Transport and the Urban Economy: The Urban Dynamic Model

John SWANSON, Steer Davies GLEAVE

(John SWANSON, Steer Davies GLEAVE, 28-32 Upper ground, London, SE1 9PD, UK john.swanson@sdgworld.net)

1 ABSTRACT

Transport planning authorities are frequently interested in the way transport investment can contribute to regeneration and economic growth. The argument is that by improving the access employers have to the resources they need – a workforce, customers and suppliers – transport can help attract new employers and boost a local economy. Similarly by improving access to employment and other essential services transport can help make a location more attractive as a place to live, and so help attract and retain a workforce.

This paper describes how the Urban Dynamic Model (UDM) has been developed and applied to help address this issue. The UDM is formulated using System Dynamics to simulate the interactions between transport, land-use, population and employment over years or decades. After a short explanation of the motives for developing the model, the paper reviews some of the key features of the model. A recent case study in which the model was used is discussed, and the paper ends with some comments on current and future developments.

2 INTRODUCTION AND BACKGROUND

This paper describes the development and use of the Urban Dynamic Model, or UDM, to simulate the interactions between transport and the wider social and economic activities of an urban area, especially transport's impact on jobs and employment.

Transport schemes and projects are often promoted on the grounds that they will help regenerate a city or town's economy. This is a popular theme, but while common sense suggests that good transport must be related to economic activity and growth, in practice it is much harder to demonstrate the nature of the connection. The motivation for developing the UDM was to develop a tool that could be used to help address this issue.

Many models of how urban areas form and change have been developed over the past 50 years or more. Batty, for example, provides a review[1]. Until recently these have tended to be large, complex and, usually, equilibrium models, with a reputation for being 'black box': users had to take their outputs on trust. In the late 1990s there was an active debate about the role of equilibrium models in transport (eg Goodwin[2]) and Steer Davies Gleave was exploring the role System Dynamics might play in addressing the criticisms. Forrester's classic urban model[3], seemed to offer an attractive theory of how urban areas might evolve and a way of simulating that process. However it was not a spatial model, and had no explicit representation of transport. Both of these shortcomings had to be overcome if Forrester's model was to be of any help.

3 THE DYNAMIC URBAN MODEL

The UDM borrows many ideas from Forrester's original model, but where he treated the city as a single zone and said very little about transport, the UDM divides the city into a number of zones all linked together via one or more transport networks.

A key idea is that of the attractiveness of each zone as a place to live or to do business.

Attractiveness as a place to live is taken to be a function of the availability of two things: suitable housing and employment. In reality there are other factors affecting attractiveness, but these two were chosen because they are fundamental things that people need: somewhere to live and employment.

For businesses, attractiveness is assumed to be a function of the availability of suitable premises, the ability to recruit a suitable workforce, and access to customers and suppliers. While other factors could be hypothesised, these are fundamentals that a business needs in order to operate: premises, a workforce, customers and suppliers.

While the original model had, in effect, only one zone, the UDM has many, and the attractiveness principle is applied to each. Taking households first, the UDM assumes that households are constantly in a state of flux, with new households moving in and others moving out. The rates at which this inward and outward migration occurs are determined by the attractiveness of the zone: if a zone becomes more attractive, it will tend to attract more inward migration, while outward migration will slow; if it becomes less attractive, inward migration will reduce and outward migration will increase.

Figure 1 illustrates this with a simple stock and flow diagram. More plentiful housing will make a location more attractive, more unemployment will make it less so. Rising attractiveness will tend to increase inward migration and decrease outward migration. This structure is replicated for every zone, and because the model allows several different types of household to be distinguished, each with their own attractiveness functions, the structure is also replicated for household types.

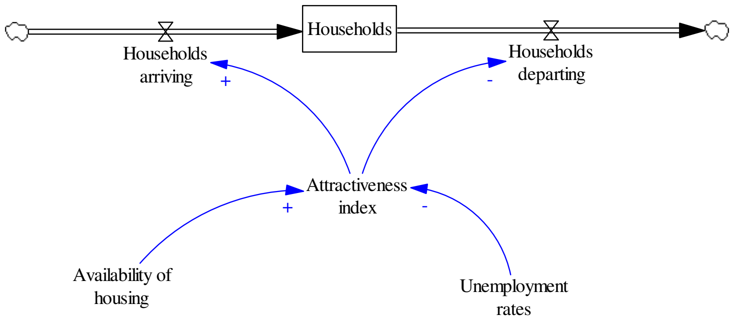

Figure 1: Household Migration

A similar structure is used for businesses. The rates at which new businesses arrive and depart is affected by a measure of attractiveness constructed from other measures of the ability to recruit, the availability of premises and access to customers and suppliers. As with households, the structure is replicated for each zone, and, because the model can also distinguish between different types of business, for each type of business[1].

