1. INTRODUCTION

This paper describes a project carried out for the UK Department for Transport (DfT) to investigate the impact of transport on business location decisions, and to develop a model to enable the department to produce forecasts of how transport proposals might affect those decisions.

The work was carried out by a team lead by Steer Davies Gleave, with assistance from the planning consultants Llewelyn Davies Yeang, and expert academic advice from Dr Iain Docherty, senior lecturer at the Business School of the University of Glasgow, and Dr Philip McCann, Reader in Regional Economics at the University of Reading.

The work ran in parallel with another study commissioned by the DfT and led by the David Simmonds Consultancy (DSC), into the impact of transport on household locations.

2. PROJECT OBJECTIVES

The brief stated that the aim of the project was:

“..to gain a quantified understanding of business location, particularly the role of transport within this, and implement that understanding within a model that can be used for forecasting the number of jobs in each area of the country.”

The central idea was to develop a model based on the available evidence, and then to test it using two contrasting case study areas, in each case simulating how the area had evolved over the decade 1991 to 2001, and comparing the results with actual events.

If new transport infrastructure is built, this may make a location more attractive for businesses, but it will take time for the businesses to respond, to recognise the new opportunities and act on them. New or expanding businesses will need new buildings – offices, warehouses, workshops etc – and these will take time to provide. They may be built on green field sites, or may require the conversion of existing infrastructure to new uses, all of which requires time. For these reasons it was clear that the model would have to be able to
look at quite long time periods of perhaps ten years or more, in order to capture these relatively slow processes.

It was agreed that the model should distinguish between different business types, because of their different transport requirements and therefore their sensitivity to transport costs.

3. LITERATURE REVIEW

An important source was a recent research project carried out by Napier University, “The Importance of Transport in Business Location Decisions”, published in January 2004\(^1\). Napier had carried out an extensive review of evidence about factors affecting businesses’ choice of location, and listed the following as being important influences:

- The quality and scope of the physical and business infrastructure;
- Factor cost and supply, especially labour;
- Market demand and links to international markets;
- Institutional infrastructure and networks;
- A culture supporting ‘civicness’ and entrepreneurship;
- Indigenous company growth;
- Agglomeration economies;
- Technology development;
- Social factors such as climate, lifestyle, image and crime rates.

The Napier report notes that none of these relates to transport directly, but of course transport does contribute to at least two of these, the access to factor inputs and market demand. The authors note repeatedly the importance of the top three factors on this list: premises, workforce, markets & suppliers.

This suggests that rather than using transport supply directly as an influencing factor on business location decisions, a model should focus on how transport affects those indicators that do have influence. So, rather than kms of motorway, travel times to the city centre, or public transport levels of service, decision makers actually respond to operational factors that are affected by these things.

A model structure is needed that reflects how transport affects these primary influences, and how businesses experience them. The most important factors to address in this way would be:

- The availability of suitable premises;
- Access to a suitable workforce;
- Access to customers and suppliers, whether other businesses or the public at large.

Similar findings were reported in “The People: Where Will They Work?” (1999, Breheny, Chapter 10, contributed by Ian Gordon). This reported the findings
of business surveys conducted in London, Reading and Swindon in 1995, listing 16 factors influencing business location decisions. Of these:

- Three were concerned with access to labour
- Two were concerned with the availability of suitable premises
- Four were concerned with access to markets and suppliers.

A further three were concerned with overall transport conditions, mainly the availability of bus services and traffic congestion.

The Napier report made several other interesting comments about the state of theory and modelling in this area:

- “Because the factors influencing location are inherently dynamic in nature, theories that ignore them, or treat them as static, are likely to be incomplete”
- “Of these (limitations of existing models) the most significant was deemed … to be the absence of a lag between accessibility improvement and activity location”
- “There is a need to investigate more dynamic forms of model that better reflect actual business location decision-making”
- “… investigate the greater use of practical dynamic, non-equilibrium models”

This is an argument for a dynamic approach, recognising how events unfold through time. Business location decisions take place in time, are heavily lagged, may take long periods to implement, and have consequences that last for years. For a modelling framework to say anything useful and valid about choice of business location, it must address the concept of time and lags.

