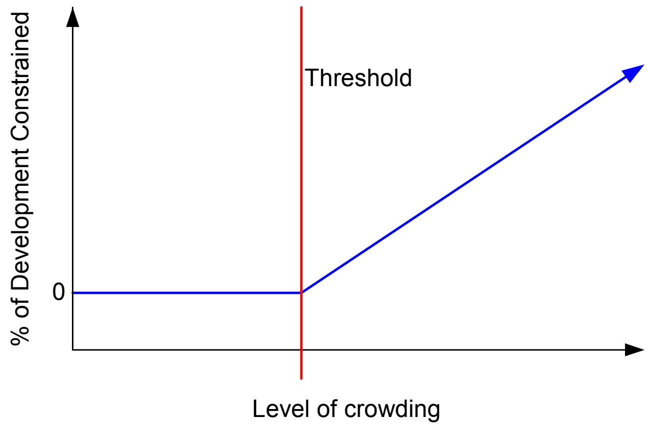
Figure 3.5 plots this relationship for the observed links with a fitted line. Zones above a crowding level of around 0.8 show (as denoted by the orange line) declining average demand growth. At high levels of crowding, passengers are less willing to bear further discomfort/cost and are deterred making the trip, as indicated by Figure 3.6. In terms of the future employment or development of an area, the analysis can be extended to the idea of a threshold level of crowding beyond which a proportion of growth in a particular zone is lost.

Figure 3.5: Crowding and Growth Relationship



Source: Volterra/ Colin Buchanan

Figure 3.6: Crowding Deterrence Function



Source: Volterra/ Colin Buchanan

The London Plan projections envisage a continuation of past trends in employment, with significant growth in jobs projected for the central area to 2026. A major part of the argument for Crossrail was that existing levels of crowding on the tube and rail network would restrict the future growth of the central area. The scheme supports this growth by relieving crowding on the most congested routes into the City and the West End, encouraging mode shift and redistribution of trips. By enabling more jobs to be located in the central area (rather than elsewhere or outside London) the scheme would result in further agglomeration benefits and aid productivity growth.

3.6 Implications for Policy

To date the modelling of the economic growth resulting from transport investment in London has been concerned with the impact of individual schemes and how improved accessibility/higher capacity affects growth in the central area. Aside from the TANDEM project, there have been few attempts to measure how transport investment, or the lack of it, may affect the distribution of employment and its evolution at a London-wide level, and the subsequent implications for productivity.

The pattern of growth in London is clear evidence that agglomeration is a dynamic process. The rapid development of the Isle of Dogs is not the only example of this; similar patterns are evident elsewhere within and on the fringes of the central area as in Islington and Southwark. It is therefore insufficient to assume that additional employment will be accommodated on the existing network or will simply locate in outer or less dense areas of London. The international market in which many highly dynamic sectors operate, in all likelihood means they will consider Paris, New York or Tokyo as alternative locations to London.

This requires a better understanding of the types of activities that will choose to be based in London and what informs their locational preferences. Accessibility to labour is key attraction factor, but less is known about the relative importance of other aspects of agglomeration benefits such as the density of suppliers and information flows, and whether these can be accurately modelled. Similarly we need to understand better how wages influence the willingness to travel to central areas and the distances commuted.

Finally, London is a unique city. Its economy and transport systems have characteristics that are different from other places in the UK and abroad. The international orientation and the concentration and status of business, cultural and institutional activities together create interactions and dynamism that are only weakly present in other UK cities. Likewise, the dominance of rail and public transport in the central areas, present opportunities and problems that differ from those elsewhere.

An effective modelling framework therefore needs to be focussed on and tuned to the issues confronting London. Evidence for the nature and strengths of feedbacks between the economy and transport in other cities or regions may have limited applicability to the capital and so new evidence focussed on London itself may be required.

4 A Broader View of Modelling

4.1 A Very Brief History of Urban Models

Urban, land use and transport models have been developed throughout the 20th Century. The styles and focus have matched changes in the development patterns of cities, in policy focus and importantly in the availability of data and computing tools.

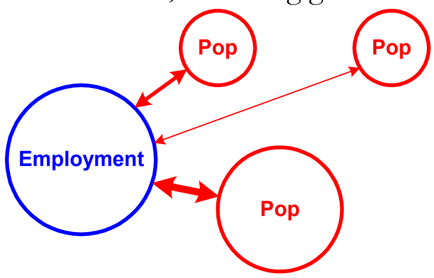
Useful introductions to the history of urban modelling, which have informed this brief review include:

- M. Batty, 2007, Fifty Years of Urban Modelling: Macro-Statics to Micro-Dynamics
- P. Torrens, 2000, How Land-Use-Transportation Models Work
- M Batty, P Torrens, 2005, Modelling and prediction in a complex world
- D. Lee, 1973, Requiem for Large-Scale Models
- M. Wegener, 1994, Operational Urban Models - State of the Art

Descriptive models of cities were developed from the 1920s. Burgess drew his classic diagram of the concentric rings around a central business district (Burgess 1925), Hoyt developed the sectoral model, which included transport corridors into city centres (Hoyt 1939) and Harris and Ullman developed the multinuclear, cellular model of city layout (Ullman, 1945). The models were hugely useful descriptions of urban layout and helped in discussions about the changing nature of the city.

By the sixties, armed with computer power and strong analogues from science, large scale urban modelling, as we recognise it today was taking off. The sixties were a time of comparative continuity in cities. The focus was 'where does the growth go'. From social physics, models using an analogy to gravitational force were describing people's likelihood of living, working and commuting along certain routes depending on the attraction of places and the distance between them. The attractiveness of places was said to act like the mass of a planet increasing the number of journeys, while distance decreased it.

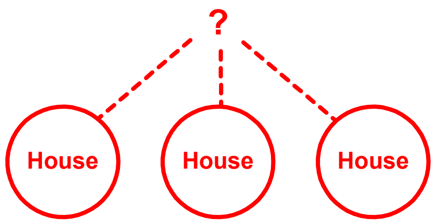
Figure 4.1 Social Physics – Strength of commuting links dependent on distance and attractiveness, mirroring gravitational laws



Source: Volterra

From micro-economics came discrete choice theory, in which residents and employers chose between locations in order to maximise the benefit (or utility) they derived from their location.

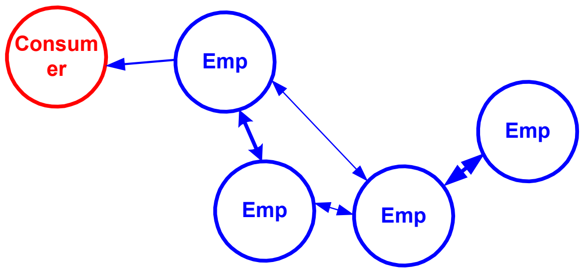
Figure 4.2 Discrete Choice Modelling – residents choose between locations to maximise utility



Source: Volterra

Meanwhile input-output modelling from macro-economics helped shape the debate about the locational choices of employers, and their needs to locate near to other businesses and consumers of their products and services.