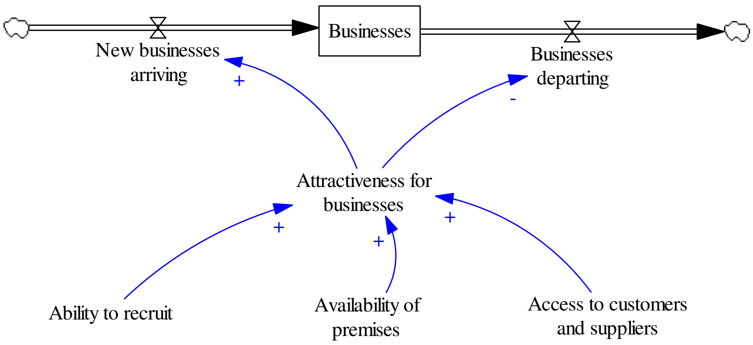

Figure 2: Arrival and Departure of Businesses

Households need houses to live in, while businesses need premises to occupy so the model also includes representations of builders and developers who provide this infrastructure. The structure is similar to that used for businesses; we assume that premises are being built and demolished all the time and that the rates at which this happens will depend on how attractive the zone is from the point of view of the developers. This attractiveness depends on three properties of the zone: adequate land to build on; rising demand, so that good returns can be had from the investment; and a favourable balance of supply and demand, (ie a shortage of premises rather than a surplus).

Each model zone is stocked with information about housing, households, land, businesses, business premises and so on, all of which can vary over simulated time as the attractiveness measures shift.

[1] There are at least three sources of new business investment: inward investment, new start-ups and expansion of existing businesses. The UDM does not distinguish between them, because it assumes that they are all affected by the same measure of attractiveness, while the source of the new businesses is not of central interest.

4 TRANSPORT

Transport networks link the model zones, providing access within and between them, and affecting the zone's attractiveness in three ways.

First, reduced transport costs and times will tend to increase the range of employment opportunities available to the resident workforce, making it easier for them to get into employment and therefore increasing attractiveness as a place to live. The effects of this can be mixed, because in the early stages the effect is to increase competition for the existing jobs, so that employment becomes redistributed, but if the employers respond to the improved recruitment conditions and increase the number of jobs the effect can be a net increase in jobs, population and employment.

The second way is the mirror image of the first: it increases the accessible workforce available for employers to recruit from. This may stimulate further growth in business activity as recruitment eases, although as before, in the early stages the main effect is to redistribute the recruitment patterns for the existing jobs.

Third, it can affect businesses' access to customers and suppliers. The model assumes that as the pool of accessible businesses increases, this increases a location's attractiveness and in turn attracts more businesses.

If something happens to stimulate growth in population or jobs, the growth will not continue indefinitely, because at some point a new constraint will start to bite. Growth in jobs will slow if recruitment starts to become difficult, or if no more premises are available; growth in population will slow if insufficient houses are available or if there are insufficient jobs for newcomers. Ultimately, land is the limiting constraint.

The most recent version of the UDM can represent five transport modes: highways, heavy rail, light rail, bus, walk and cycle[2]. The model uses traditional logit and hierarchical logit models to handle mode and route choice in ways that most traditional transport modellers would recognise, the main difference being that they are used in a dynamic framework in which explicit recognition is made of the time needed for people to adapt their behaviour. Figure 3 illustrates how mode choice, for example, is handled via a fairly standard goal-seeking mechanism. 'Bus mode shares' is an array of bus mode shares for each origin-destination pair in the model, while 'network conditions' is short-hand for arrays of travel costs and times for each available mode for each O-D pair. Given a set of mode-choice parameters the target mode shares can be calculated reflecting current instantaneous network conditions, while the goal-seeking structure generates the actual mode shares by tracking this target.