Our two academic advisors wrote interesting papers setting out rather different viewpoints. Dr McCann argued that while transport costs tend to be a small part of total business costs, this does not mean, as is sometimes claimed, that they are unimportant. The first reason is that inventory costs depend on transport delivery times, and these costs may be very large indeed: close proximity between suppliers and customers, with frequent deliveries, can reduce inventory costs substantially. Second, transport costs may be low compared to total costs, but they may be large compared to profits, which in the freight and distribution sector are often quite small. Third, customer expectations for rapid delivery times have become ever more demanding, and this increases the importance of transport, and, fourth, for many businesses face-to-face meetings are important, and the ability to make such a round trip within a reasonable time, such as a working day, is important. The net effect is that we should find transport is indeed important in business location decisions, at least for some sectors.

Dr Docherty provided an analysis of the Central Scotland Business Survey, in which 1,672 interviews were carried out in 2001. He found that when asked about the perceived benefits of their location, “easy access to premises” was the most commonly cited by a wide margin (46% of responses overall, rising
to 64% in Edinburgh; other factors were mentioned by fewer than 5% of the sample). Interestingly, easy access was cited as a benefit even where traffic congestion was also mentioned as a disadvantage (as, for example, tended to be the case in Edinburgh).

The lessons we took from the review were:

- That we can expect to find that transport is important for some sectors
- That rather than use direct measures of transport supply, such as kilometres of motorway or point to point travel times, it would be more realistic to use measures that reflect how businesses perceive the effects of transport on their day to day operations
- That the top two such measures should be based on the ability to recruit a workforce and access to customers and suppliers
- That the availability of suitable premises should constitute a third factor in the model
- That a dynamic structure was required that would reflect how circumstances change through time.

4 DATA REQUIREMENTS AND CASE STUDIES

4.1 Data

The data requirements were quite demanding. Ideally we would have full geographic data for each year from 1991 to 2001, but in practice we collected data for the two census years, 1991 and 2001, plus 1995 and 1998. The primary data sources were:

- for households and the workforce, the census for 1991 and 2001, plus the NOMIS database for intermediate years
- for businesses and jobs, the Annual Business Inquiry, the Labour Force Survey and the Small Business Service

Six categories of business types were used based on SIC codes: primary; industry & manufacturing; finance and business; retail and catering; education; other services. The model also distinguishes between four types of business premises: commercial offices; shops hotels and restaurants; warehouses and workshops; and ‘other’. Originally we used five household types and six person types, but it became apparent that this led to technical difficulties, and the workforce types were reduced to two: manual and non-manual.

Some difficulties arose because ward boundaries, Standard Industrial Classification codes and definitions of socio-economic groups all changed quite markedly between the two census years. This meant that we had to construct look-up tables to put the codes onto a common basis, so far as possible, for each of the four sample years, so that consistent data could be presented to the model.
Table 2: Summary of Data Requirements

<table>
<thead>
<tr>
<th>Data Requirement</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Businesses and jobs</td>
<td>For each zone, the number of businesses and the associated jobs, split by six sectors to reflect the different ways transport may be used by different businesses.</td>
</tr>
<tr>
<td>Business premises</td>
<td>The stock of business premises, classified by type, either occupied by existing businesses or vacant.</td>
</tr>
<tr>
<td>Land for business activity</td>
<td>Land shortages could constrain business expansion, while plentiful supply will tend to reduce prices and stimulate growth. An estimate of the available land is therefore needed.</td>
</tr>
<tr>
<td>The workforce</td>
<td>Strictly speaking the availability of a workforce is the subject of the sister project examining household locations. However the model must have access to workforce numbers, preferably segmented by skill groupings to match the job categories.</td>
</tr>
<tr>
<td>Transport costs</td>
<td>Zone to zone generalised costs or times for highways, public transport modes, and walk or cycle.</td>
</tr>
</tbody>
</table>

4.2 Selection of Case Studies

It was hoped that we would be able to select case study areas where significant changes had been made to transport infrastructure in the late 1980s or early 90s, allowing time over the subsequent decade for businesses to respond and adapt. As many as twelve options were considered for the case studies, but it proved surprisingly difficult to find suitable examples.

However it was decided at an early stage that one of the case studies should be the same area as was already being addressed by the parallel project looking at household locations. This was the South and West Yorkshire Multi-Modal Study area (SWYMMS), a large and diverse area comprising the metropolitan areas of West of South Yorkshire and their commuter hinterlands in Nottinghamshire, Derbyshire and North Yorkshire. Figure 1 shows this area, with the zone system finally chosen.

The second area finally selected was Milton Keynes. This was chosen on the grounds that:

- It was relatively free-standing, in so far as any town in the UK is, offering the possibility that it might be modelled without too many complicating interactions with the surrounding area; and
- While there had been no major transport changes, there had been a great deal of growth in business activity and population, and that it might be possible to examine how this new growth had located itself to exploit the existing transport infrastructure.