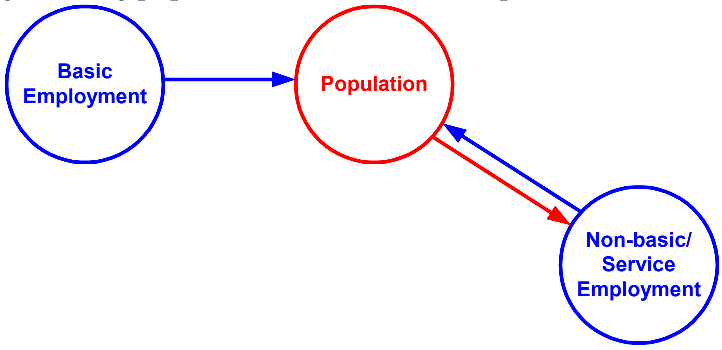
Figure 4.3 Input-Output Modelling – Employers like to locate near to other businesses and end consumers



Source: Volterra

A seminal model was created by Lowry in 1964, which brought together some of these key themes and established a framework which is still widely in use today. The Lowry model considered two types of employment. 'Basic employment' represented the footloose industries, whose growth is largely driven by external markets and is relatively independent of the local population. External forecasts for this basic employment formed the foundation of the model. He then defined population which would provide the employees to undertake the basic employment, and non-basic employment which would service the increased local population. Lowry called his model 'instant metropolis' because given the location of the basic employment he could build up a model of the entire city.

Figure 4.4 Lowry Model – Basic Employment determined by exogenous conditions, generating population and non-basic employment



Source: Volterra

The 'Lowry model' has been developed as the basis in many of the most common models in use today. MEPLAN models, and in particular LASER v3 which is discussed in detail in the following chapter, rely on this type of framework.

The 'Forrester Model' published in 1969 was radically different. He introduced systems dynamics theory in which feedbacks allowed the exponential and logistic growth of the city.

By the end of the 1970s however the policy and modelling environment had changed considerably. Many cities were in decline, so policy was shifted towards supporting and creating growth, rather than just locating it. Objectors to the dominant modelling types were becoming louder and more vitriolic too. Douglas B Lee Jnr's 'Requiem for Large-Scale models' (Lee 1973) was a damning critique including a list of the seven sins of these models: hyper-comprehensiveness; grossness; hungriness; wrongheadness; complicatedness; mechanicalness and expensiveness. The key concern that these points cover is that while the models looked impressive, they needed vastly more data than was available, were very opaque, and the key assumptions behind them were not backed by evidence. They were therefore in danger of being misleading and poor value for money for the departments funding them.

There was increasing a call for models which represented the dynamics of changes, the differences between individuals, and a stronger reflection of how people make decisions. There was also an increased questioning of the simple split between basic and non-basic services as the importance of service industries began to grow.

On the back of the developing field of complexity sciences, the 1980s saw a brief foray into catastrophe theory, chaos and bifurcation theory in cities. This exploration of 'radical dynamics' showed how one might proceed, but very few, if any, applications were developed in practice.

The more recent history of modelling has seen two directions of research. On the one hand, academic research exploring agent based and cellular models of cities has been ongoing. This research has sought to examine the way in which the micro-scale interactions of individuals control the macro-scale dynamics observed in cities. In many ways this analysis has highlighted and explored the great uncertainty of social systems, and the diverse and intricate ways in which patterns develop.

On the other hand operational models, building largely on the frameworks introduced in the 1960s and 1970s, have generally stuck to understanding aggregate level dynamics. These models have improved considerably from the early attempts by making use of the broader data availability and computational power of the current decade. Techniques for estimating parameters using extensive cross-sectional data have been refined and standardised, while dynamic and quasi-dynamic processes have been incorporated. The models have also begun to integrate findings from a wide range of research fields in order to understand and describe the ways in which people make location decisions, and to make use of GIS systems to make the outputs of the models much more accessible.

In 1993 when Michael Wegner published his paper on 'Operational Urban Models' he commented on the progress made from Lee's damning critique 20 years earlier. In particular he cites the improved data and computational techniques as crucial in improving the usability and practicality of the modern models. A key outstanding issue relates to the calibration and validation issues:

> "Nevertheless, in one respect Lee's criticism is as valid today as it was twenty years ago. While calibration has become easier, the limits to calibrating a model with data of the past have become visible. Calibration of cross-sectional models, as it is practised today provides the illusion of precision, but does little to establish the credibility of models designed to look into the far future. There has been almost no progress, moreover, in the methodology required to calibrate dynamic or quasi-dynamic models."

Validation of large models remains a key challenge for modellers and policy makers today, and has profound implications for the spirit in which the models should be understood and applied. In particular, it highlights the impossibility of claiming that one model has 'solved the problem' of predicting what will happen in future. The insights from complexity theory and micro-simulation compound this problem by highlighting the inherent unpredictability of social systems, and the unexpected dynamics that can be experienced.

4.2 Key Themes and Challenges

The experience and critiques of urban modelling point to a number of important considerations for any major modelling process.

1. **Asking the right question**

   There are an infinite number of possible models that could be developed, many of which will look sensible. This has been clearly demonstrated by the wide range of models which have been attempted over the years.

   It is therefore very important to 'Start with the end in mind'[11]. The first consideration is what question the model is intended to answer and then, as discussed below, to consider what is the best way to get there.

[11] Steven Covey – The Seven Habits of Highly Effective People

2. Validation and calibration

While calibration refers to the process of matching a model to a particular area, and setting values for the model's parameters, validation is the process of testing if the model works well.

For dynamic models in particular, methods for testing how well a model fits are limited. The strongest method would be to create retrospective forecasts from historic base years, and to compare these to observed histories. Ideally this would be repeated for a number of time periods, with transport or planning interventions similar to those being forecast occurring. In reality, detailed testing is a data intensive exercise and is therefore very expensive and difficult to do with limited data.

Before undertaking a large modelling exercise a consideration of the validation implications needs to be undertaken. In particular, what data is available for testing? Where data is limited, how can we decide if the results look sensible? What sense checks can be performed on the model outputs to ensure they are realistic? In what spirit should we understand the model results if we are aware of the limitations of testing?

Pragmatically then, there is a payoff between the amount of time and money invested in testing and understanding a model, and the confidence that can be put in it. There is therefore a strong need for ongoing statistical and case study research to inform and validate models.

3. Economic Focus

The focus of modelling has been historically directed towards the distribution of population, and the manner in which location decisions are made. This has been a reflection of the policy concerns of the past century, and is shown by the names Land-Use, Urban and Transport models. Modelling of the effect of transport and planning on economic growth and productivity has been much more limited if it has been attempted. Capturing these processes is a major challenge, given both data availability issues and the uncertainty associated with economic systems.

In the next chapter we look in detail at the different approaches to the economy taken in each of the models, in order to understand what is and isn't included.

4. Complex versus simple models

One of the key pay-offs made in modelling is the decision of how much detail to include. Generally there is a tendency towards increased detail, in the form of more processes with the model (eg labour markets, property markets, ways in which people work ect) and in increased segmentation between different types of people and jobs.

Extra detail has a number of important benefits. Firstly, it allows one model to estimate the impacts of a wide range of types of intervention on the same framework. This makes it much easier for policy makers to understand and prioritise between interventions, and helps justify the investment in the model which is required. Additionally detail reflects the immense complexity which we do see in the real world.

