Abstract: This paper offers first a description of the Transport/Economic/Land-use Model of Scotland, which is an application of the DELTA package, and then presents some applications to which it has been applied. TELMoS is a general-purpose model which has been and is being used for a wide range of studies in relation to planning and transport, and whose results have informed a number of major policy decisions.

The DELTA package was developed as an urban modelling system in 1995-97, and was substantially extended by the addition of a regional level in 1999. It can model one city in detail, taking account of the surrounding areas, or all of the urban areas across a region or country – in the present case, the whole of Scotland. DELTA does not include a transport model, but is linked to a specialist transport modelling package. TELMoS is working in interaction with the Transport Model for Scotland (TMfS), which is an application of the Voyager software.

We first describe DELTA package and TELMoS model. We then outline some of the enhancements developed in the latest version of TELMoS. We finally present some of the applications to which TELMoS has recently been applied, discuss the corresponding results and describe their interpretation.

Keywords: land-use model, land-use/transport interaction, mapping
1. INTRODUCTION

This paper describes the latest land-use/transport interaction modelling work carried out by David Simmonds Consultancy (DSC) and MVA Consultancy on the TELMoS model (Transport/Economic/Land use Model of Scotland). The work was carried out for Transport Scotland as part of the Land-use And Transport Integration in Scotland (LATIS) service. The paper concentrates on the presentation of the model and on the descriptions of both the Do-Minimum Reference Case and one application which shows the impacts of transport on jobs and workers. The issues arising in appraisal of these impacts are only briefly considered.

The note is in three parts. The first introduces the DSC DELTA package and the TELMoS model. The second describes briefly the main enhancements which have been carried in the latest version of the model, namely TELMoS07. The third finally compares two model runs, the reference case and a variant run that included an alternative set of transport policies. The analysis of the output concentrates upon the differences in terms of impacts on accessibilities and land-uses.

1.1 DELTA and TELMoS – an overview

1.1.1 The DELTA package

General - The development of DELTA started in 1995 in response to a perceived demand for a new “land-use” modelling package with two key characteristics: to complement free-standing transport models (see Roberts and Simmonds, 1997); and to leverage the wide range of research related to change processes in urban and regional economics, geography, demography, sociology, etc. Since its first application, in conjunction with the transport model of Edinburgh, in 1996, the model has been used in a number of applications to regions of Great Britain.

DELTA models are based on four components (see Figure 1). The transport and urban models work at the level of zones, whilst the migration and economic models work at the broader level of areas. Areas typically correspond to travel-to-work areas, at least within the region of main interest; zones represent finer units within these areas (or within the area we are concentrating on).

Figure 1 Overall structure of a DELTA-based model
A Land Use and Transportation Model can be used both at the outset of the planning process, where strategy and policy options are being considered, and subsequently when the authorities are monitoring and reviewing their plan.

In particular, at the plan preparation stage, it can be used to:

- Appraise the land-use/economic impacts of transport schemes within specific regions;
- Assess the sensitivity of strategy/policy options to different economic scenarios. At the most basic level this might involve introducing high and/or low economic growth options. A more sophisticated approach might be to explore the impact of varying the performance of key economic sectors (for example the energy sector or the financial sector);
- Assess the impact on the transport network of different land-use options or indeed the preferred strategy. This could identify specific links on a highway network where congestion increases/decreases, or could be presented in terms of average trip lengths or an indicator of congestion at local authority or plan level. Further environmental analysis that assesses the transport emissions resulting from land-use alternatives under consideration may be possible within the transport model;
- Assess the outcomes of policy or strategy options in terms of spatial changes in population, households, employment and levels of development.

**Calibration** - The approach to calibration of DELTA has been that on the one hand it is unrealistic to expect to be able to estimate the required models of change on local data for any one application of the package, whilst on the other hand it is positively desirable that the model responses should be informed by a wider range of circumstances than are likely to be observed in one area at one time, and in particular that they should draw upon the wide range of research into urban and regional change that is carried on in academic and other institutions. The intention and expectation has therefore always been that model coefficients would be based largely on a wide range of previous findings and experience, and relatively little on formal statistical calibration carried out specifically for one model application. The coefficients used in TELMoS reflect this approach. Some, such as the initial input-output parameters, are taken directly from survey data; others (such as the demographic transition rates) are based on survey data adjusted to reproduce the overall demographic scenario for Scotland. Others are based on the modelling team's interpretation of reported research results and on professional experience from previous modelling activities.