Extensive reviews of both study areas were carried out by our partners, Llewelyn Davies Yeang. Taking South & West Yorkshire first, they showed how the area’s economy had undergone major structural changes following...
the de-industrialisation of the 1980s, with manufacturing declining and being replaced by service sector jobs. However the process was far from even, with Leeds recovering particularly well, but South Yorkshire lagging with fewer jobs in 2001 than it had 20 years before. Significant infrastructure changes included the electrification of the East Coast Mainline in 1991, improvements to the M1, the Sheffield SuperTram (opened 1994) and Doncaster’s Railport (1995).

By contrast, Milton Keynes is a planned new town which saw rapid growth over the decade: the population grew by 16% and the number of jobs by 47%. If anything, a shortage of labour, rather than a surplus, is becoming a problem for the area. Figure 2 shows the Milton Keynes area, and the zoning system eventually selected.
Notes: Coloured areas are model zones. The modelled area is approximately 77km wide and 100km from North to South. The population of the whole area is approximately 12 million, and the model uses 112 zones to cover this area.
Figure 2: The Milton Keynes Case Study and Selected Zoning

Notes: Coloured areas are model zones. The modelled area is approximately 72Km from east to west, and 72Km from North to South. The population of the whole area is about 950,000, and the model uses 69 zones, of which 23 define the city of Milton Keynes.

Because of the severe complexity of the SWYMMS area, and the difficulties we encountered during the data collection, it was decided to focus first on Milton Keynes, developing and calibrating a model for that case study area, then to transfer the model to South & West Yorkshire (SWY) to see how well it would perform there.

5 MODEL SPECIFICATION

5.1 Outline

This section outlines the main components of the simulation model.

As already seen, the model was based around geographic zones, each of which is stocked with businesses, business infrastructure and a workforce. These quantities can vary through time as conditions change.

The zones are linked by transport networks. The model allows for highways, public transport, walk and cycle, using generalised costs for each. The model uses matrices of zone to zone generalised costs for each mode, and these
matrices can be changed through simulated time to reflect changes made to the networks over the simulated period. These costs and changes to them were provided externally by existing models: the National Transport model (NTM) for Milton Keynes, and the original SWYMMS model for SWY.

The model is built using the System Dynamics modelling software, Vensim\textsuperscript{3}. This provides a high quality generalised modelling system capable of handling the large quantities of data required by the model, and the heavily arrayed capability needed to replicate the same fundamental structures across geographic zones and across business sectors.

5.2 Businesses

A central idea used in the model is that each location can become more or less attractive as a place to do business as conditions change over time, and that within the scope of this model, attractiveness is related to:

- The ability to recruit a workforce
- The availability of suitable premises
- Access to customers and suppliers.

If a zone becomes more attractive, we assume this will tend to increase business activity, until new local constraints, such as the ability to recruit, or the availability of suitable premises, slow the growth and eventually halt it. We also assume that there will be a lag between conditions changing and businesses responding, because it takes time for awareness to spread and for businesses to organise new activities.

Next, to make this operational, we assume that in each zone, for each business sector, there is a turnover of businesses as they open and close, and that these turnover rates vary as conditions alter. So, if the average business life for a particular sector is, say, ten years, then in equilibrium roughly 10% of the businesses will close each year and 10% open. If conditions for business improve, then we might expect the start-up rate to rise above 10%, as new activity begins, and the closure rate to fall below 10% as the existing businesses tend to last longer. The net effect will be a gradual increase in the number of businesses. If conditions get poorer, the reverse might happen: start-ups slow down and closure rates increase.

The simple argument assumes that each zone contains enough businesses for average start-up and closure rates to have a useful meaning: it would not apply to specific sites or businesses. Also it does not distinguish between the different ways in which business activity can increase: expansion of existing businesses, new start-ups or inward investment. It simply assumes that if attractiveness improves, then more business activity will be take place, and vice versa, without worrying about the source of that activity.

5.3 Model structure
Figure 3 sets out the model structure that can generate the process just described.
This diagram was drawn with the modelling software, Vensim. Each text label represents either a variable or a data item. If a variable, then there is a formula ‘behind’ the label, defining how the calculation is made; if a data item, there is simply a reference to where the data value can be read. All the variables in this diagram are subscripted by zone and business type. This means that the model structure shown here is replicated for every zone in the model, and for every business type within each zone.