Detail does come with costs however. As the number of parameters within the model goes up, so the challenge of picking appropriate values gets harder. It becomes more difficult to tell if the model is really capturing the main dynamics, or whether the parameters have been tweaked until forced to match the short-term dynamics, without making much sense for the longer-term. It also increases the range of possible results the same model could give to the same intervention, making it harder to perform a strong validation. Finally detail carries the danger that policy makers, or even modellers, will not understand exactly how the model is working, and what that means. This is a particular danger when models become 'institutionalised' and developed over such long time frames that no one person can understand the model they have.

There is a clearly a difficult payoff between the two. The appropriate model in any case will depend on the way in which it will be used. If there is a single well defined question, it may be that a simpler and more focussed model might be the best way to proceed.

5 The Models

5.1 Overview of the review

5.1.1 Introduction

It is not the intention of this review to provide a thorough description of all models of transport and economy in great detail. Instead, the aim of this section is to get a handle on the different approaches that the main policy models take, and to understand what this means for their ability to get a grip on understanding the key economic impact issues we've outlined.

For each model we consider the following:

A. **Modelling Approach**
   It is really important to understand the general framework with which a model approaches the issues. What kind of questions are being asked? What processes are being represented?

B. **Calibration and Validation implications**
   For the approach undertaken, what are the requirements to fine tune the model and check that it is generating sensible, believable results? What validation tests have been tried?

C. **Modelling the Economy - Inputs**
   What is inputted exogenously to the model? Eg. is housing location, or employment growth assumed? How does this affect the way we understand the model's conclusions?

D. **Modelling the Economy - Dynamics**
   What are the key dynamics within the model? What assumptions govern the way that the model will respond to changes in different variables? What general trends would we expect these to cause? Does the model consider the impact of transport on the health of the economy, or is it simply focussed on employment distribution?

E. **Implications for London**
   What would be the likely result if the model was applied to London?

5.1.2 The models

A number of models stand out due to the level of refinement and the extent of their use. We have therefore focussed our review on a small number of the most relevant models, in policy use in Britain:

- **LASER v3 (An implementation of the MEPLAN modelling framework)**
  Developed by: WSP
  The London and South East Region Model (LASER v3) is a land use interaction model. The third version of the model was implemented by WSP, using their MEPLAN modelling framework. It is currently providing the outputs for the SOLUTIONS modelling program, which is looking to understand spatial policy and its implications. It should be noted that LASER v4 will be implemented by the DELTA team, and will therefore be significantly different to v3.

- **DELTA**
  Developed by: David Simmonds Consultancy
  The DELTA modelling framework has been developed over the past 15 years and has been used for a very wide range of studies including for Scotland, Manchester and South West Yorkshire. Recently the model was used to explore 'household location choice' on behalf of the DfT.

- **Urban Dynamic Model (UDM)**
  Developed by: Steer Davies Gleave
  The UDM (previously also called the DUM) began life in 2000. It was used for a detailed study entitled 'The impact of transport on business location' for the DfT in 2007. Other recent applications include productivity benefits in South Yorkshire, the impacts of WEBs on transport improvements in Leeds, and strategic transport options for the North Way Group.

Alongside these three, we also considered three other, very different models, which provide an interesting contrast.

- **Tyndall Model** *Developed by: M. Batty CASA at UCL*
- This is a simpler model developed for climate change research.

- **TIGRIS** *Developed by: RAND Europe and TRC* Netherlands

- **California Land Futures** *Developed by: John Landis, Berkeley*

We are very grateful to the modelling teams for meeting with us to discuss their models, and reviewing our write up. The wording and descriptions below, however, are entirely the responsibility of the authors of this review. We recommend that interested readers examine the full write ups of model implementations in order to understand in more detail the exact way in which the models work.

5.2 LASER v3

The aim of the LASER v3 model can be summarised as:
"Solving for household location"

The first thing to say about the LASER v3 model is that it doesn't actually model most employment location. Apart from locally serving jobs which follow housing around, all other jobs have to be input into the model. It therefore doesn't help us to understand how employment might be affected by transport change.

It is included in the review for several reasons:

1. It is a widely used land use and transport interaction model, and it is therefore important to understand what it does and doesn't do.

2. It works in a method similar to many other of the models designed for transport analysis. In London, for example, LASER operates in a similar spirit to the transport model LTS, albeit with a broader land use focus.

3. It provides an estimate for housing location following employment location, and therefore may be a useful tool for understanding the housing implications of employment growth.

Key report for the review

- Mott MacDonald, 2004, LASER Model Use Audit Report

5.2.1 LASER v3 - Approach

The approach itself is quite abstract. The model sets up a large optimisation problem for household location, which it can then solve. The key components are:

- It assumes a function for generalised cost for living in a particular place, as well as a generalised cost for the commute associated with it.

- These costs are bumped up if too many other people are trying to make the same journey or to live in the same place.

- Given people's employment locations, it then allows them to change house or route to work if there is a better option available, continually shuffling people, and updating the generalised costs until everyone is happy with their choice

The generalised cost of the commute is of the same type as those used in transport modelling and encompasses journey times, frequency, reliability and monetary costs as well as the crowding factor, which depends on how many other people are travelling.

The generalised cost for housing, meanwhile, is something new. The components here are commuting costs, housing costs and the catch-all 'attractiveness' factor. This attractiveness factor is a score which should reflect everything else about a particular location which makes it desirable. For example, an area with good amenities and nice properties should score highly, while a crime-ridden sink estate could be expected to score poorly.

In order to set up and then use the model, two runs are required. In the first calibrating run, the model solves for the 'housing attractiveness factors' by finding the values that make the model match base year data. In the second run, typically in a future year, these same factors are used alongside any future forecast of employment and an updated transport network, to find the new commutes people are likely to take.

This approach has two very large benefits. Firstly, by making some large assumptions about how everything should tie up nicely in any given year (convergence), the modellers can turn the question of housing location into a solvable optimisation problem. Secondly, by focussing on optimising across space, the model can make use of the considerable cross-sectional data which is available (for example, from the Census) and completely sidestep any discussion of how and when the process happens.

The flip side is that the model does not take into account the processes by which change happens. By using the catch-all attractiveness factor it is also tricky to know how places will change into the future, or to understand what effects regeneration policies are likely to have. Analysis and sense-checks of the attractiveness factors can and must be undertaken outside of the model.

Technically this approach can be called a spatial-econometric model, because it acts cross-sectionally rather than through time. It is defined as an 'interaction-location' model by Webtag, since the commuting patterns (interaction) lead to the location decisions. The location choice mechanism works using logit models for the choices that residents can make.

5.2.2 LASER v3 - Implications of the Approach for Calibration and Validation

Calibration for this model is relatively straightforward. As said above, the model makes use of the extensive cross-sectional data available, and solves in a base year for all the missing parameters that are needed. For future years, the employment forecasts and future transport network are set alongside the solved-for attraction factors.

Validation however, is trickier. By fitting the data in the base year, and using 'attractiveness' as the residual, there is no external measurement of how appropriate the model is. Is the functional form of the correct type? Are the weights between attractiveness and commuting costs set correctly? A strong validation would need to find another way of checking whether the assumption that attraction factors stay constant is a reasonable approximation.