**Comparison with other models** - The design of DELTA can best be concisely compared with other packages and approaches by noting that the overall approach embodied in DELTA was strongly influenced by that of Wegener (1982) in the development of the IRPUD model – which has also influenced UrbanSIM (Waddell, 2001) and TIGRIS (Zondag and de Jong, 2005), but that this approach is implemented in DELTA using deterministic rather than microsimulation methods. Like the original IRPUD design, DELTA considers location and spatial choice at two different levels, one considering local choices and the other higher-level choices between different areas within the modelled region. The market-clearing methods used to solve the location sub-models are somewhat similar to the equivalent calculations in the “Martin Centre” packages, ie MEPLAN and TRANUS (see Hunt and Simmonds, 1993), but in DELTA they are used only for the households and jobs being located in one year, whereas in MEPLAN and TRANUS all households and all
modelled jobs are located simultaneously for each future year considered. DELTA uses a spatial input-output model similar to those in MEPLAN or TRANUS, but uses it only to locate production and distribute trade within the context created by all the other processes of change, whereas in both MEPLAN and TRANUS the spatial input-output model is the primary (or only) mechanism of location. Most importantly, whereas MEPLAN and TRANUS are largely (or wholly) models of equilibrium in a future year, DELTA forecasts a range of adjustments in each year, some of which involve very temporary and partial equilibria but which collectively are unlikely ever to reach a full equilibrium. (For further comparison between DELTA and other models, see Simmonds, 2005.)

1.1.2 The Transport/Economic/Land-use Model of Scotland (TELMoS)

TELMoS, the Transport/Economic/Land use Model of Scotland, is an integrated land use and transport model combining the DELTA package and the Transport Model for Scotland (TMfS). It interacts in the following manner:

- the land use model provides information to the transport model on the patterns of residential, retail, commercial, industrial and other activities. This information is used to generate the origins and destinations of the various trips that are modelled within the transport model (i.e. journeys-to-work, journeys to shop, school etc); and
- in return, the transport model provides information on the accessibility of different areas. This information is used, along with information on rents, floorspace, quality etc, by the land use package when modelling the location (and relocation) of economic activity, employment and residents across the modelled area.

A key application of the model is to look at change in transport patterns over time. To do this effectively we need to take account of those factors that will influence future demand for travel. Two such influences are modelled within the DELTA package:

- future development patterns; if new residential or commercial developments are built then the associated trips will impact upon the transport network; perhaps causing increased congestion in one area and/or easing congestion in other areas; and
- changes in activity without changes in development. The model represents the continuing turnover of households and jobs in the ‘second-hand’ property markets, as well as forecasting the take-up of new property. The intensity of use of the stock may change. For example, the opening of a new road or public transport route may increase the attractiveness of an established residential area for commuters to a neighbouring employment centre with the effect that, over the course of time, the area will attract in-migrants.

1.2 Model scope

Figure 2 provides an overview of the model, highlighting the key inputs, in terms of base year data, scenarios and planning policy inputs and the land use model’s interaction with the transport model.
The model starts at a base year and then forecasts through time in single-year steps, taking the output from one year as the inputs to the next. For each year, the model calculates the changes in floorspace by land use type (i.e., residential, retail, office, and industrial), as well as the changes in the activities that use that floorspace. This calculation generates information on the change year-by-year for each zone.

The main inputs to the model are:

- **Base Year Data**: the current base year has been set to 2001 and the forecast period runs to 2031. This choice of base year allows the 2001 Census Small Area Statistics to be used to inform on the number and characteristics of the population, households, employment, and car ownership levels within each zone;

- **Demographic and Economic Scenarios**: these are taken as given at the Scotland-total level, but are reproduced by modelling processes of demographic and economic change (as distinct from simply inputting control totals for each year). The demographic scenario has been constrained to reflect:
  - General Registrar Office Scotland mid-year population estimates for the period 2001-2006 at the national level;
  - GROS household estimates for the period 2001-2006 at local authority level; and

- The **economic scenario** has been based upon work done by consultants Tribal for Transport Scotland’s Strategic Transport Projects Review, which in turn used national projections from Oxford Economics. Some further adjustments were made to reflect Tribal’s forecasts at regional level within Scotland; and

- **Planning Policy Inputs**: both the amount of available land for development and distribution of that development are derived from the information provided by local planning authorities.