The blue arrows indicate the sequence in which calculations are made. Thus the variable ‘current business attractiveness for operating businesses’ is calculated using three inputs: ‘access to other businesses multiplier’, ‘access to a workforce multiplier for each business type’, and ‘effect of revenues on business attractiveness’. In turn, ‘current business attractiveness for operating businesses’ is used in two subsequent calculations, ‘current attractiveness for new businesses’ and ‘change in local perception’.

The three variables drawn in rectangles are ‘stocks’; they record quantities whose values are increased or decreased through simulated time by accumulation or depletion. The rates of accumulation or depletion are also indicated on the diagram, represented as ‘valves’ on ‘pipelines’. These are really derivatives with respect to time, and as the simulation runs the model integrates these derivatives to vary the stock levels.

The top stock, labelled ‘Businesses’ records the number of businesses in a zone at each point in simulated time. ‘new businesses’, to the left, is the ‘flow’ of new businesses arriving, while ‘closed businesses’, on the right, is the outward flow of businesses that close or move out. These are rates of change. The simulation advances through small time steps, recalculating all
the variables at each step, and generating near-continuous outputs for all of
them. In this implementation one 'time unit' is defined to be a quarter of a
year, but the simulation works in smaller steps of one quarter of a quarter year
(i.e., the entire model is recalculated 16 times per simulated year).

The notion of a 'business' needs to be clarified here. The model works with
average sized businesses; each new businesses is the same average size,
requiring exactly one business unit (premises) and the same average number
and mix of staff. These averages were calculated using actual data from the
study areas. In practice businesses vary in size, but this model treats such
larger businesses as aggregations of the smaller average sized operations.
So, if the model has ten businesses of a particular type in a zone, these may
represent ten real businesses, or one large one, or some other combination.

The lower half of the diagram uses information calculated elsewhere in the
model to calculate an index for how attractive the zone is for business
activities. This index is a value that pivots around one, so that it can be used
to increase or decrease the start-ups and closures. A compound index is
calculated as the product of three separate indices, each representing a
different aspect of the overall attractiveness.

“Current business attractiveness for operating businesses” reflects the
attractiveness of the location for businesses already operating in a zone; this
is taken to include everything except the availability of suitable premises, and
is used to alter the rates at which existing businesses close. "Current
attractiveness for new businesses” is designed to reflect how attractive the
zone is for new or expanding businesses. For them we assume that the
availability of premises is also important, so the index for existing businesses
is multiplied by the index reflecting the availability of premises, and this is
used to alter the rates at which new businesses arrive.

Neither of these indices is used directly to alter start-ups or closures, because
they represent the current, instantaneous level of attractiveness, but as
already noted, businesses cannot respond immediately to changes in
conditions. Both indices are therefore smoothed and lagged, using a simple
stock and flow structure, to generate 'perceived' attractiveness indices. In fact
these structures generate exponentially smoothed averages of the input
values, with average delays of two years for new start-ups, and nine months
for closures. The difference is justified on the grounds that existing
businesses know very well what local conditions are like, so the time to gather
information and act on it is less than it is for others who may be considering
the suitability of the location as somewhere to open new operations.

The three component attractiveness indices are described below.

5.4 Availability of premises

Each business occupies exactly one business unit (e.g., an office, workshop
etc.). If there are no vacant units available, there can be no expansion in
businesses, but if vacancies are high, then the availability of units will not
constrain expansion, and if rents fall enough they may stimulate new activity. In reality this is mediated through rents, but the model works with vacancy rates rather than money, on the grounds that these can be calculated, and that they are the primary driver of actual rents.

The question of whether vacancies are high or low is decided by comparison with a reference value of 3%, a level taken to represent a market with a satisfactory turnover rate. The model calculates the relative vacancy rate as “actual fractional vacancy rate / reference fractional vacancy rate” and then generates a multiplier using a power function of the form “multiplier = relative vacancy ^ a”, where a is a parameter to be estimated. If a<1 the function will rise as the vacancy rate rises, which is what is required. Also, when the relative vacancy rate is 1 the multiplier will be 1 (ie it will have no effect) and when vacancies are zero, the multiplier will also be zero, preventing any further expansion in businesses.

5.5 Access to a workforce

The model includes a module that simulates the turnover of staff and their recruitment into posts. The rate at which employers in one zone will recruit from the pool of job-seekers in another depends upon:

- The number of vacant posts
- The number of job seekers in the zone
- The transport costs between the zones, calculated as a logsum across all the available modes
- The effect of employers in other zones competing for the workforce, and of job seekers in other zones moving into vacant posts.