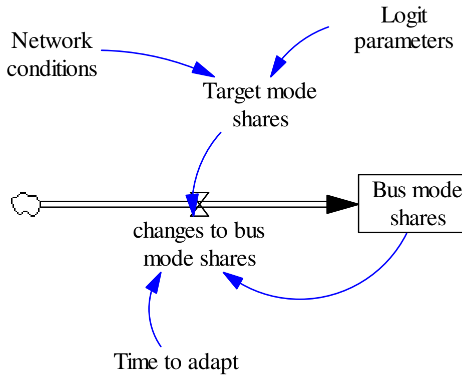

Figure 3: Goal seeking structure for mode shares

The highways model can handle congestion directly using speed-flow curves, via a similar goal-seeking mechanism. Congestion can thus be modelled without the complicated iterative processes involved in more traditional equilibrium models.

5 SETTING THE UP AN IMPLEMENTATION OF THE UDM

The UDM has been used for 14 studies in the UK to date. Published statistics can be used to assemble much of the data required to stock the model zones, or, using a little ingenuity, to infer the necessary values. However transport is usually more problematic.

[2] Walk and cycle are treated as a single mode. This is justifiable given the geographic scale of most applications of the model.

Various ways of supplying the necessary transport information have been developed. If a transport model already exists then it is possible to convert its network structures to a form that the UDM can use. This has been done with SATURN and TRIPS networks, both popular transport modelling packages in the UK, although some simplification of the networks is typically needed because these models will usually work with smaller zones than does the UDM. There are also publicly available highways models which can also be used to provide highways information. Bus networks can be more difficult, but it is possible to infer zone-to-zone bus generalised costs on the basis of observed behaviour if adequate data is available; in the UK the travel-to-work census provides detailed information about mode shares that can be used to do this.

The largest applications to date have had up to 200 zones, with around 1500 highways links explicitly modelled, six classes of business and between two and four classes of people, houses, business premises and work skill groups. Models of this scale require up to one hour to simulate ten years. Explicit modelling of the highways network (route choice, congestion etc) accounts for much of this time, and we have found that reducing the travel costs to generalised cost matrices can reduce run times from an hour to about ten minutes, but at the cost of removing some feedbacks, such as drivers' responses to congestion.

6 A CASE STUDY: SHEFFIELD CITY REGION

Sheffield City Region is a large region of England containing the cities of Sheffield, Barnsley, Doncaster, Rotherham and Chesterfield. Its population is around 1.7 million and it had about 675,000 jobs in 2006. After the closure of the mining industries in the late 1980s, the area suffered a period of decline and unemployment, but since 2000 recovery has been under way as regeneration initiatives have started to pay off.

In 2007 Steer Davies Gleave was commissioned to use the UDM to demonstrate the benefits to South Yorkshire of significant investment in transport. An implementation of the model was built with 198 zones, stretching from north of Leeds down to Chesterfield and the East Midlands, and as far west as Manchester. Transport network data was assembled using existing highways models, a specially commissioned model for rail, and inference of generalised costs for buses and walk/cycle. The model was initialised for 2001 (the year on which much census data is based) and then benchmarked against actual data for the period 2001 to 2006. Information about a large number of proposed transport schemes was assembled and grouped into two area-wide strategies on the basis of their current status in the funding programmes.

The model was then used to simulate ten years with and without the bundles of proposed schemes. This showed that when coupled with a programme of land releases for development the transport packages could generate an additional 20,000 jobs in the region. It also showed that there was a tendency for the transport schemes to shift jobs away from the lower density rural and semi-rural locations towards the cities. This is a direct result of the way transport improves the important patterns of accessibility, making conditions better for firms located in places of high density and, by increasing the competition for resources such as a workforce, making conditions harder in low density locations. There also seemed to be a limit to the capacity for transport to generate new jobs because other constraints, such as the land available for new business activity, started to bite.

7 THE FUTURE FOR THE UDM

The UDM has been in regular use since 2000. We would argue that it is now a proven model, and that it demonstrates the value and viability of using System Dynamics in this context. Many of the difficulties associated with models of this type, such as calibration, apply equally to all other land use and transport model technologies, but we have gained much experience in using such evidence as is available to demonstrate the validity of the model's results.

There has been much interest recently in the UK in the 'Wider Economic Benefits' of transport. These are the benefits that are gained by encouraging agglomeration and making jobs more productive, thereby increasing economic output per head. The UK Department for Transport has published guidance on how these benefits may be calculated, and this has been done using the outputs from the UDM. In the case of Sheffield City Region this suggested that the economic benefits of the transport schemes would be increased significantly if these productivity gains are taken into account. Productivity benefits can be generated even if there are no new jobs, because the productive output of those jobs can be increased. This points to what may be a fruitful new use of the UDM.

8 REFERENCES

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