The strongest practical form of testing would be to fit the model in the base year, and then test how successful future year predictions are, by testing them against data. For example, if the model were based in 1991, forecasts for the years 2001 and 2006 could be tested against observed data to explore if fixed attraction factors are appropriate over long time periods. Ideally the length of time between tested years would be similar to the time between base year and forecast years being used in policy testing.

In practice this type of analysis is very hard to undertake, because of the difficulties of collating large data sets for multiple time periods. As a result, model tests are limited to only being 5 years apart, while forecasts are some 20 years ahead. While this limitation is understandable it raises some important questions about the strength of this type of modelling. In particular, it seems likely that this type of model will struggle to predict large, long term changes correctly, and will cope best with small marginal changes, for which changing attraction factors are likely to be less of a concern.

The final option open to modellers, although this hasn't yet been tried, would be to analyse and predict the attractiveness factors outside of the model. This could be attempted by determining the relationship between Census statistics and the factors in a base year, and by comparing zones which match the desired future characteristics of regeneration areas.

5.2.3 LASER v3 - Modelling the Economy

The model only considers the location choices of 'locally serving' jobs. Forecasts for the number of other jobs must be produced separately and inputted. It does not therefore contain an economic model.

While the model cannot be used in isolation to understand transport and economy details, there are a number of analyses that it can help with:

- Exploring the housing implications of employment location scenarios
- Finding the housing which would be needed to support a level of employment growth
- Understanding the extent to which specific transport investments support the achievement of policies for housing and employment location

5.3 DELTA

The approach of DELTA can be summarised as:

"Modelling how choices are made"

It should be noted that the DELTA package can be implemented in a number of different ways. We discuss the general possibilities of how it can be used below. The forthcoming LASER v4 will be a purely household location and local services model in the style of LASER v3. Typically (and preferably) however, the model includes household and all employment location choice.

We have not considered in this review SimDELTA, which is still under development by David Simmonds Consultancy. This model is a micro simulation tool for exploring household and individual changes at an even more detailed level. It works off an external economic scenario, very similar to that in the DELTA model, and therefore is not closer to the requirement for a transport and economy model than the original model.

Key reports used for this review:

- David Simmonds Consultancy, 1996, Introduction to the DELTA package

5.3.1 DELTA - Approach

The approach behind DELTA is radically different from that of LASER v3 described above. The model has been developed by considering how people make choices. It works through time, with changes and choices being made within each time step. The impacts of interventions can therefore take some time to occur, perhaps 10 years for a motorway improvement's effects.

The main process is as below:

- In each period, work out which residents/businesses will be relocating or locating for the first time in the area

- Work out where those households and jobs are likely to want to go depending on characteristics of each area including both accessibilities and available floorspace

- Use a bidding process to determine which of them occupies each available location

- Match up workers and jobs in a recruitment cycle

- Work out how the final choice feeds back in to changes in the characteristics of each area, and the choices made by different workers. Allow developers to respond by building, subject to planning constraints.

Overall the model tries to take into account as many observed features of how people make choices as possible, making use of an approach which steps through time.

The benefits of this type of approach are that it can reflect our own observations of what, and why land use decisions are made, including the types of decisions that don't seem 'rational' and changes that take time to happen. It is therefore closer to how we believe the world to operate. Comprehensive models can also be used to estimate the impacts of a very wide range of land use and transport interventions on a consistent basis.

The drawbacks of this approach are those of any large scale model, as discussed in the previous chapter. Firstly, it takes a considerable amount of time to understand what is included in a specific implementation of the model and how to interpret the implications of this for the model results. Secondly, validation and calibration become difficult due to the large numbers of parameters and processes to test.

The DELTA model can be described as a quasi-dynamic model, since the model solves for a set of partial adjustments in each time step, and a Location-Interaction model, because the site choice is used to determine the interactions (between businesses and commutes).

5.3.2 DELTA - Implications of the Approach for Calibration and Validation

The model requires both implementation and calibration. Implementation refers to setting up the base data correctly, while calibration refers to determining coefficients than govern the links between each of the steps in the model. For example, parameters will describe how often households locate, and the relative weight assigned to locating somewhere of high quality compared to somewhere with good accessibility. The parameters may vary by type of household, type of job, and by the location. Within a model of this type there may be hundreds of parameters which need to be chosen.

Validating both the model structure and the calibration is tricky because there are so many possible combinations of parameters to choose and so many sub modules and processes to test. The approach that David Simmonds Consultancy have taken is threefold:

- Examine literature on location decisions and other processes to decide what should be included, how they work, and parameter values (if possible!)
- Conduct field work to understand local areas better (eg surveys of relocating households)
- Use trial and error adjustment to parameters until results look sensible

Through using these methods the modelling team are able to ensure that the final model will produce sensible results from a process that mirrors the real choice making process. However, there will always be considerable scope to argue that the model misses out something that is important, or has been parameterised in such a way that it considerably over or under estimates the impacts of a change, or the length of time over which it occurs.

As discussed in detail in the previous section, validation of large land-use transport models is very difficult. Ideally a broad range of tests would be carried out. The strongest individual test of the model would be to create retrospective forecasts and compare them to observed histories. Preferably this would include a test covering a time period for which a land-use or transport intervention of a similar kind to that being tested occurred. This has not been tried because of the considerable data collection issues, particularly:

- Obtaining detailed and reliable data between Census years
- Gaining retrospective data about the amount of development that local authorities were planning to permit (as distinct from the planning permissions actually granted).

As a result it is difficult to tell how strongly the model fits over long time periods, and what types of areas the model works best in. As with other models, it is therefore important that sufficient time is allocated to testing and developing the model in each individual implementation. It also implies that this type of model will be much more reliable for comparing schemes than estimating the absolute level of impact of any one scheme.

5.3.3 DELTA - Modelling the Economy

The DELTA model is primarily a location choice model. The focus is upon where employers chose to locate, and the implications, rather than upon the overall levels of economic growth or productivity.

Key Economic inputs

- Economic scenario for the total modelled area – including employment, value added and productivity
- Input-output table statistics, relating each sector to the other sectors they trade with
- Income for employees in each socio-economic group – to help determine what type of housing they will be able to afford and what they will spend as consumers

Economic dynamics

- Each year new businesses and relocating businesses enter into the choice making process. They will prefer to locate where similar businesses have located before, but will be affected by changes to key variables – access to product markets (see below), access to labour and land costs

- There is a bidding process between businesses to decide who gets to locate where. In pricier locations businesses will be forced to work at higher densities. There is no limit on the amount of money businesses will pay.