The model as a whole can therefore be seen as a means of allocating given rates of change for Scotland down to area and zonal levels, taking account of numerous...
factors and interactions including the supply of built environments and the planning policies affecting changes in these. In forecasting, only the top-level scenarios and the zonal planning policy inputs are strictly fixed by the model user; everything in between is to some extent variable over time and in response to other variables within the model. Some additional factors are adjusted so as to match, for example, particular regional trends, but these are done so as to influence rather than to control the results of the model.

The distributions of households and economic activity are also influenced, as mentioned before, by the performance of the transport system, taking account of infrastructure, public transport services and congestion. Transport infrastructure and public transport services are inputs specified by the model users; the location and level of congestion is generated as a result of the interactions between economic activities and the travel of household members, given the available infrastructure and services.

1.3 Planning policy inputs
As part of the original development of TELMoS, DSC undertook a round of consultation with Local Planning Authorities in 2004 in order to collect information on future levels and distribution of development within their area. This relied heavily upon development plan land allocations and their databases of outstanding planning permissions.

Further consultations with the Local Planning Authorities took place in 2006 and in late 2007/early 2008. The latter coincided with the start of the current round of model building. This regular updating of the information on planning policy, in part, reflects the observation of local planning authorities back at the outset of this process that the information needed to be updated on a regular basis so that it (and the transport model’s forecasts) reflected the latest plans and commitments.

2. RECENT ENHANCEMENTS

The latest version of the model includes a number of enhancements and refinements. These are described below.

2.1 Zoning system, model and database definitions

The model’s forecasting period has been extended from 2021 to 2031 to allow a longer forecasting period.

TELMoS07 is a more strategic model. The number of zones has been reduced from over 1100 (in previous versions of the model) to 720 zones (712 within the Fully Modelled Area, 0 buffer zones and 8 external zones). The number of Areas has increased from 17 to 50. The new zones reflect the 2001-based Travel to Work Areas and are shown in Figure 3.

We have increased the disaggregation of household types. There are now 20 different household types modelled, compared to 18 in previous versions of the model.
Furthermore the modeling of persons not in households has been improved. The model now models four categories of persons not in households. There are 27 employment categories modelled.

2.2 Development model
An enhanced development model has been introduced in TELMoS07 to calculate the demand for development at the Area level. Previously development was only modelled at the national (fully modelled area) level. The increase in development for each floorspace type was calculated and assigned to zones according to relative attractiveness of each zone that contained permissible development (based upon the planning policy inputs from the local planning authorities). The new Area model reflects the fact that in addition to national development processes there will be local development processes within the various areas of Scotland, where developers will respond to local demand for additional premises. The Area Model has a similar three stage process to that of the Fully Modelled Area model involving:
- Calculating the unconstrained development local developers would seek to build;
- Calculating a total constrained development that would apply to local developers within each area;
- Allocating the additional development that is generated by the previous two stages of the area model to zones.

Whereas the fully modelled area development model calculates a proportionate increase in floorspace, the area model calculates an absolute amount based upon the difference between the amount of floorspace that would be required if the activities (households for residential floorspace, employment activities for other

Figure 3 DELTA Areas
activities) using the space category occupied it at the activity/floorspace ratio observed in the base year and the available floorspace in the current year (including the floorspace that has been identified for development by the Fully modelled area model).

2.3 Car-ownership model

TELMoS07 has a new version of the DELTA car ownership model. It is based on a car ownership model for Great Britain (see Whelan, G., 2004). That model was developed using data from the Family Expenditure Survey (FES), at five yearly intervals from 1971-1996, and the National Travel Survey (NTS) 1991. The model implemented in DELTA is an incremental form of the car-ownership model developed by G. Whelan. The model is applied separately to each household type in each zone.