The net effect is that employers in each zone will have some vacant posts that they seek to fill, and that the vacancy rate will reflect the employers’ access to the workforce and the competition among employers to recruit them. Changes in transport costs may increase the pool of accessible job-seekers, making some locations more attractive because recruitment becomes easier. The job vacancy rate is used as a measure of the ability to recruit. If vacancies are unacceptably high, this will deter business expansion; if they are low this will at least remove recruitment as a constraint, and may encourage expansion.

The process used to construct an index is similar to that for unit vacancies. Vacancy rates are compared to a reference rate, to give a relative vacancy rate, and this is then transformed into a multiplier, this time using a function of the form y=exp(a.(x-1)), where a is again a parameter to be estimated, and x is the relative vacancy rate. This function can take several shapes, depending on the value of a; Figure 4 illustrates. Values of a less than one give curves of the required shape.
5.6 Access to Customers and Suppliers

Proximity to other businesses, who may be customers or suppliers, is the third factor contributing to attractiveness. An index based on this requires two steps in the calculation:

- Calculation of how many businesses are ‘accessible’, that is, how many are within acceptable range, taking into account transport costs and times;
- A mapping from this to an index reflecting how important this accessibility is to each business type.

The number of accessible businesses can be calculated using a formula of the form:

\[ \text{Accessible businesses}(i, \text{bustype}) = \sum_j \text{Businesses}(j, \text{bustype}) \cdot f(\text{travel cost}(i,j)) \]

The function \( f() \) expresses the rate at which the influence of distant businesses falls off as travel costs rise; it is a business-to-business deterrence curve. We have used a two-parameter function here, of the form:

\[ f(\text{cost}) = 1 - \left( \frac{a \cdot \text{cost}^2}{b + a \cdot \text{cost}^2} \right) \]

Figure 5 illustrates the general form of this function: it takes the value 1 when the cost is zero, and falls to zero as the cost rises, following a bell-shaped curve that can be flexed by altering the two parameters, \( a \) and \( b \).
This process calculates how many businesses are within an acceptable range of a zone; the attractiveness multiplier function then converts this to an index reflecting how important this is to businesses in that zone. The function chosen uses the exponential form shown in Figure 4, allowing for cases where businesses seek to be in proximity (\( a > 1 \)), and where they prefer not to be (\( a < 1 \)).

In fact the calculation here is a little more complex because of the requirements of different business types. Business type \( j \), for example, may have different preferences for proximity to each of the other available business types, so to handle this we allow the parameter \( a \) to be indexed on business types in local zone (ie where business type \( j \) is located) and the business types in the distant zones (ie where the distant businesses are located). The result is that we have a matrix of values for \( a \), as in \( a_{(local\ business\ type,\ distant\ business\ type)} \).

For business type \( j \) in a given zone, this delivers a separate attractiveness index reflecting proximity to each of the other business types. We prefer to have a single index reflecting the attractiveness to business type \( j \), and this is calculated by taking the product of the component indices, as in:

\[
Attractiveness(zone, j) = \prod_k attractiveness(zone, j,k)
\]

To give even more generality we might also allow the parameters in the deterrence curve to vary by business type, but because this risks over parameterising the model we have not done so.

Finally, the attractiveness function is applied not to the absolute numbers of accessible businesses, but to a relative measure of accessible businesses, standardised against the average number of accessible businesses calculated across all zones at the start of the simulation period (ie 1991). In this way we construct a relative accessibility measure that reflects the performance of each zone relative to all the others in the modelled area.

Retail customers are a further class of customer, which is handled rather differently. In the model these are residents, and locations with access to large residential populations will be more successful than those without, while
this accessibility is, of course, provided by transport. The model estimates the expected distribution of retail expenditure across zones on the basis of: the average monthly retail expenditure per household; the numbers of households in each zone; the number of retail businesses in each zone; and the transport costs linking the zones. An attractiveness multiplier is calculated based on the estimated revenue per square metre retail floorspace, referenced against the average across all zones at the start of the simulation. The multiplier function uses the power function form, \( y = x^a \), where \( a \) is a parameter to be estimated.

### 5.7 Developers and the Provision of Business Units

Given the importance of the availability of suitable premises, the model needs also to address how those premises (‘units’) are supplied. During the study we arranged discussions with property developers to explore how they assessed and selected sites for development of commercial property. Their primary criteria were whether they can obtain good rents, and whether those rents could be expected to rise in future years.