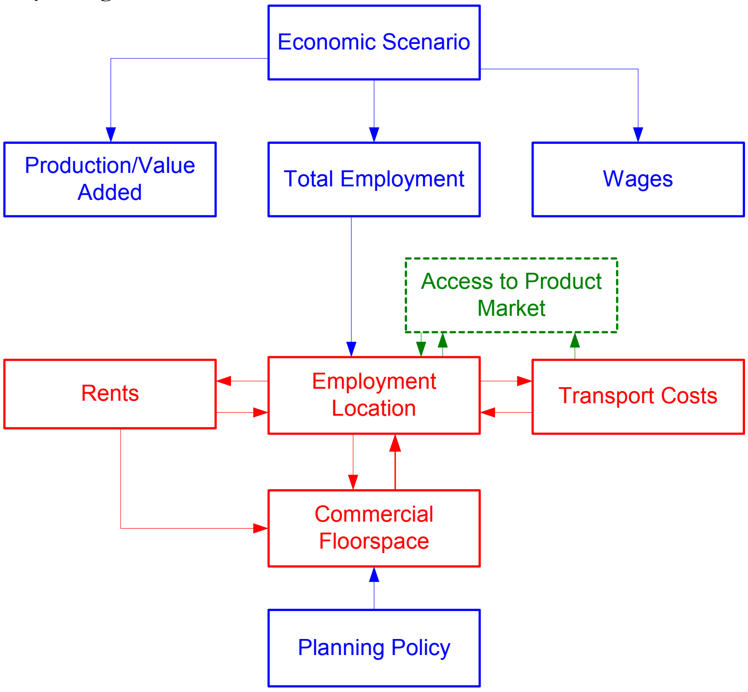
- Once households have located, workers and job are matched, and workers assigned incomes consistent with the type of job they are assumed to do.

One of the key drivers of economic location choice is the access to product markets. Product markets means any other type of business, or the population at large, to whom the company supplies its goods. These are estimated using input-output tables. For most business services the product market is other businesses, so this feature will cause activity to tend to cluster.

Overall, when a transport intervention is introduced, we would expect to see businesses relocating to take advantage of the increased accessibility. This relocation may in turn cause further clustering of the sector in order to take more advantage of the close ties. In consequence we will always see decreases in employment in other, less accessible, locations.

The economics of the full DELTA model can therefore be summarised in the diagram below:

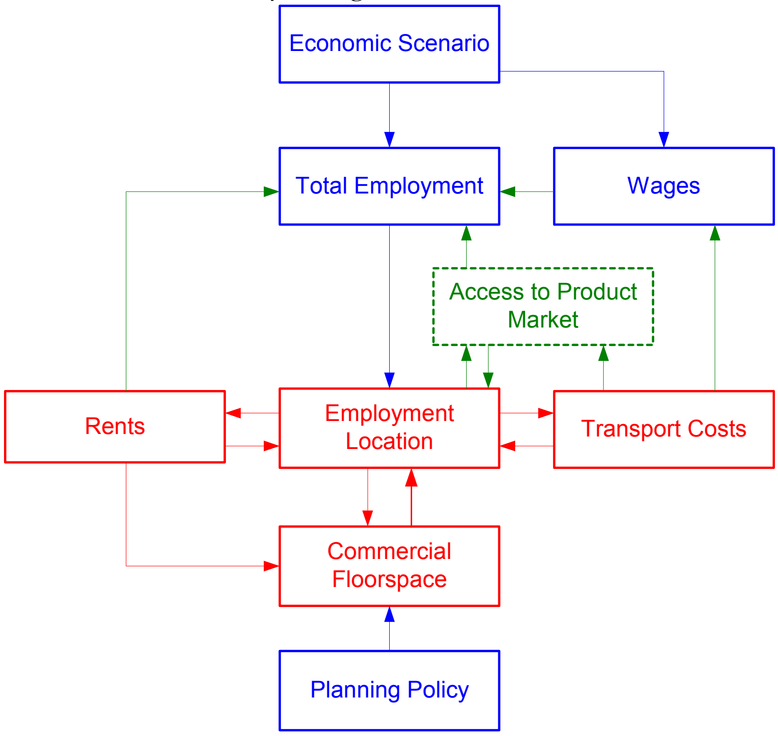
Figure 5.1 Full DELTA model: Links between key economic variables – Economic Scenario is entirely exogenous



As shown above, the economic scenario remains unaffected by the costs or benefits associated with locating in the area. There's a one way link from employment to location.

For one of the model implementations, the link was made two way however. In the SETLUM model in the Thames Gateway, the total employment level was allowed to vary. An elasticity of employment to rents, access to labour and wages was applied to the exogenous growth rates. The SETLUM model diagram can be seen in the figure below.

Figure 5.2 SETLUM DELTA model: Links between key economic variables – Total employment level can be affected by changes in other variables



There are three important points to note about the revised model:

1. The links incorporated are generally the more conventional links from land, space and labour effects

2. More complex effects such as any agglomeration feedbacks are not included

3. A full statistical analysis of the appropriate value for the elasticity has not yet been undertaken.

The current versions of the DELTA model have focussed on understanding and explaining the distribution of employment and household location. They have not explored in detail the ways in which the economic scenario may itself be impacted by land use or transport changes.

The results from DELTA implementations have been used in the estimation of Wider Economic Benefits, and some research is currently being undertaken to incorporate the labour market WEB of more people in work into the model mechanism.

5.4 UDM

This model can be summarised as:

"Evolving locations"

Key reports used for this review:

- Steer Davies Gleave for the Department for Transport, 2007, The Impact of Transport on Business Location Decisions
- Steer Davies Gleave, 2004, The Dynamic Urban Model

5.4.1 UDM - Approach

The Urban Dynamic Model approaches the issues of transport and economy interaction in yet another way altogether. It considers the rates of growth of housing, employment and sites in each zone. Rates of growth are adjusted up when the zone is particularly attractive and down when it is less attractive. Growth takes place through time, with the full effect of an intervention taking some time to work through.

The model is programmed in Vensim software, and is based on 'system dynamics' technology. The model is a dynamic simulation which works through time in time steps of 3 months.

The main process is:

- Start with locally steady rates for housing, business and property start up and closure. These can optionally be adjusted up or down by an exogenous rate.

- In each period use 'multipliers' to increase or decrease these growth levels, depending on how well the zone compares to reference values (either compared to an benchmark level or to all other zones in the region)

- Use a recruitment cycle to match people to jobs, and the inbuilt transport model to match commutes to routes

This framework has some interesting implications. Unlike in other models, there isn't a fixed amount of employment or population being distributed between different sites; instead the model generates growth or decline in each zone as conditions change. The reference values are used to ensure that the balance between workforce, jobs and land are all maintained, through realistic mechanisms.

It is also possible for feedback loops to kick in. Rising development could lead to further development until eventually a constraint starts to bite (usually from planning or labour supply). For example, growth in business can lead to growth in property development, leading in turn to growth in business as properties become available, until eventually all available land in the zone has been used up.

5.4.2 UDM - Implications of the Approach for Calibration and Validation

The model suffers from similar problems to DELTA when validation is attempted. While collecting base year data is relatively easy, finding the correct parameters to describe the way the dynamics work and finding evidence that the model represents the real world well is much trickier.

As part of their work for the DfT on business location, the team undertook a large validation exercise. For this study brief, household location was fixed, and the test was of the ability of the model to forecast the employment levels and location. The steps were:

1. 'Sensible' looking parameters were chosen

2. The model was run to forecast business growth from 1991 to 2001 in Milton Keynes, and the results compared to baseline data describing the actual changes over these years.