2.4 Location model

In TELMoS07 we have introduced a distance-deterrence function to allow cross-area-boundary moves. Previously short-distance moves (of mobile households) were constrained so that they took place within Areas. (Longer distance moves are modelled within the Regional Migration Model and reflect the relative economic performance of different areas. This function has remained unchanged).

The utility of consumption in the location model has been revised to add a minimum floorspace per household. Utility of consumption is defined as the utility which households obtain from spending their income. The basic utility of consumption function allows income to be spent on just two goods, namely housing space and all other goods and services. In the activity-space function implemented in TELMoS07, if the household income is insufficient to cover the minimum expenditure, the cost of location is fixed to the cost of the minimum expenditure (even if this is greater than the income), whilst the floorspace occupied is set to a fraction of the minimum.

2.5 Income model

Finally, we implemented a new approach to calculate incomes for variable-worker households. The household incomes are calculated by the income model assuming the approach of variable number of workers per household.

The incomes are calculated for each year per household type and zone by considering the number of workers per household. The variable-worker approach includes:

- inputting household incomes as a minimum plus a marginal rate per worker;
- using these inputs to calculate the average income of each household activity in each zone based on the previous year’s workers per household;
- using that calculated income in the car-ownership model, and
- using that calculated income in the location model as the “expected income” for households moving to (or remaining in) that zone.

The household income $y$ (for each zone and relevant activity) is calculated as $y = aw + b$, where $a$ and $b$ are input coefficients, and $w$ is the workers-per-household in that zone and activity, calculated from the numbers of workers and of households read from the database.
3. APPLICATIONS

3.1 Do-Minimum Reference Case

3.1.1 Model inputs

The Reference case has been ran from 2001 to 2021 and received generalized costs from the transport model in 2007.

The key inputs to this Do-Minimum test are:

- **The base-year data**: base year population and number of households by Local authority area; the number of jobs disaggregated by employment activities; the amount of floorspace for each of the land-use types modelled and the occupancy rates; and the numbers of people in households with no car, one car and two or more cars.

- **The planning policy inputs**: they reflect the plans and policies of the Local Planning Authorities. They are based upon a series of consultations with the Local Planning Authorities within Scotland. Most of the data has been processed using GIS functionalities. It has been geo-coded and aggregated at a zonal level within the model. Within the reference case we have assumed that all commitments, planning permissions and allocations that are planned to be available for development in the period 2011 will be built. Beyond 2011, the planning policy inputs are entered as permissible development. This floorspace is available for development if there is sufficient demand.

Map 1 shows the amounts of development within each Local Authority area for permissible residential development. Note that each dot on the maps represents a quantity of floorspace within the zone, not a specific development.

- **The Demographic scenario**: The demographic model within TELMoS07 has been adjusted so that the totals of households and population reflect the population trends implicit within GROS’s national population forecasts for the period to 2021. For the period 2001-7, constraints are used to control the numbers of households locating in each zone in line with estimates based on Mid-Year Estimates of population. From 2008 onwards, no constraints are applied, nor is there any local adjustment of demographic change: the distribution of households and population within Scotland are entirely forecast by the model.

- **The Economic scenario**: The economic strategy has been estimated so as to reproduce levels of national economic growth that are consistent with externally generated forecasts and assumptions. For the period to 2022, the strategy reproduces the rates of growth contained with the economic forecasts used in Transport Scotland’s Strategic Transport Project Review. For the period beyond 2022, some assumptions have been made for this scenario.
3.1.2 Model outputs

The population of Scotland increases from 5.10 million in 2007 to 5.25 million in 2021. This represents a 2.9% increase. There is a variable pattern across Scotland with increases in population in Edinburgh and the Lothians, decreases in locations ranging from parts of Strathclyde and the Tayside and Central Scotland areas to more rural areas. **Map 2** represents the percentage change at zone level across Scotland for the total population.

Many variables are outputted from the model, population is one example. We use GIS software as a mapping tool to analyze the results. It allows to represent the data at a zonal level and to see easily if the pattern seems reasonable.
3.2 Transport Intervention on Highway Network

This test is designed to demonstrate the response of the land-use model to changes in the highway network.