A good rent will reflect the cost of the investment, including acquisition and preparation of land, planning, design and construction. However the rent that can be charged will also reflect current local market conditions, while the desire to look ahead to growth in rents indicates that the developers must also take a view of how business activity and thus demand is likely to change in future.

In view of this, the model includes a property developer simulation, structured in a similar way as the business model in Figure 3, with units being constructed and demolished over time, and the rates at which these happen varying with conditions, after a lag. The three inputs to the attractiveness measure for developers reflect:

- The availability of land
- The current property vacancy rates
- The smoothed historic business growth rates.

The first of these reflects the fact that land is needed for new business units. In the model this may be either green field land, or brownfield land released as older units are demolished. The second reflects current market conditions. It allows the model to reduce construction rates when vacancies are high, or to accelerate construction when they are low. The third is a simple representation of how developers may make forecasts. The model calculates exponentially smoothed rates of growth in business activity with an averaging period of one year; higher rates will encourage more construction, lower rates will discourage it, while negative rates will eventually halt it altogether.

### 5.8 Transport

Transport costs are represented by zone to zone generalised costs, with highways, public transport and walk/cycle represented separately. Because
there is no network model, congestion costs are not explicitly modelled, but the model is set up so that different cost matrices can be read in for different years, with the model automatically interpolating costs for intermediate years.

Mode choice is modelled for commuter trips; this is necessary so that the recruitment process can be handled properly. The model uses conventional logit mode choice models. Household car ownership is included in the model so that car availability can be taken into account in those calculations.

6 Running the Model

6.1 The process

Our approach was to begin by using the model for the Milton Keynes case study, calibrating and checking it, and then to transfer it to SWY to see how well it would perform in this larger and more complex area. The first work was thus for Milton Keynes.

The first step was to initialise the model for 1991. This meant not only providing it with 1991 base data, but ensuring that with its dynamic processes operating the model could generate outputs that were acceptably close to the 1991 situation. The outputs tested included:

- Travel-to-work matrices and mode shares
- Numbers of jobs and businesses
- Employment rates and job vacancies.

Next, the model was allowed to simulate the decade, taking the assembled data series as inputs. These were used in two ways:

- Workforce numbers and transport costs were used as inputs to the model. In other words, it was told how these had actually changed over the decade and used those values while simulating.
- Numbers of business and jobs were used to benchmark the model, reference points against which the numbers of businesses and jobs generated by the model could be compared.

The aim was to adjust the primary model parameters until the jobs and business numbers it generated matched as closely as possible the actual figures. Vensim helps here by providing a semi-automatic calibration process. When given a list of the parameters to vary and a definition of a ‘loss function’, it will then run the model repeatedly, adjusting the parameters incrementally in a controlled search in order to minimise the loss function. This loss function was defined using the summed squared differences between the actual and modelled numbers of businesses in each zone through time, calculated separately for each business type.
6.2 Land

Even before the calibration work was carried out it quickly became clear that a crucial factor was what we assumed about the availability of land. Milton Keynes saw a growth in job numbers of 47% over the decade, and this expansion required land; the problem was to provide the model with estimates of how much land was actually available.

In the early model runs we used data extracted from Local Plans to estimate how much land was available for new commercial development over the decade. However this published data was evidently quite inconsistent from year to year: in some cases zones seemed to shrink, or the developed area shrank, or sometimes there was no information at all. There are many legitimate reasons why this might be so, but when used in the model the data gave poor results. Inquiries with the local authorities indicated that we would not be able to acquire better data within the timescales or budget of the project.

The alternative approach was to calculate how much land would have been needed to accommodate the known expansion in jobs and businesses and to make this land available, all at once, in 1991. This was relatively easy to do, given the construction densities already estimated for the model, and it quickly became clear that it gave much better results. While there was little choice about this, there are three obvious criticisms:

- These estimates would give the minimum amounts of land available – there may have been more that was not used by 2001
- The fact that all the new land was made available in the model in 1991 may not have been realistic
- This approach might mean that the model would over-forecast in the early part of the decade, but towards the end it could not over-forecast, because of the limit on land.
6.3 Results: Milton Keynes

Using the inferred land estimates, the model was able to generate quite good estimates of the numbers of businesses in Milton Keynes even before the calibration work was carried out, using parameter values chosen by judgement. Figure 6 compares the modelled and actual numbers of jobs and businesses over the simulated period obtained in this way: in each case the blue line is the model’s output and the red is the actual.