3. New parameter values were chosen, using an optimising algorithm, to fit the model results to the observed history

4. The model (with the fitted parameters) was run to forecast growth from 1991 to 2001 in South and West Yorkshire.

5. These results were compared to the observed history in South and West Yorkshire for 1991 to 2001.

This method of running the model and comparing to an observed history in a number of locations is ideal for the validation of dynamic models. It can highlight the strengths, and weaknesses, of the approach, and give a better idea of how appropriate the model design is.

The results from the exercise were mixed. The model was able to match the pattern of growth in Milton Keynes very well, but didn't replicate growth in Yorkshire so successfully. A number of explanations were raised for why this might be so. We discuss these alongside the more detailed discussion of the method of economy modelling below.

5.4.3 UDM - Modelling the Economy

As discussed above, the UDM is primarily a model of growth levels in each zone, spurred on by the zone's performance relative to the others, and its access to resources, such as labour, land and infrastructure.

Key Economic inputs

- Steady state employment, property and population growth rates (uplifted by exogenous increase if required)

- Evidence on co-location habits of different firms (interestingly, at present this includes repellents between sectors which seem to actively not co-locate).

- Employment densities to be used by zone and year

Economic dynamics

- The starting growth rates are applied for population and employment

- Each period a set of 'multipliers' is calculated that can be applied to the growth rates to scale them up or down depending on the relative attractiveness of each zone. The multipliers are subjected to a delaying process which means the full impact of a change of the multiplier takes some time to work through.

    - The multipliers for job growth go up if:
        - Job vacancy rates are low relative to benchmark level (indicating an availability of workforce)
        - Access to other businesses and customers is high relative to other zones (indicating more of a cluster)
        - Property vacancy rates are high relative to benchmark level (indicating cheaper prices)

    - The multipliers for property growth go up if:
        - Jobs have been growing
        - Land is available
        - Property vacancy rates are low, relative to an benchmark (indicating high prices)

- When the growth has occurred, a job market is then initiated to match workers with jobs and find the job vacancy rate for each zone. Workers can then be matched to commuting routes.

There are a couple of important points to note, especially around the representation of prices, and on the way in which feedbacks and constraints feed in.

The model does not include any prices, other than for transport, but rather uses vacancy and growth rates as a proxy for the desirability and price of different areas. This is a useful simplification from a modelling perspective, since it avoids the very tricky business of capturing prices realistically. When vacancies are high, they indicate that demand is low enough to reduce prices and therefore attract more people in, when vacancies are low they indicate that prices are rising therefore deterring extra relocation.

However, by considering prices only implicitly within the model, the economic implications are not fully teased out. Often in city centres prices rise even as development continues, so that they will be higher than those in other locations even with the same vacancy rate. The final economic implications of prices, or responses to them, therefore need to be carefully considered outside of the model. This is a reflection of the model's focus – it is not primarily an economic model, and therefore is less interested in the balance of wages, productivity and rents.

Feedback loops develop within the model. Growing business activity leads to growth in property development which in turn leads to increased business activity, as vacancy rates rise. These cycles will continue until a constraint is hit – normally either the labour market which may be constrained by transport - or planning constraints.

The constraints are therefore critical to the results that the model produces. All the business and property reference values (with the exception of access to consumers and businesses) are to benchmark levels, so if there is more land or labour available, growth will tend to increase until something is used up.

This has some big implications for what kind of results we expect to see in the model. Understanding how much land is available for development is crucial, as is making sure that the estimated labour catchments and job markets are set up realistically, and use the transport networks in a believable manner. This is a useful perspective for which to understand the results of the validation exercise.

Implications of validation exercise

As we mentioned above, the business impacts report found mixed results from the validation undertaken. While Milton Keynes' history was forecast well, the model struggled to represent the growth observed in South Yorkshire.

The report suggested a couple of reasons for this result. Firstly, the model struggled to forecast the effects of large scale industrial change and the social and economic implications this has had. Secondly, it was suggested by one of their reviewers that the model may be more suited to modelling a growing planned city such as Milton Keynes, but may not capture the subtler dynamics observed elsewhere.

It is useful to consider the results in light of the constraints on growth, primarily land availability and workforce. We first need to consider how data on constraints were used in the runs. Due to the difficulty of collecting information on the level of land planned to be released by the local authorities the model runs were actually undertaken using the amount of developed land as an estimate for the amount of planned land, with all the land available at the start of the period. Meanwhile, the actual observed workforce numbers were used, effectively fixing the labour market to the actual history. The test runs of the model were therefore constrained by the actual land and workforce available by the end of the period. The real test of the model was therefore whether it could anticipate the *timing* of the change, since the total levels would be guided by the inputted constraints.

It is therefore not too much of a surprise that the growth achieved in model fitted very well in Milton Keynes, since it had very strong input data to work with, although it is very encouraging that the timing was matched well. The mismatch in South Yorkshire is more interesting. The key issue here seems to be that while the model can forecast the attractiveness of locations for different business types, it doesn't currently explore the growth potential of each business type. This created large problems as industries could continue to grow if sites were attractive, even while the industry as a whole was in decline. The results highlight how difficult it is to predict these responses in a time of change.

In light of the validation it looks like the model is primarily focussed on exploring land and labour constraints, and that it can achieve that well where these are well described and growing. For example, the model would be well suited to testing the likely final patterns of development and commuting in a growing town under different planning regimes. The model is likely to be a weaker fit in places where land is not a primary constraint, in places with complex changes in the labour force and industrial structure, and in places where growth is limited.

The outputs from the model have been used in the calculation of Wider Economic Benefits from transport investment. While the model explicitly includes clustering effects from access to other businesses and labour, the productivity and output feedbacks implied by these benefits are not explicitly contained within the model.

5.5 Other Models

5.5.1 Introduction

There are, of course, a large number of other models on the market and in academic departments. While we have not examined these in detail we present a short discussion of three in particular:

A. **The Tyndall Model**
   CASA, UCL
   The Tyndall model has been developed to produce long term projections to input into climate change models. The model uses a simple 'gravity model' framework in which commuting is related to distance. The model moves away from detailed analysis and towards a high level overview.

B. **Tigris**
   RAND Europe and TRC Netherlands
   This is a model in a similar spirit to DELTA, but making use of the comprehensive data available from the Netherlands

C. **California Land Futures**
   John Landis, University of California, Berkeley
   This is a radically different approach, reflecting the different planning approach adopted in the United States. The focus is on the wider implications of the land types available and zoning. It has been a very influential model across the US.

5.5.2 The Tyndall Model

Key report:

- A Crooks, C Castle, M Batty, 2007, CASA Working Paper 121, Key Challenges in Agent-Based Modelling for Geo-Spatial Simulation

The Tyndal model has been developed by Professor Mike Batty at CASA in University College London (UCL). The model is a component of the larger climate change modelling which is being undertaken, and it looks to model impact of urban growth on commuting trips and the associated pollution over the next 50 to 100 years.

The model is a gravity model, which works cross-sectionally for any given year. Employment and population are distributed across a fine grid over London, and then commutes are assigned between them.