It involves adjustments to the TMfS07 ‘Do-minimum’ Reference Case. In particular:

- An extension of the south Glasgow Motorway network from M74 to M8, west of Kingston Bridge. This connection allows additional capacity for road travel across Glasgow and provides some relief to sections of the M8; and
• More direct connections from the Motorway to the south side of Glasgow

Initial comparison of the impact of these adjustments, within the transport model, indicate around a 10 minute peak period time saving for vehicles travelling across Glasgow (ie A8 to Glasgow Airport) and smaller time benefits for some movements to/from central Glasgow.

In this test we consider the impact of a change to the highway network. This will impact upon the generalised costs that are passed from the transport model to the land use model as the cost of travelling between some pairs of zones will be affected by the extension to the Motorway in South Glasgow.

Within TELMoS we would expect this to influence the relative accessibility of zones both as origins (the ease in which it is possible to travel from the zone to others) and destinations (the ease in which it is possible to travel to a zone). Such changes should influence the location decisions of households and business and hence result in changes in the spatial distribution of these activities.

Measures of origin and destination accessibility are calculated, at zone level, for each of the transport measures and three car ownership levels used within the model. When comparing the accessibility within a zone for two tests, a negative value represents an improvement in accessibility, a positive value a deterioration in accessibility.

Here we focus upon two measures of accessibility:

• Measure 1 (Access to work, non-manual workers), households with one car. These accessibility calculations are based on generalised costs for the AM and PM peaks
• Measure 4 (business to business), households with one car. These accessibility costs are based on generalised costs for the off-peak period

Map 3 and Map 4 show the spatial change in accessibility compared to the Reference Case. In the two maps there are widespread improvements in accessibility, but particular improvements along the route of the M74 extension, in the area south-east of Glasgow where the scheme will be particularly important in improving access to the rest of the conurbation, and along existing strategic highway routes linked to the scheme including the existing M74 to the south, the M8 to the east and the M77 to the south-west.

The geographical extent of the change in accessibility is largely limited to Strathclyde, Ayrshire and the Central Scotland Belt. Clearly there is a strong correlation between the patterns of changes for the three different types of accessibility, reflecting that all are essentially measures of access to workplaces.
This improvement, in turn, influences the relative attractiveness of zones along these corridors.

Many variables can be outputted and analysed from TELMoS (population, household, employment, rents, resident workers etc). In this kind of scenario testing, we compare them with the Do-Minimum Reference case to see the impacts of the transport policies.
Map 5 shows the percentage change in employment in 2017, compared to the Reference Case. The forecast impact of the motorway scheme is to increase employment in the area south-east of Glasgow by up to 12% in 2017 (ie 6 years after the modelling opening of the scheme). Smaller gains are forecast across much of the south side of the Glasgow conurbation and the adjoining areas of South Lanarkshire, and along the major highway corridors to the north-west and north-east. Given that the overall employment scenario for Scotland is fixed, some areas must be losing employment to balance these gains; it can be seen that some zones within the Glasgow area but more remote from the major highway network are losing jobs. Other losses are forecast to occur in other parts of Scotland.

Map 4 Change in Accessibility, Measure 4, Households with one car
The purpose of this test was to examine the responses of the model to a substantial change in the transport infrastructure. We have demonstrated that:

- The changes made within TMfS07 to the highway network, are converted into changes in accessibility within TELMoS07
- These changes in accessibility influence the relative attractiveness of zones both in the immediate vicinity of the changes to the highway network, but also along those parts of the primary highway network that would benefit from the addition of the extra road link. Other zones within the same conurbation, but in locations that do not benefit from the improvement experience a relative decline in the accessibility.
- The demand for residential and employment floorspace is influenced by this change in accessibility. This is reflected in the changing rents.
Ultimately there are changes in the distribution of population and employment as a result of the change to the highway network.

4. CONCLUSION
This application described above has demonstrated the use of a major land-use/transport interaction model to test the impacts of a transport proposal. The TMfS/TELMoS system has been used for a variety of studies over the past few years.

The model is of course open to improvement, and we hope to continue to implement some enhancements in the future. We also note the possibilities of further advances in the methodology for appraisal in schemes where land-use/transport interactions are being considered.

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