Figure 6: Modelled and Actual Jobs and Businesses, Milton Keynes

These plots are the summation of jobs and businesses in all 23 zones covering the city of Milton Keynes. However the results were also quite good for individual zones: Figure 7 plots a few of the results for job numbers.
The results were poorer when different business types were taken into account. Figure 8 is a scatterplot of the actual and modelled numbers of jobs in 2001; each point represents a zone/business type combination.
The plot includes two lines: the diagonal, \( y=x \), along which the points would lie if the model replicated reality exactly; and a line fitted by linear regression. The dispersion of the data points is quite high, with an \( r^2 \) of 0.59, while the slope of the fitted line is less than one, indicating a tendency to under-forecast.

The calibration process was then used to estimate the parameter values described earlier, namely:

- The parameter used to define the attractiveness power function for the availability of suitable premises, distinguishing between business types
- The parameter used to define the exponential attractiveness measure for recruitment, also distinguishing between business types
- The two parameters in the business-to-business deterrence function
- The matrix of parameters used to define the business-to-business accessibility attractiveness function.

This produced a useful improvement to the results. Figure 9 compares the results for jobs in 2001 before and after calibration, and Figure 10 does the same for numbers of businesses. In each case the top pair of graphs shows the total jobs or businesses in a zone, and the second pair shows jobs or businesses split by business type.

In each case the dispersion has been reduced, and the slope of the fitted line is closer to 1.
Figure 9: Modelled and Actual Job Numbers Before and After Calibration

### Before

**Aggregated for Each Zone**

- Modelled Jobs vs. Actual Jobs
  - $y = 0.8536x$
  - $R^2 = 0.7568$

**All Business * Zone**

- Modelled Jobs vs. Actual Jobs
  - $y = 0.8617x$
  - $R^2 = 0.5867$

### After

**Aggregated for Each Zone**

- Modelled Jobs vs. Actual Jobs
  - $y = 0.9481x$
  - $R^2 = 0.9229$

**All Business * Zone**

- Modelled Jobs vs. Actual Jobs
  - $y = 0.9931x$
  - $R^2 = 0.7233$

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6.4 Results for SWY

The SWY model contains 112 zones, and covers more than 17 administrative areas (Districts), including several large cities. To simplify the analysis we reported the results aggregated by District. Model runs were made using the parameter estimates derived from the Milton Keynes model and the inferred land availability, calculated as for Milton Keynes. As with that model, analysis was carried out first to ensure that the travel to work patterns and mode shares in 1991 were correctly reproduced by the model, then simulation runs of the whole decade were made.

In most cases the results in 2001 were fairly good. Figure 11 reproduces the scatter plots of businesses for some of the Districts. As for Milton Keynes we find that the results tend to be better for the total number of businesses in each zone than they are when business types are distinguished. The fitted lines show a tendency to underforecast, as before, but many have slopes very close to one, and in a few cases the slope actually exceeds one.
Figure 11: Modelled and Actual Businesses, SWY Model, 2001

Leeds:

Sheffield:

Bradford

Cont…
Problems become more apparent when we look at the time series plots for each district. Figure 12 gives a typical example, in this case for Leeds. The graph shows the actual and modelled numbers of businesses over the decade, showing how the model tracks the actual numbers quite well up to 1997/98, and then it falls back, with a decline in businesses, so that by 2001 the match is quite poor (the red line plots the actual numbers, the blue plots the model’s output).
The reasons for this appear to be connected with the structural changes seen in the area over the decade. Figure 13 plots several model variables over the simulated period and the externally imposed workforce numbers. It can be seen that:

- The workforce falls steadily over the decade: this, of course, is imposed on the model
- The simulated number of businesses rises from the start of the simulation, up to a peak between 1997 and 1998, after which it falls back
- The number of unemployed job seekers falls as the number of businesses and hence jobs rises and the total workforce shrinks
- The vacancy rate among employers rises as recruitment becomes harder.
The problem is that the model cannot reconcile the growth in businesses with the imposed fall in the workforce, and it reaches a crisis point in 1997/98, when the number of businesses peaks, but recruitment difficulties halt the growth and the number of businesses starts to fall again. The job vacancy rate falls as a result over the last three years.

Arguably, of course, the model’s response was quite reasonable: the initial growth in businesses was stalled by a growing recruitment crisis, and it therefore gradually reduced the numbers of businesses until a better balance was struck. However this is not what actually happened, and this conflict raises lots of interesting questions about what really did happen in Leeds over that decade, but they go beyond the scope of the present study. It is however probably fair to say that the source of the difficulty is unlikely to be transport.