"The logic of interaction is based on the well-established gravitational hypotheses where the flow from employment site to residential location is inversely proportional to some measure of the impedance – distance or travel cost between these origins and destinations and directly proportional to some measure of attraction or size of each two locations".[12]

Forecasts for total employment and population must be inputted into the model. Different scenarios are considered within the analysis, representing different possible levels of growth.

The model uses agent based modelling to represent the difference at a very fine grained level between different precise locations within wider zones. This approach replaces the need for random utility theory logit models.

In some respects the model is most similar to LASER v3, since it works cross-sectionally and seeks to effectively optimise the commuting trips given fixed origins and destinations. It can be calibrated to a base year, with future 'attractiveness' being imputed from the current levels.

The key differences of the Tyndall model are the focus on the very long term, instead of a need for very detailed short term outputs, and the move towards agent based modelling, to allow for heterogeneity between nearby locations.

The model is also designed to be used on a desktop, with a wide range of graphical outputs available, to enable users to understand what the model is showing.

[12] A. Crooks, C. Castle, and M. Batty (September 2007), Working Paper 121: Key Challenges in Agent-Based Modelling for Geo-Spatial Simulation. Available from http://www.casa.ucl.ac.uk/working_papers/paper121.pdf

5.5.3 Tigris XL

Key reports;

- RAND Europe, 2006, TIGRIS XL land-use model
- B Zondag, M Pieters, 2004, Influence of accessibility on residential location choice

The TIGRIS XL model, developed by RAND Europe and the TRC in the Netherlands, is a choice focused model, which is most similar in spirit to DELTA. The model allows evolution through time, with hierarchical logit models for who makes choices each year and what choices they make. The Generic Urban Model, which is being built in the UK for the DfT follows a similar approach to the TIGRIS model.

Again, like DELTA, the model uses population and employment forecasts to determine the total growth levels, and concentrates on the way in which they are distributed.

One of the most interesting aspects of the TIGRIS project has been the calibration exercise they have undertaken. They used a very large survey of over 10,000 relocating households to calibrate the hierarchical location choice within the model (Zondag and Pieters 2005)[13], and to produce estimates for the statistical significance of model values. This is therefore a useful study of how calibration may be performed on activity based models, when strong data is available.

5.5.4 California Land Futures (CUF)

Key Report:

- J Landis, M Zhang, 1998, The second generation of the California urban futures model. Part 2: Specification and calibration results of the land-use change

California Land Futures 1 and 2 are models developed to examine land use change in the USA. Given the very different policy environment, the model focuses on the range of land packets available and their suitability for development.

One of the key selling points of the model is the extensive use of GIS to manage and overlay information on the modelled areas. This includes city boundaries, slope of sites, current and historic land uses, wetlands and transport networks.

The CUF-2 model generates projections for the level of growth at a zip-code level, estimates probabilities that land packets will be (re)developed into each type

[13] Zondag, B. and Pieters, M. (2005) "Influence of accessibility on residential location choice." Transportation Research Record: Journal of the Transportation Research Board 1902: 63-71

of land use, and allows the different land uses to bid against one another to decide who gets which location.

5.6 Summary – What roles do the models perform?

We summarised the three main models with the following taglines:

- LASER v3 – Solving for Household Location
  The model focuses on understanding where housing and local employment locates, following an exogenous employment forecast. All household locations are adjusted in a forecast year until everyone is content with their choice.

- DELTA – Modelling Choice
  In a given year, a certain number of households and businesses relocate or move to the area for the first time. Evidence on choice making is used to understand where they may want to go, and a bidding process is used to see where they do go.

- UDM – Evolving locations
  Each period growth rates for zones are adjusted in response to the local conditions. In particular they are stimulated to grow until constraints are reached, while making sure that the balance of jobs, workers and sites are maintained.

Table 5.1 Comparison of Key Features of Three Main Models

	LASER v3	DELTA	UDM
Dynamic/Static	Static	Quasi-dynamic	Dynamic
Economic Dynamics	None	Employment location choice. One application included elasticity of employment w.r.t wages (via transport costs), rents and product market accessibility	Growth rates for each zone responsive to constraints on labour and land.
Total employment fixed?	Yes	Yes (apart from SETLUM project)	No
Agglomeration	No	No Some feedback – more density gives better access to product markets – no impact on productivity	No Some feedback – increased employment stimulates more development which in turn stimulates more employment

While the models contain useful analysis of the implications of economic scenarios, and generate outputs which can be used in the estimation of Wider Economic Benefits, none of them currently embraces the feedbacks implied by the economic theory behind them.

In particular output and productivity are not typically variables within the models, and therefore do not respond to the location of growth.

This is also true of the three additional models we examined. For each the focus has been on the distribution of employment, rather than levels of growth. The three additional models are interesting case studies, due to their approaches to GIS presentation and calibration.

The key conclusion is that the way in which locations impact on economic growth, as opposed to simply redistributing employment, is not explicitly estimated in any of the models.

6 Conclusions – modelling transport and the economy in London

6.1 Where we have reached

6.1.1 Overview of the report

The policy requirements to understand and explore the impacts of transport and land use policies on economic growth and productivity are growing. These have been driven by a renewed focus on the use of transport to support and enable growth. In Chapter 3, we discussed some of the key issues for London in some detail, alongside the growing body of evidence and theory to explore it. It is clear that London is a unique place in terms of the range and types of economic activity undertaken.

Modelling has been a key tool in the arsenal of planners and policy makers over the past century. The modelling enterprise has a number of uses, to help explore and explain what is going on and to understand and compare possible future scenarios. Modelling itself is fraught with major challenges. The payoffs between simple and complex models, between static and dynamic, and between micro and macro scales in particular have been highlighted through several damning critiques of the modelling profession. The key challenge of validation remains – how can we test that the models we use reflect the world in which we operate?

Despite the challenge of modelling, a number of well developed models are in current policy use today. In our review we considered in detail the LASER v3 model (an implementation of the MEPLAN modelling framework), DELTA, and the Urban Dynamic Model (UDM). The three models use very different approaches. Which LASER v3 solves for the distribution of households at future points in time, DELTA models the annual locational decisions of firms and households, and the UDM explores changing growth rates for zones. Further to these, we considered in much less detail the Tyndall, TIGRIS and California Urban Futures models.

What is striking from our review is the limited handling of economic issues within the existing models. Broadly speaking there are two views taken. In one set of models the economic scenario is a fixed input, with the number of jobs fixed at a regional or subregional level. These models then examine where the jobs go, and how will they be matched to the labour market.

In the second set are models for which the overall level of growth is not fixed. For these models however it is the availability of attractive premises which drive growth. If the sites and workforce are available, then the jobs will come, whether or not the industrial sectors themselves are growing, or particularly attracted to the region in question. These models are therefore most informative when there is scope for strong growth, and it is the constraints on growth which need to be considered – from land or labour supply.

Both sets of models can capture some of the simpler economic processes at work. Sites with good access to other businesses, or to the consumers of their goods, are generally deemed more attractive and therefore take a larger slice of the growth. This is turn can reinforce the attractiveness of a site and encourage further growth. In this way the models can capture the observed clustering of businesses.

The outputs from the models have been used in the Wider Economic Benefits of transport interventions as outlined in the Dft draft guidance, since they estimate future patterns of employment.

However, the full, more complex, interactions implied by the Wider Economic Benefits have not been explicitly incorporated into any of the models we have seen. The way in which location can enable new types of business to begin, or existing businesses to become more productive, for example, still needs to be examined. Further the links between productivity, wages and rents and the full implications of these for output growth have yet to be teased out.

6.1.2 How should existing models be interpreted?

Existing models clearly incorporate much intellectual effort and data collection. In using them, still further thought is necessary.

First, it is essential to be clear what assumptions about the future have been incorporated when they are used for prediction purposes. Any model results must always headline these. Second, results must also be clear what has been held constant – for example attraction factors or employment distribution.

It is only by understanding what the model does and does not do, that we can understand where the genuine insight provided by the models lies, and where further research is needed to firm up and grapple with the issues.

6.1.3 The TANDEM Model

The TANDEM model was developed by Volterra and Colin Buchanans on behalf of the GLA[14] in response to the need for a transport – economy model. The aim was to generate estimates of the impact of transport, and particularly capacity and crowding issues, on the levels of employment and output growth obtained in London. The aim of the model was to use elasticities derived from the LTS model of the link between demand levels and generalised cost at an aggregate level, and estimates for the 'drop out rates' as passengers are deterred from living, working and travelling in London alongside an analysis of the economic impacts. In the end the LTS elasticities were not suitable for using in the model, so estimates of the values had to be created, using professional judgement.

The key messages from the modelling exercise were that:

- The treatment of crowding in the LTS/RailPlan models only reflects the softer 'discomfort' effects of crowding, and not harder capacity constraints. The models therefore tend to allow very large passenger growth with relatively low

[14] See Colin Buchanans (2007) TANDEM 3 and (2005) Investigating the Potential Impact of Transport Changes on the London Economy

increases in costs. The elasticities derived from the LTS model were therefore inappropriate tools for understanding capacity issues;

- It was agreed that LTS elasticities reflect short term and cross-sectional responses, but not long term behavioural ones;

- The links between employment densities and productivity; between accessibility and the location of population; and between trips and crowding are key economic issues to explore in a modelling framework.

The TANDEM model therefore raised a number of important questions and helped point to the type of evidence which will be needed to create fully operational transport economy models.

6.2 Moving Forward

6.2.1 Need

It is apparent that models of transport and land use have not yet been able to incorporate economic change into their systems. Rather they either make underlying assumptions about the economy and then ask how this might be distributed, or they allow site availability to drive the levels of economic growth, with limited consideration of the ability of the economy to respond.

At the same time, economic models also have limited views on the role of transport. Modern work on the spatial economy has focused on incorporating transport costs into a business location decision where there are also agglomeration benefits. These models have been used to identify the theoretical scope for agglomeration benefits and their role in evaluating the benefits of transport investment.

These economic approaches have been used to consider the value of increasing densities and to identify agglomeration elasticities. However, the relationship of this to the willingness of people and business to use transport systems is much harder to establish.

The transport system is a pre-requisite for economic activity. This particularly applies to the ability to provide 'base' activity in Lowry's terminology. This terminology has also been used by Krugman in identifying the potential for base multiplier relationships, in which one type of activity then supports further employment and spending, and which might create discontinuities which can enable locations to jump to higher density outcomes[15].

The potential for such feedback loops means that both the timeframe for change to occur and the ability to attract such base activities looms much larger on the modelling agenda than has previously been thought.

Thus the important gaps are three fold:

[15] Fujita, Venables, Krugman (1999) *The Spatial Economy*, The MIT Press

- How does the transport system affect the location of 'base' employment?
- How does it limit or enhance the ability to develop or grow such employment?
- How do productivity, wages and the choice of people to undertake particular commutes drive development patterns?

Base employment is essentially that employment which generates value added which can be used in a locality to create income related services. It crucially depends on the ability to sell goods or services outside that community. The wider the sales, the greater the value added is likely to be, from the cotton industry in nineteenth century Lancashire, to banking in 21st century London.

The transport system may also play a role at a number of levels and broaden out into communications more widely. Clearly air transport and telecommunications are potentially as important as the investment in under or over ground railways. Recent studies of agglomeration have focused on the ability to deliver people into the high density centre and this is clearly one crucial role. But it may not be the only one.

A difficulty is to distinguish between the forces which create outward looking trade and those which force higher density and agglomeration. The two successful agglomerations in the UK's history have rested on the ability to trade internationally – both in Lancashire and London. The density has itself rested on distant linkages. The ability to go far made it possible to create closeness on another dimension. Only by understanding this linkage can we hope to establish the value of transport investments.

6.2.2 Research Questions

The challenge to modelling is two-fold. Firstly there is a gap in the evidence base for the type and strength of transport and economy linkages. While some research has shown its importance, the base is not well enough developed for confident analysis of economic consequences to be easily identified. Secondly, the linkages need to be built into both analysis and modelling of economic impacts.

In order to bridge this gap further empirical research is needed to then allow new models to be developed, or existing models calibrated to London. To date, research has been limited due primarily to data availability issues. Therefore research will be needed which uses new data sources or which brings together existing data sources in different ways in order to establish the key dynamics. This research should be focussed on London and other world cities in order to understand the issues specific to the capital, including global businesses, heavy public transport use and the density and size of the city.

The key questions to explore and understand are:

1. **Evolution of accessibility alongside economic development**
   What are the behavioural responses to overcrowding and to new transport availability?

2. **Local connections - co-location of firms and industries together**
   What types of activity cluster, and how densely? Is it sectors or similar types of functions across sectors that cluster?

3. **Wider connections – trading outside of the community of interest and how it changes**
   Can we categorise places by the types of outside trading they do? Is there a link between outside trading and accessibility – particularly to wider markets?

4. **Incomes from that activity and how they are distributed**
   What are the links between productivity, wages, commuting and locally serving employment?

In order to make headway into this research exploration of the possibilities for different data series is needed. Firstly, evidence on the changing accessibility and crowding levels across London exists in historic counts, service information, population and employment statistics and other sources. Constructing high level accessibility series which could be tested against these sources should provide a useful time series for analysis.

Data on local and wider connections may be more difficult to access. For analysis of co-location of firms datasets which identify the location of business units and the type of activity that they undertake will be necessary. This would need to be at a very local level if very local clustering is to be pinpointed. For wider trading the challenge is even greater. While regional input-output tables exist, these are created using assumptions about the very processes we would wish to measure.

This evidence should be brought together in a transparent way, in order for it to be tested and used in the calibration and development of analysis. It may be necessary to construct smaller models that collate and test the relationships in the data. For example, high level abstract models which see examine how patterns observed in the data may have been created. These may need to be of different forms to linear regression models in order for the complex and interwoven relationships to be teased out.

6.2.3 Final Thoughts

The existing models of Transport and Land Use contain considerable intellectual thought and present a comprehensive framework for considering the key issues for transport and land use policy. However, limits to our understanding of how economic processes work necessarily limit our confidence in the ability of models to be able to estimate this. The questions of calibration and validation come to the forefront.

The primary need, therefore, is for a firmer evidence base to use for testing existing models and as a basis for building new models. In order for the results to be used in London with confidence, this evidence needs to specific to the challenges faced by the capital.