7 Using the Model to Generate Forecasts

The final Requirement of the Brief was to use the model to generate forecasts. This is relatively straightforward to do, by simply setting a longer time limit for the simulation, and tests were carried out running the Milton Keynes model up to 2011.

Four test scenarios were constructed in which:

1. The generalised time of car travel to or from selected zones was reduced by 20%
2. The land area available for commercial development in those zones was increased by 20 hectares
3. Both of these changes were implemented together

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4. The generalised time of car travel to or from the selected zones was increased by 20%.

In each case the changes were implemented in 2001. However the other transport costs remained fixed at the 2001 levels, and the workforce also remained fixed at the 2001 levels.

The scenarios were tested on three zones, each with different characteristics. The results were fairly consistent across the zones, and are illustrated here by reference to one zone, Linford North. Figure 14 shows plots of job numbers in each scenario, compared to a base do-nothing case.

**Figure 14: Forecasts of Jobs under Test Scenarios**

Reducing car costs:  
![Plot of jobs by zone for reducing car costs](image)

Additional Land:  
![Plot of jobs by zone for additional land](image)

Reduced transport costs & extra land:  
![Plot of jobs by zone for reduced transport costs and extra land](image)

Increased Transport Costs:  
![Plot of jobs by zone for increased transport costs](image)

In the first case, reducing transport costs to the zone has very little effect on jobs; the difference is barely discernible.

Additional land has a substantial effect, although it takes several years for the expansion to be completed. However it has to be said that the extra 20ha is a large increase for the zone: the inferred land area available for commercial development in 2001 was about 32ha, so 20ha is an increase of 62%.

Interestingly, adding extra land and reducing transport costs together seems to have a bigger effect than the sum of the two actions taken separately. On its own the transport improvement had little effect, but when combined with another growth initiative it provided an additional further gain.
Finally, increasing transport costs seems to have had very little effect.

8 Conclusions

This paper describes a large and ambitious research project carried out for DfT to quantify and model how transport might affect business location decisions. A simulation model was developed drawing on the findings of previous research work that attempts to model how the attractiveness of locations for business activities varies over time, how transport affects this attractiveness, and how businesses respond, though time.

The work suggests that transport’s influence on location decisions is somewhat indirect, and works through intermediary factors that have a bearing on the day to day operations of businesses. These are:

- The ability to recruit a workforce, since the recruitment catchment of an employer will be influenced by transport provision; and
- Access to customers and suppliers, who may be other businesses or the general public.

The model has mechanisms in it to address both of these. It also recognises the importance of suitable premises for businesses, and, beyond this, the availability of land on which those premises can be built.

The model was used to simulate ten years of change in two case study areas, Milton Keynes and the SWY area.

The model was able to replicate changes in jobs and businesses in Milton Keynes quite well, but it quickly became apparent that assumptions about land use policy were quite critical, especially in Milton Keynes, where expansion of business activity had been substantial over the study period. We were unable to obtain usable estimates of land assigned for commercial development from local authority sources, and therefore used estimates we calculated based on the growth that had actually happened.

The results were fair, but less good for the SWY area. This is a very large and diverse area that saw large scale structural changes over the decade, and the effects of this became apparent within the model where those structural changes introduced tensions that the model was not able to resolve. This would merit further study, to understand better what really happened here.

In both cases the measured changes in transport costs, supplied from external models, were actually quite small, so that their effects were arguably dominated by other, larger changes. This assertion is supported by the results of using the model to generate forecasts under test scenarios. In these cases we find that the impact of transport changes on jobs and businesses seems to be quite small; that other changes, such as land
allocation, can have a large effect; but that transport changes coupled with land re-allocation can then provide an additional boost to growth.
Notes
1. Available at:  
2. He states that “In the logistics and distribution sector, and some extraction industries, transport cost may be as much as 15-20% of total costs. On the other hand, for most manufacturing industries, transportation costs are typically only of the order of 1-3% of total costs.” Similar figures were reported in the 1999 SACTRA report, “Transport and the Economy”. He also notes that businesses may not know what their transport costs are: “in fact, many firms do not know their transport costs without making very careful calculations … all in all, most firms feel that a more sophisticated approach to transport costing would not be worth the time involved.”
3. See www.vensim.com
4. The changes in zone to zone highway costs tended to be very small. For example, in Milton Keynes the average change across all zone pairs was -0.35%, and for zone pairs within the city of Milton Keynes it was -0.75%. The maximum change for trips into Milton Keynes was -6.3%, and for trips within the city, -16.1%.